Analyzing the Impact of Spatio-Temporal Sensor Resolution on Player Experience in Augmented Reality Games

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Abstract

Along with automating everyday tasks of human life, smartphones have become one of the most popular devices to play video games on due to their interactivity. Smartphones are embedded with various sensors which enhance their ability to adopt new new interaction techniques for video games. These integrated sensors, such as motion sensors or location sensors, make the device able to adopt new interaction techniques that enhance usability. However, despite their mobility and embedded sensor capacity, smartphones are limited in processing power and display area compared to desktop computer consoles. When it comes to evaluating Player Experience (PX), players might not have as compelling an experience because the rich graphics environments that a desktop computer can provide are absent on a smartphone. A plausible alternative in this regard can be substituting the virtual game world with a real world game board, perceived through the device camera by rendering the digital artifacts over the camera view. This technology is widely known as Augmented Reality (AR).

Smartphone sensors (e.g. GPS, accelerometer, gyro-meter, compass) have enhanced the capability for deploying Augmented Reality technology. AR has been applied to a large number of smartphone games including shooters, casual games, or puzzles. Because AR play environments are viewed through the camera, rendering the digital artifacts consistently and accurately is crucial because the digital characters need to move with respect to sensed orientation, then the accelerometer and gyroscope need to provide sufficiently accurate and precise readings to make the game playable. In particular, determining the pose of the camera in space is vital as the appropriate angle to view the rendered digital characters are determined by the pose of the camera. This defines how well the players will be able interact with the digital game characters. Depending in the Quality of Service (QoS) of these sensors, the Player Experience (PX) may vary as the rendering of digital characters are affected by noisy sensors causing a loss of registration. Confronting such problem while developing AR games is difficult in general as it requires creating wide variety of game types, narratives, input modalities as well as user-testing. Moreover, current AR games developers do not have any specific guidelines for developing AR games, and concrete guidelines outlining the tradeoffs between QoS and PX for different genres and interaction techniques are required.

My dissertation provides a complete view (a taxonomy) of the spatio-temporal sensor resolution dependency of the existing AR games. Four user experiments have been conducted and one experiment is proposed to validate the taxonomy and demonstrate the differential impact of sensor noise on gameplay of different genres of AR games in different aspect of PX. This analysis is performed in the context of a novel instrumentation technology, which allows the controlled manipulation of QoS on position and orientation sensors. The experimental outcome demonstrated how the QoS of input sensor noise impacts the PX differently while playing AR game of different genre and the key elements creating this differential impact are - the input modality, narrative and game mechanics. Later, concrete guidelines are derived to regulate the sensor QoS as complete set of instructions to develop different genres or AR games.

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I dedicate my thesis to -

My father, A. K. Mohammad Ali Sikder - who spawned the dream to achieve the goal

My mother, Asma Yasmin - who prepared me with her everything to walk towards the goal

My husband, Minhaz Fahim Zibran - who held me strong through all ups and downs in this journey

My son, Ehaan Fayiz Zibran - the newest and best addition of my life

Contents

List of Tables

List of Figures

Chapter 1

Introduction

1.1 Introduction and Motivation

In early 70s, video games were mostly played in arcades. Eventually, with the evolution of computer technology, video games became more popular at home on personal computers and gaming consoles in the 80s. With the progression of technology, computers have permeated life and smartphone games are one of the most popular kind of video games played by a large portion of gamers [191].

Smartphones are equipped with various kinds of sensors which enhances the ability of adopting new technologies while developing video games. Embedded sensors such as motion sensors or location sensors make the device able to adopt new interaction techniques. For example, the GPS (Global Position System) provides the location of the device on Earth, accelerometer sensors can track the motion of the device in many DoF (Degrees of Freedom).

However, despite of its mobility and embedded sensor capacity, smartphones are more limited in processing power and display area than their desktop similitude. Players might not experience the rich graphics environment that a desktop computer can offer. A credible workaround in this regard can be removing the need to create and render a game world by employing the real world as the game board, viewed through the device camera by rendering digital game characters over the camera view. This technology is known as Augmented Reality (AR).

AR is a technique where digital artifacts are superimposed on top of the real world view while looking through the camera. Because smartphones are equipped with cameras and many other sensors (e.g. GPS, accelerometer, gyro-meter, compass), different genres of AR games such as shooter, casual or puzzle games can and have been be developed. Because in AR the play environments are viewed through the camera, rendering the digital artifacts and view mapping is crucial. These digital game characters must be placed correctly in the scene and should be viewed from the appropriate angle. For example, while playing location-based games, the GPS reading provides information on the particular location on Earth where the player is during gameplay so the digital characters can be rendered on the screen. In addition, the readings from gyroscope and accelerometer help track the camera angle.

Augmented Reality is a virtual representation of live, interactive 3D objects superimposed on the real environment. In other words, Augmented Reality is a fusion of reality and imagination attained by overlaying virtual objects on the real world. For example, figure 1.1 represents a screenshot of an AR geo-tagged game THEEMPA [64]. In this game, the players see different 3D characters through their smart phone camera based on their activity and geo-tagged location on earth. Due to its ability to superimpose digital artifacts on reality AR, has spread to different areas such as medicine, manufacturing or entertainment. Entertainment is an obvious application of AR, particularly video games. Players experience an immersive game environment while playing AR games as the real world becomes fantastic through the addition of digital artifacts.

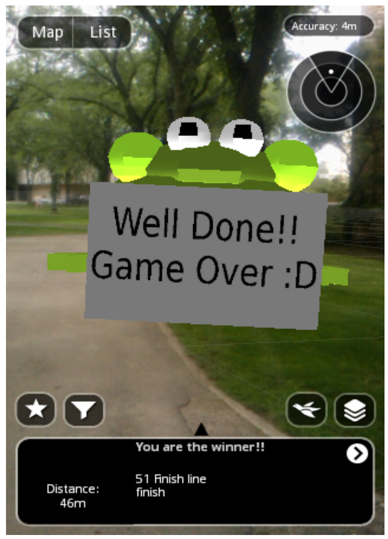


Figure 1.1: AR representation of the game PasswARG

If the digital characters need to move with respect to sensed orientation, then the accelerometer and gyroscope need to provide adequate reading stabilities to make the game playable. Unlike the virtual camera used to render the game environment in purely digital worlds, physical sensors are subject to noise. In particular, determining the pose of the camera in space is crucial as it determines the appropriate angle to view the rendered digital characters. This particularly determines how well the players will be able interact with the digital game characters leading towards User Experience (UX). Because the primary outcome of a game is UX or more particularly PX (Player eXperience), ensuring a sufficient Quality of Service (QoS) from these sensors is crucial. A sufficiently noisy QoS could disrupt the accurate rendering of the digital artifacts. Traditionally, the term QoS referrers to the data transmission quality when considering task performance over the network. However, because different kinds of sensors provide services to the game and sensor quality impacts the quality of an AR game, QoS is an appropriate term to describe the utility of sensors for a particular game. While QoS is focused on service provision, Players' Experience (PX) is more focused on players' gameplay experience.

Spatio-temporal sensing plays major role in AR QoS. In an aiming game, the target object should have a sufficiently consistent position in the presence of sensor noise to facilitate targeting. Having the digital artifact move erratically due to sensor error could cause the player significant difficulty. On the other hand, in a treasure hunting game, where the requirement is to reveal information to complete quest, a slight displacement of the digital artifact would not normally compromise gameplay. Therefore, the sensitivity of the game to the QoS from the sensor depends on the game genre and interaction mechanism. Spatial sensing in AR games can be characterized by the accuracy, precision, and the span of the sensed parameters. An indoor shooter game might need a 360 degree orientation span where table-top shooter might just need of a 45 degree span to explore the game area. To perform any task or interaction with a game artifact, timing is crucial. Aiming games typically demands an accurate timing of triggering to target the game object, and movement of the physical camera should be time aligned with movements of the virtual camera.

The registration issue is vital in AR games. While playing a location-based AR games, accurate pose estimation including the location on Earth is still not reliable on commercially available devices [149]. Even in the games where targets (planes, robots or mosquitoes) move randomly and are not anchored to specific real world locations, the apparent location of the target within the display area can be subject to noise, drift or jitter [143]. This could significantly impact PX because aiming is the primary interaction technique for most available AR games as described in literature review (chapter 2). However, the impact might vary depending on different aiming techniques and interface type.

Confronting such problem while developing AR games might be difficult in general as it requires creating wide variety of game types, narratives, input modalities and testing them all in controlled user studies. Current AR games developers do not have any specific guidelines while developing AR games, and concrete guidelines outlining the tradeoffs between QoS and PX for different genres and interaction techniques are required. These guideline should include substantial descriptions of sensor dependencies of AR games and their impact upon PX. Because little research has been undertaken on this particular aspect of AR games, game developers currently lack proper guidance when it comes to recognizing and ameliorating the sensitivity of sensors towards different genres of AR games. To address this problem, a complete literature review was performed with the existing AR games to analyze their spatio-temporal dependencies and a taxonomy of sensitivity was created. Later, by conducting four experiments I demonstrated how the sensor noise impacts the gameplay of different genres of AR games in different aspect of PX. Based on the findings of these experiments, I provided guidelines to regulate the QoS of sensors while playing an AR games of different genres. The guidelines will provide AR game developers with heuristics for managing sensor impacts on player experience across different kinds of AR games and input.

1.2 Problem Statement

Unlike other video games, AR games posses the distinctive characteristic of embedding game elements within the real world. This implies that the camera must render real (observed) and virtual elements simultaneously, which is different than traditional video games where an entire virtual world is rendered through a virtual camera. A mapping between the physical camera and virtual a camera must be implemented. In this mapping, the spatio-temporal resolution of sensor plays a key role as the actual location of the digital artifact with respect to the player viewpoint is determined by these sensors.

Good gameplay experience depends on a good game mechanic. The Quality of Services (QoS) of the sensors can impact the Quality of Experience (QoE) of the players during gameplay. QoE is critical in games because play experience is the primary outcome of a gameplay. Computer game interaction can be divided into three levels - interface, mechanics and gameplay [179]. Effective interface design plays a vital role involving the player in immersive gameplay [189]. Key elements affecting QoE include QoS, context leading towards User eXperience (UX). UX is typically evaluated using of concepts such as immersion, flow, and playability. Fundamentally, UX depends on perfecting the game mechanics and interface [179]. In AR games, the spatio-temporal position and orientation accuracy are primary game interface inputs and by extension can have a significant impact on QoS. However, one could expect sensor errors to have differential impacts on different games, game mechanics and input techniques. For example, in a geo-tagging game such as THEEMPA [64], a player uses the smart phone to find clues held by virtual 3D characters by walking around a play area with the device. In this game, the target must only be held in the frame and does not need to be tapped or interacted so input timing is not important. On the other hand, in ARQuake [190], both time and space have a major impact on the playability as accurate aiming at virtual objects is required to play the game. In short, sometimes a good QoS is not able to provide a good QoE whereas, a game with different or simpler mechanics might have an acceptable QoE during gameplay with the same sensor performance.

In this thesis I codify the differential impact of sensor noise in AR games and input techniques using controlled experiments and standard PX evaluation techniques. This analysis is performed in the context of AR games, which classifies games by their sensitivity to QoS on position and orientation sensors.

1.3 Solution and Contribution

Because computer games are a leisure activity, my research must evaluate the Quality of Experience (QoE) or Player Experience (PX) during gameplay. The PX of an AR game depends upon the QoS of the spatio-temporal sensor resolution and the interaction techniques and game mechanics. Because very few researchers have explored this aspect of AR design, I analyzed a large number of existing AR games and categorized them based on their sensitivity to spatio-temporal sensor QoS. However, this analysis was largely subjective. To add quantitative data addressing this issue, several experiments were conducted or proposed to identify the impact of QoS on PX in AR games depending on game mechanics and interaction techniques.

1.3.1 Analyzing existing handheld AR games and their spatio-temopral resolution in a taxonomy

Rather than creating a new model of AR games, a systematic framework of sensor sensitivity in handheld AR games is the focus of this work. Therefore, a large scale literature review was necessary to analyze the behavior or AR gameplay and cluster them based on sensor utilization. In this chapter, an overview of existing AR games both in the research and commercial arenas are presented. I propose a classification based on their spatio-temporal sensor dependencies and their impact of players during gameplay. To do the classification three major sensor aspects - space, time, and orientation were evaluated. Time, position and orientation are the typically required sensed parameters in handheld AR games. The later part of this work includes a rigorous discussion of my research and a proposed approach of achieving the research goal. A conclusion has been made with summary of findings as well as challenges faced during the classification process. The proposed taxonomy provides an overall concept of the spatial and temporal dependency of the games during gameplay. Although many games clearly belong in specific branches, there are some grey areas, and where appropriate these grey areas are identified and noted.

1.3.2 Spatio-temporal contribution in of the AR games and the player experience (PX)

Several different experiments have been performed to examine the impact of spatio-temporal sensor resolution in different genres of AR games and input modalities including both indoor, and outdoor AR games. Employing standard within subject experimental design and statistical analysis from the HCI literature, I performed a series of experiments on a variety of Android AR games by modifying the operating system to allow me directly inject controlled noise signals into any Android game. These experiments demonstrated that, as expected genre and input technique are differentially sensitive to sensor QoS, although often in surprising ways. From this general finding we have derived a number of recommendations about AR game design.

- **Experiment 1**:This experiment investigated players' reaction to different aiming techniques under different spatio-temporal sensor resolutions; in particular, distinguishing the aiming technique that depends the most and the least on sensor resolution. I developed a system capable of modifying the resolution of spatio-temporal sensors of the device by modifying the the Android operating system. Three different kinds of aiming AR games were investigated. Participants played these different aiming games under different sensor QoS and answered standardized questions about the play experience. I found that the impact of noise varies significantly depending on particular aiming technique.

- **Experiment 2**: The experiment examined the impact PX in a single indoor game with varying input techniques. The primary purpose of investigation was to identify play techniques that provided the best PX under different level of spatio-temporal QoS. In this regard, a novel AR game 'MonstAR' was developed. MonstAR was playable through both smartphones and a head mounted display. The existing system of modifying sensor accuracy designed during my earlier experiments were applied with some modification. A total of 48 participants were recruited to play this AR game in different controlled experiment under different level of sensor accuracy. Players' activity logs were recorded and online surveys were filled by the players' after each gameplay to record the play experience, and identify techniques which provided the best PX with least impact of QoS. I found that, depending on the different aiming techniques, the PX varies with varying sensor QoS.

- **Experiment 3**: In this experiment I analyzed the impact of QoS on outdoor (location-based) AR games. Using the same modified Android OS, I noted differential impacts on different games with differing GPS resolution. Three different location-based games were analyzed under varying GPS noise conditions. Game and sensor logs were compared to standard PX surveys to determine the relative impact of sensor QoS. I found that the impact of noise varies significantly depending on particular genre of these location-basd games.

- **Experiment 4**: In the previous three experiments, the analysis of PX was made under the zero-mean Gaussian noise model employed to represent aggregate noise process. While investigating such situation is crucial, some sensor such as GPS can experience non-Gaussian disruption.I conducted another controlled experiment where I applied a noise generator capable of injecting noise into the sensor readings using a three state noise model under varying noise to determine how much a change in baseline precision inputs player experience. The purpose of the experiment was to investigate the play experience of playing different kinds of AR games under more sophisticated noise model. A differential PX between the multi and than single zero-mean gaussian noise model was observed through the experiment.

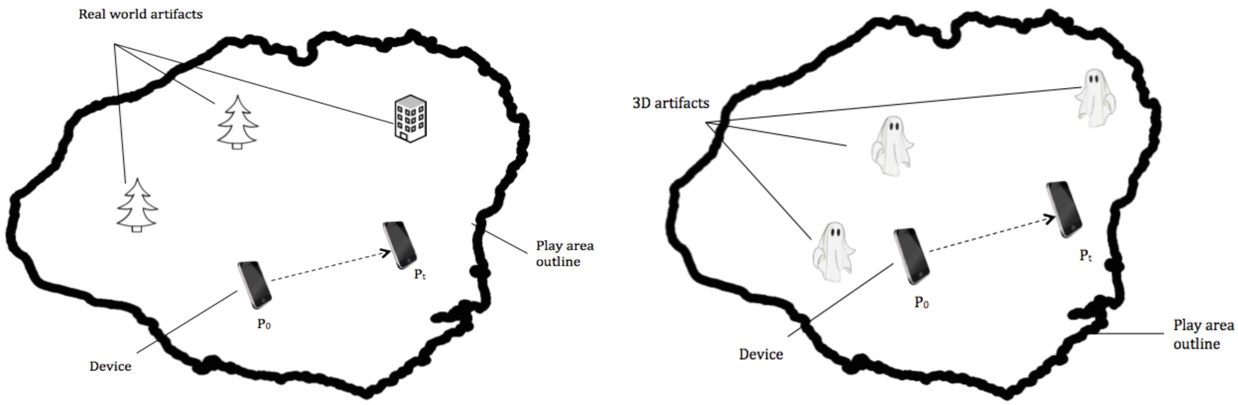
1.4 Scope and Definitions

In this section, we prepared scope and definitions associated with AR games discussed in this dissertation. Several key criteria are defined to illustrate the underlying kinematic constraints and how they are addressed in AR games.

1.4.1 Spatial Behavior of Smartphone AR Games

The embedding behavior of virtual objects in a real scene makes AR games different than traditional video games. Mapping between real and game world is required for AR game mechanics. In this section, a thorough description of the underlying kinematic framework of real and game world is described. In addition, the method of encoding this relationship and relationships between are discussed.

While playing an AR game, the term 'real world' refers to the the physical world players are in while the term 'game world' is the virtual game environment with digital artifacts the player interacts with to achieve the game goal. Figure 1.2a shows a real world scenario with the device camera and geographical elements such as trees and buildings. Figure 1.2b shows a game world with the rendering camera and digital artifacts. For both cases, let's consider P_0 is the initial position of the camera and P_t the posi-



(a) Real World **(b)** Game World

Figure 1.2: Real world and game world frames

tion after t sec. Let's consider the position P_0 as PR_0 and P_t as PR_t. In 3D real world, let's assume, $PR_0 = \{xR_0, yR_0, zR_0, \theta R_0, \phi R_0, \Phi R_0\}$ and $PR_t = \{xR_t, yR_t, zR_t, \theta R_t, \phi R_t, \Phi R_t\}$. Similarly, for game world, $PG_0 = \{xG_0, yG_0, zG_0, \theta G_0, \phi G_0, \Phi G_0\}$ and $PG_t = \{xG_t, yG_t, zG_t, \theta G_t, \phi G_t, \Phi G_t\}$. The transformation function from real world to the game is-

$$f : R \to G \tag{1.1}$$

If $\vec{x}$ is any location point in the real world (could be PR_0 or PR_t) that should map to a specific location in the game world. Both these domains have six degrees of freedom.

$$\vec{x} \in \mathbf{R}^6 = \{x, y, z, \theta, \phi, \Phi \in \mathbf{R}\} \tag{1.2}$$

Now, let's consider the combined game and real world in figure 1.3. According to the previous, vector description, let's consider, $PA_0 = \{xA_0, yA_0, zA_0, \theta A_0, \phi A_0, \Phi A_0\}$ and $PA_t = \{xA_t, yA_t, zA_t, \theta A_t, \phi A_t, \Phi A_t\}$ where $P_0 \Leftrightarrow PA_0$ and $PA_t \Leftrightarrow PA_t$.

These 3 diagrams (figure 1.2a, 1.2b, 1.3) will be used to describe different scenarios of different AR games based on their game mechanics in the rest of this section. Among portable AR games, the camera behavior varies depending on the game mechanic. For different types of games, the origin of the real world, and the origin of the game world is defined. A taxonomy of these relationships is shown in figure 1.5. What differs from game type to game type is the game mechanic method by which the real and game cameras are aligned, particularly the definition of the origin of locations in the virtual and real worlds, and the presence or absence of a model of real world artifacts in the virtual representation.

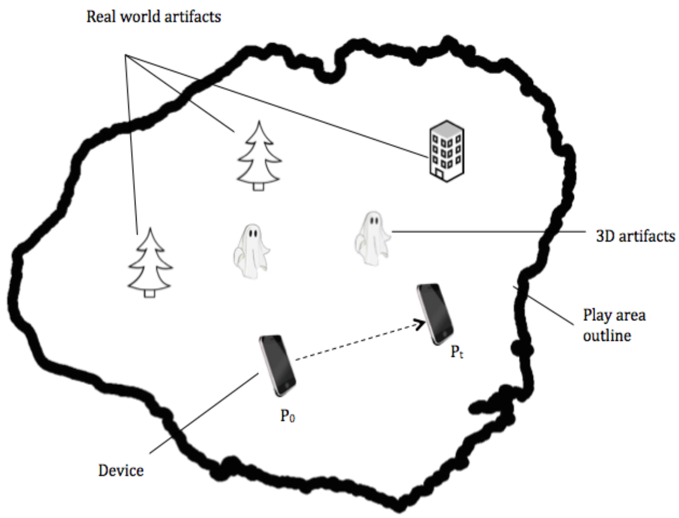


Figure 1.3: Augmented Reality World

1.4.1.1 Location-based Games

Location-based games define the location of game objects, both real and virtual, on the face of the earth. The primary sensor used in location-based games is GPS but other location sensing methods can be used, particularly if the game is played indoors. Location-based games are further sub-divided into strict and relative location based games.

1.4.1.1.1 Strict Location Strict location-based games are played over a defined geo-tagged area on Earth. The gameplay area is strictly defined with specified UTM (Universal Transverse Mercator coordinate system) or Lat/Long coordinates and the game is playable only in that location. For example, in the game PasswARG [67], the digital characters renders only when the players are near a defined location on Earth. Starting the game in a physical geographic area distant from a digital artifacts will cause the device to render only what is seen through the camera. In such a game environment, the spatial parameters are:

- **Origin of the real world**: The UTM or Lat/Long origin
- **Origin of the game world**: The UTM or Lat/Long location of the camera. The origin of the game world has an equivalent UTM or Lat/Long coordinate. With the movement of the camera through physical space, the game world coordinate changes.

1.4.1.1.1.1 Obstacle Aware In obstacle aware strict location-based games, the games are designed such way where the real world location of game-critical objects are known, and the camera reacts appropriately. For example, in ARQuake [190] or CYSMN [37] the interactive objects are deployed on open space and physical artifacts like buildings are explicitly part of the game model. These systems do not work reliably with mobile obstacles and require static defined settings. These are sometimes referred to as installation games because games are played in a controlled environment or installation.

1.4.1.1.1.2 Obstacle Unaware In games like PasswARG, real-world artifacts are not part of the game model and only digital artifacts are tied to physical locations. Game designers often place digital artifacts knowing the location of obstacles in the real world but they are not accounted for explicitly in the virtual model.

1.4.1.1.2 Relative Location These geo-located games can be played anywhere in the world. Game objects render depending on the location of the device. Here, the location of the device camera at game instantiation is the origin of the game world. The game origin initializes to the world coordinates at the start of the game level and remain the same until the game ends. The position of the camera with respect to the real world could be derived from the figure 1.4.

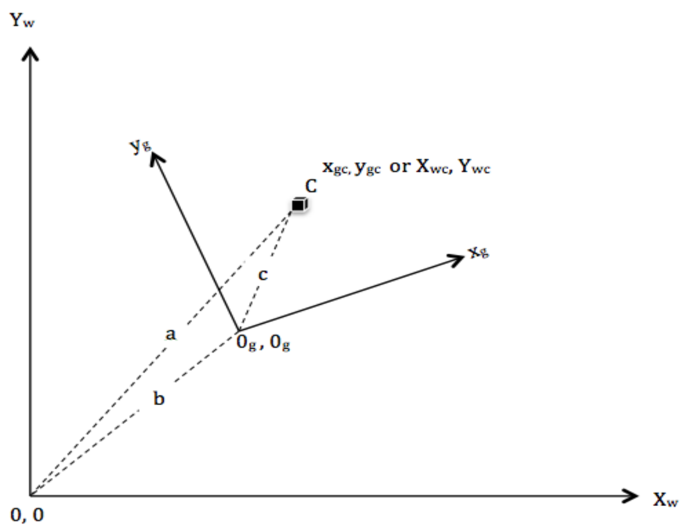


Figure 1.4: Frame references while playing a relative location-based games

The origin of the real world is the UTM or Lat/Long origin. Let's consider the real world origin as (X_{w0}, Y_{w0}). The origin of the game world is the location of the camera. The origin of the game world has an equivalent UTM or Lat/Long coordinate. Let's consider the game world origin as x_{g0}, y_{g0}. The location of the camera with respect to game world is (x_{gc}, y_{gc}). The location of the camera with respect to game world is (X_{wc}, Y_{wc}). According to figure 1.4, if the UTM coordinates of the game world origin and the camera position in game world are known, then the position of camera with respect to the real world could be determined by the following equation:

$$\begin{aligned} X_{wc} &= x_{g0} + x_{gc} \\ Y_{wc} &= y_{g0} + y_{gc} \end{aligned} \tag{1.3}$$

An example of such a game is SpecTrek [129] where the game is playable in any location on earth and the digital artifacts are rendered based on a camera-centric view. While moving towards the target (3D ghosts), the game coordinates change and the ghosts become larger and the origin remains the same until that level ends. These games are typically played in large open areas such as soccer fields to avoid unintended collisions with real world objects.

1.4.1.2 Rotation-based Games

This category of games use the orientation sensor of the device for rendering. The location on the Earth is not considered in the tuple which describes digital artifact location. Expressed mathematically, given $PA_0 = \{xA_0, yA_0, zA_0, \theta A_0, \phi A_0, \Phi A_0\}$ point (figure 1.3) in rotation-based games, only the angular tuple ($\{\theta A_0, \phi A_0, \Phi A_0\}$) will be employed.

The sensor used in this category is the orientation of the device as detected through accelerometer, compass and gyroscope. Object rendering is performed based on the origin of the game world. Unlike location-based games, these games only vary the angle of the virtual camera.

- **Origin of the real world**: The vector (0,0,0) for orientation. These games are independent of spatial extent and have no origin in (x,y,z).
- **Origin of the game world**: Arbitrary, but relative to (0,0,0) in angular terms as there is a 1 to 1 mapping between angular coordinates in the real and virtual representation.

An example of such game is Skeeter Beater [157] where the digital mosquitoes are rendered in a camera-centric manner wherever the game is loaded. If the player changes his position from $PA_0 = \{xA_0, yA_0, zA_0\}$ and $PA_t = \{xA_t, yA_t, zA_t\}$, the mosquitoes follow the same path. If the player rotates the camera the view will change and new sets of mosquitoes will be visible.

1.4.1.3 Marker or Table-based Games

Tabletop games are rendered on a fixed surface employing high resolution sensing techniques such as Polhemus systems or optical fiducial markers. The space is tightly constrained to the table top, particularly if markers are employed. If the camera is not focused on the marker, the game is unplayable because the transform and the origin P_0 are unknown. The specifications of such marker-based are:

- **Origin of the real world**: Usually the marker - the central location of the gameplay on Earth or some calibrated location on the table.
- **Origin of the game world**: Usually the marker - digital artifacts are rendered with respect to a location on the table.

1.4.1.3.1 Single Marker-based Games: Only one marker is used for gameplay. For example, in AR Basketball [89] a single marker is needed to render the entire gameplay environment. Players interact with the digital ball and attempt to make baskets by aiming the device towards the marker.

1.4.1.3.2 Multiple Connected Marker-based Games: The markers describe different discrete locations in a contiguous game space. Game space seamlessly links locations through a contiguous game world as at least one marker is always in view. Examples include ARQuake [190].

1.4.1.3.3 Multiple Independent Marker-based Games: More than one marker or play-space exist which are not related to each other. Each marker origin defines its own game space. While players may travel from marker to marker, each maker functions as a distinct game world. The game Interference [38] is an example of such a game.

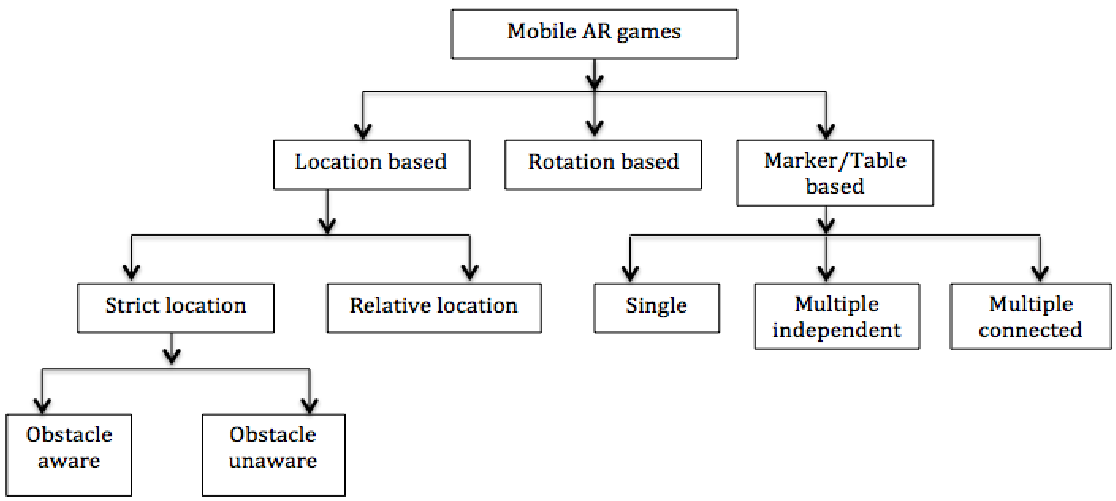


Figure 1.5: Spatial Behaviour of mobile AR Games

1.4.1.4 Summary

While playing an AR game, the spatial mapping between real world and game world is important because the digital artifacts are overlaid on the real world. However, the behavior of this spatial mapping varies based on different types of AR games. The tree in figure 1.5 demonstrates an overall scenario of the spatial nature of AR games. While processing the taxonomy, a bottom-up approach was adopted (detail in 2.1.1).

The three major classifications include: identified location-based, rotation-based and marker or table-based AR games. If a common scenario for these three types of games are considered, different spatial behavior will be observed. For example, in location-based games, if the player moves from PA_0 to PA_t (figure 1.3), the digital object nearer to PA_t will be larger, as the game coordinates change with the movement of the camera. While in rotation-based games, if the same movement occurs from PA_0 to PA_t (figure 1.3), the

3D characters move along with the device. For the last type (marker-based games), if the player moves from PA_0 to PA_t, and the marker is no longer in the camera frame, the game is unplayable.

1.4.2 Statistical Analysis Overview

Experiments conducted in this dissertation were subject to statistical analysis to examine the significance of sensor resolution in AR gameplay. This section provides an overview of the statistical analysis performed depending on the research goal, hypothesis and experimental design.

1.4.2.1 Type of Variable

The experiments conducted in this analysis are consist of following sets of variables -

1. Independent Variables
   (a) Games (Nominal)
   (b) Noise Level (Ordinal)
2. Dependent Variables
   (a) Positive and Negative Experience
      i. Positive Experience
      ii. Negative Experience
   (b) Intrinsic Motivation
      i. Interest and Enjoyment
      ii. Competence
      iii. Effort
      iv. Tension and Pressure

1.4.2.2 Analysis Methodology

In general, Repetitive Measure Multivariate Analysis of Variance (MANOVA) was applied which allowed to simultaneously test two main effects and one interaction effect. The main effect analyzed two research questions - 1) Does PX vary in different games and 2) Does PX vary in different Noise Levels. The interaction affect was between two independent variable Game and Noise Level. It demonstrated whether the PX vary based on the noise level for different genre of AR games. Because we performed repeated measure ANOVA to exploit the best of limited number of participants, the control data was collected with no noise level.

Pairwise analysis was performed to analyze the difference of variance of each group of data to the other. Because several statistical analysis were performed on sing data set followed by pairwise comparison, Bonferroni correction was applied as the Post-Hoc analysis technique to reduce the risk of Type-1 error (false-positive result).

1.4.3 Chapter Overview

This dissertation is presented in a manuscript style format. According to the guideline[1], an introductory chapter is included followed by literature review. The next four chapter includes three published papers in international conferences and one submitted work. The writing has been summarized by discussing the significance of the dissertation as well as the scope of possible future work.

Chapter 1: Introduction

Motivation, problem statement and an overview of the contribution are provided. Definition of the keywords used, kinematic systems considered, and a general overview of the experimental protocols maintained throughout the dissertation are presented. A pre-discussion of the taxonomy of different AR games is also included.

Chapter 2: Literature Review

This chapter provides the detailed taxonomy of AR games and their descriptions along with some early history of augmented reality and its different areas of application.

Chapter 3: Manuscript 1

Title: The Impact of Sensor Noise on Player Experience in Magic Window Augmented Reality Aiming Games

Published in: International Conference on Entertainment Computing - ICEC 2015, short paper.

While playing an Augmented Reality aiming game, the aiming technique can impact the play experience significantly under different spatio-temporal resolutions. To examine the play experience, we designed a system capable of providing different levels of noisy sensor input. Later, running this system in background, we let our participants play AR aiming games with different aiming methods. Amongst three different aiming types (1. tapping the object, 2. tapping the trigger and 3. tapping with a target), PX was impacted by the sensor noise when tapping the object.

Chapter 4: Manuscript 2

Title: Quantifying the Differential Impact of Sensor Noise in Augmented Reality Gaming Input

Published in: 7th IEEE Consumer Electronics Society Games, Entertainment, Media Conference 2015, full paper.

The input technique is a core component of aiming in video games. In AR games, the significance is higher because the control must map between the real and digital world. Examining play experience in AR games under different aiming techniques could yield valuable design guidelines. In this manuscript, we developed our own AR aiming game, 'MonstAR' which is playable using four different aiming techniques - two on smartphone and two with head-mounted display. In the background, we ran

[1]https://students.usask.ca/graduate/manuscript-style.php

our previously developed system of injecting noise into sensor streams to investigate the variance in gameplay. These results demonstrated that, under the same level of sensor noise, PX is affected by sensor noise conditional on aiming technique.

Chapter 5: Manuscript 3

Title: Analyzing Play Experience Sensitivity to Input Sensor Noise in Outdoor Augmented Reality Smartphone Games

Published in: British HCI 2015, full paper.

Location-based AR games depend on location sensing techniques by sensor noise when using the GPS. While playing such AR games, play experience is affected by noisy sensor input. To examine this, a user experiment where the participants were provided three different genres of outdoor AR games -1. targeting, 2. treasure hunting and 3. trivia was conducted . The analysis showed that while noisy sensor input can increase the negative experience in a treasure hunt game, it can increase the competence in a targeting game and has limited effect on the trivia game.

Chapter 6: Manuscript 4

Title: The Impact on Player Experience in Augmented Reality Outdoor Games of Different Noise Models

Submitted in: International Journal of Computer Entertainment

In our previous experiments we employed a single canonical noise model - the zero mean Gaussian noise model, capable of injecting sensor noise as a background process while the AR games were played by the participants. In many practical applications, the noise models can often be more complex. Therefore, I replicated the experiment of manuscript 2 to compare the differential impact of sensor QoS upon PX of different noise models while playing different kinds of AR location-based games. To maintain consistency, 1. targeting, 2. treasure hunting and 3. trivia games were chosen. The findings of the experiment demonstrated that sequential noise impact PX in a different pattern than that of zero mean Gaussian noise model.

propose to build a multi-level noise model and examine the impact on players' experience (PX) as the final contribution to my thesis.

Chapter 7: Discussion and Conclusion

This chapter summarizes the contribution of the dissertation with the guidelines provided to improve AR gameplay extracted from the research work. A discussion of future work is included.

1.5 Summary

Augmented Reality (AR) games are an emerging area in video games. With the advancement of technology people can experience AR through handheld devices. However, this experience might vary depending on the quality of sensor signals and spatio-temporal resolution requirements of different genres of AR games. Because AR game are a leisure activity, the QoS requirements of these games must be evaluated on how well they provide the enjoyment to players. My dissertation provides an investigation of the problem which includes four major contributions covering system design, behavioral experiments, statistical analysis, and design recommendations. The later part of my dissertation includes guidelines to improve the Quality of Service (QoS) of AR games. These guidelines will be helpful to improve the Play Experience (PX) of the players and can be adopted by the game development community.

Chapter 2

Literature Review

2.1 Introduction

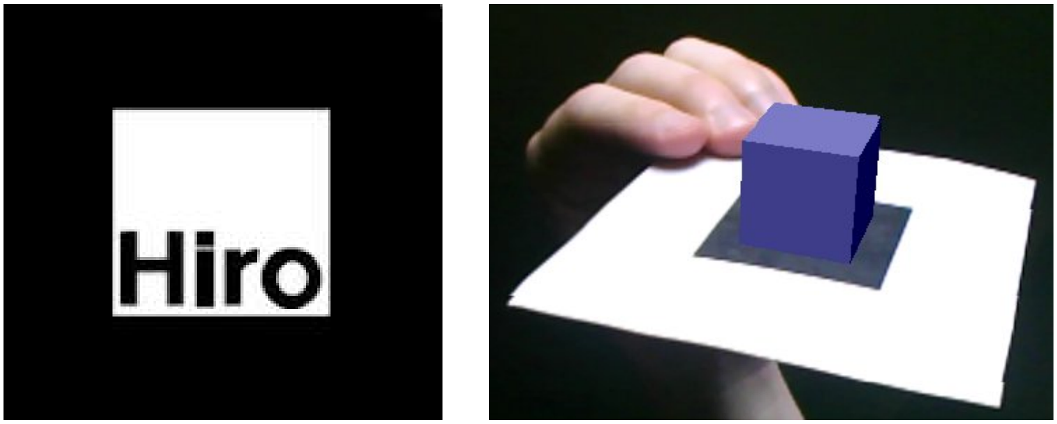
Around 1957, the concept of AR was first established with a machine called 'Sensorama' by Morton Helig, as described by Dan Sung [12]. Despite of having immersive features such as blowing wind or a vibrating seat as well as stereoscopic 3D views, 'Sensorama' was never sold commercially because of its cost. Later, in 1966 a professor from Harvard University named Ivan Sutherland produced a more convincing AR technology using a Head Mount Display (HMD). However, because of its weight, instead of placing it on human head, the HMD was hung from the laboratory's ceiling. Nevertheless, this was the first effort to make AR more useful to the researchers and end users.

Almost 25 years later, professor Tom Caudell came up with software for overlaying the position of the cables of a building based on blueprints. At the same time two other teams stepped into the promising area. The first team with LB Rosenberg used AR functionality for the US Air force. Another team formed with Steven Feiner, Blair MacIntyre and Doree Seligmann invented 'KARMA' - Knowledge-based Augmented Reality for Maintenance Assistance [14]. Figure 2.1 depicts the system. Later, another team from Columbia University built an HMD integrated with Logitech-made trackers. According to Dan Sung, in 1994, with an augmented reality dance show, Julie Martin first introduced AR as a public performance artifact.

In 1999, a revolutionary update took place in the field of AR. Hirokazu Kato of the Nara Institute of

(a) karma1 **(b)** karma2

Figure 2.1: Graphical representation of KARMA [14]

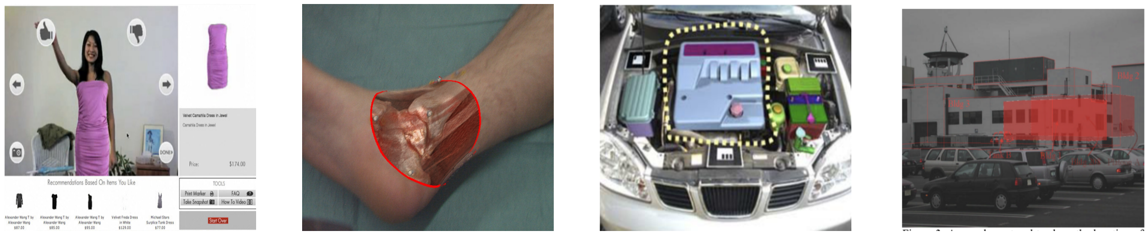


(a) Fiducial Marker [9]   **(b)** 3D object on top of the fiducial marker [70]

Figure 2.2: Graphical representation of ARToolkit

Science and Technology released the ARToolKit - a software library for developing AR applications [70]. Through this open source software tool, developers can create virtual images as an overlay on top of real world. The developers identified tracking as one of the major issues while developing AR applications. As a solution to this, the ARToolkit is integrated with computer vision algorithms which calculates the camera position. One of the major components of ARToolkit is the 'Fiducial Marker' - a black and white marker meant to be tracked. With ARToolkit installed in a device, if someone looks through the camera of the device, a virtual object can be rendered on top of the marker. Figure 2.2a shows a type of fiducial marker and figure2.2b [70] shows the representation of the virtual 3D object on top of the fiducial marker. When the fiducial marker is viewed through the camera, it detects the position and orientation of the camera relative to the maker and then it applies a computer vision algorithm to match the pattern of the marker. Once the pattern is recognized, the virtual 3D object associated with the specific type of marker is loaded. Initially, the developers released a single PC based version of ARToolkit. Later, with the evaluation of handheld technology they released different versions of ARToolkit such as ARToolkitPlus, ARTag, NyARToolkit for different platforms such as MacOSX, Linux, Android OS distributions.

Over past two decades, AR expanded through many computer science research areas. As aforementioned, starting with the heavyweight non portable HMD, now AR is practical with smartphone devices. The integrated sensors of smart phones have enhanced the opportunity for research in AR depicting its span in areas such as travel, living, medical, the marketing, military, and entertainment. While traveling, people can benefit from an AR real-time browser such as LAYAR [85] which supports different genres of AR apps such as location tagging (restaurant, gas station etc.), games, and entertainment. Beyond location specific applications, AR has a good number of application in the area of business. For example, in manufacturing, fashion retail and marketing or advertising get benefited from AR since it saves much more time with 3D real-time augmentation [15]. Medical engineering is effected by augmented reality; for example, in surgical apps [31].



(a) Marketing [5] **(b)** Medical [6] **(c)** Repairs and maintenance [112] **(d)** Military [118]

Figure 2.3: Different application areas of AR

Navigation via GPS (Global Positioning System) can be enhanced with AR. For example, AR GPS Drive Navigation [10] is an AR powered GPS navigation system that uses the Android phone's camera and built-in GPS. For repairing cars in a more convenient way, AR apps can be used. J. Y. Lee and G. Rhee presented an AR application for car repair and maintenance [112]. The authors depicted a framework able to provide collaborative distributed services for car maintenance through context-aware 3D visualization technique using augmented reality. To visualize underground infrastructure G. Schall et al. [177] used AR technology in a handheld device. Military applications also uses AR technology for training and service purposes. For example, the Battlefield Augmented Reality System (BARS) consists of wearable PCs, wireless network connections and HMDs [118]. By using BARS soldiers are trained with an AR environment to prepare themselves for an upcoming battle. Another interesting approach using AR is having a virtual assistant MARA by A. Schemeil, and W. Broll assist the user with their everyday schedule [178]. Figure2.3 shows some areas of application of AR.

Video games are a compelling area for AR applications. Starting with ARQuake [190] - the revolutionary AR shooter game, AR games are now expanding their charms to the latest smartphone. ARQuake [190] is an AR game that uses GPS, digital compass, and fiducial vision-based tracking to convert the desktop version of 'Quake' to a mobile AR game. The pervasive capability of AR can provide more impactful immersion during gameplay. Figure 2.4 shows the play view of the early AR games ARQuake and a similar game Human Pacman [58]. To improve the productivity, frameworks such as ARTHAS (Augmented Reality for Treasure Hunt Applications) [32] have been proposed. This framework replaces physical objects with 3D virtual objects to reduce the cost of playing mobile treasure hunt AR games. ARTHAS includes a client-server work environment for both android and iOS. A similar approach of deploying AR technology to urban games is proposed by Zaryachi [201]. The authors of [173] proposed an enhancement of the card game "AR-Hold'em" considering the difficulty for beginner's learning as well as the tangibility of the traditional card.

There are several different genres of smartphone AR games such as shooting, treasure hunt, and puzzle. Most of these AR games employ localization or orientation estimation. Location-based games are dependent on tracking the location in a space. AR games such as ARQuake or Human pacman [58], use GPS continuously. When playing these games near a building or under dense trees, the GPS signal was reported to be

(a) ARQuake [190] **(b)** Human Pacman[58]

Figure 2.4: ARQuake and Human Pacman: Pioneer of AR games

unstable. Most of the indoor AR games depend on orientation alone, as indoor localization is a difficult or expensive problem to solve [35].

2.1.1 Defining and Selecting the Sensor Parameters

AR games depend on the motion and position of the player or device. Different game mechanics require different fidelity from these sensors. As described in figure 1.5, the process of the classification was performed in a bottom-up approach. A large scale survey was conducted with existing AR games. A fair amount of background research was performed to accumulate the research-based AR games. Because there is no particular list available for these kinds of research, the accumulation task was quite challenging. Once the games were identified, finding a source to run the games were near impossible. To understand the gameplay, I had to depend on the game description available in the document. Compared to the research-based games, clustering the commercial game was easier since the online stores (e.g. App store or Google play) are easily accessible. Unlike the research-based games, commercial games could be downloaded providing a better chance to understand the spatio-temporal sensor dependency. However, many of the games included in the taxonomy were not performing well-enough due to compatibility issue. When all the existing AR games were accumulated and their gameplay was analyzed, clusters were defined based on their spatial behavior and eventually a hierarchical tree was formed (in figure 1.5).

This survey includes both research-based and commercial games and indicates that from the gameplay perspective research games have a greater diversity in input modalities than that of the commercial games. In the survey, I classified around 90 AR games (both research-based and commercial) depending on their sensor dependency. It is important to indicate that, while classifying, I focused on the impact of sensor performance and therefore, the classifications might be different from other points-of-view, for example, considering game mechanics, graphical representations, or camera behavior as described in chapter 1.

2.1.1.1 Defining Parameters

To evaluate the spatio-temporal resolution impact upon AR games, I picked the following parameters -

- **Space**: The location on earth. Most location-based AR games depend on GPS sensors or optical markers in more confined settings
- **Timing**: Ability to synchronize a digital and real task. For example, while playing a shooter game, the timing of pulling the trigger to kill enemies is a major component of the game mechanics. With timing I mean the sensitivity to event synchronization between the real and virtual world.
- **Orientation**: Viewing angle or aiming. It is a critical component of most AR games, which require rotating a 2D surface through space to produce the illusion of a 3D environment.

2.1.1.2 Defining States

I consider three sensor properties for each of the above parameters. They are -

- **Accuracy**: The fidelity with which the sensor measures the external phenomena.
- **Precision**: How often the same measurement is made for the same external stimulus.
- **Span**: The scope of measurement over which the accuracy and precision values must hold. For example, most of the outdoor location-based games are played over large areas whereas table-top AR games occur in a smaller play area.

While playing a location-based game, both accuracy and precision play an important role in rendering 3D artifacts on camera. Span is important in these types of games since the play environment is large and, the gameplay varies based on the area. When interactive object actions are included, timing is a vital factor. For current indoor AR games (which are mostly dependent on the orientation alone), precision of orientation is important rather the accuracy since players expects stability when aiming. Orientation span is important as larger angle change requires a range of motion of the body.

2.1.1.3 Defining Levels

To cluster the games, I divided the states in 3 different levels - High (H), Medium (M) and Low (L) recognizing that some games may fall into grey areas. The approach of defining the levels were relative. When all the existing AR games were accumulated and their gameplay was analyzed, clusters were defined based on their sensor dependencies.

- **High**: This level indicates the highest dependency on sensors of the game. For Space, generally the location-based games require highest level of Accuracy and Precision. The games played outdoor have highest span compared to other AR games. For Timing, AR games having interactive gameplay, requires

Table 2.1: Defining States, Parameters and levels of Augmented Reality Games Clustering

	Accuracy (A)			Precision (P)			Span (N)		
Space (S)	High	Medium	Low	High	Medium	Low	High	Medium	Low
Timing (T)	High	Medium	Low		x			x	
Orientation (O)		x		High	Medium	Low	High	Medium	Low

the highest Accuracy. The AR games that includes higher span of game area, requires high precision of Orientation.

- **Medium**: This level indicates medium dependency on sensors of the game. For Space, generally the location-based games that do not contain rigidly anchored game objects, require medium level of Accuracy and Precision. The games played outdoor or indoor but limited to smaller play area compared to wide open gameplay area, have medium span. For Timing, AR games having interactive gameplay, but the dependency level is not as much as mentioned in high level remains in the medium level.

- **Low**: Generally the games which can be played anywhere and adopts mostly observational gameplay, requires the lowest level of Space accuracy, precision and span. Timing does not matter for such kinds of games and orientation precision and span is also low. Examples for such games are table-top games.

Table 2.1 provides an overview of these parameters, their states and levels.

Applying the defined parameters, states, and levels I designed a taxonomy for research and commercial AR games. I rated the levels of the of the parameters in different states. I downloaded the commercial games, and ran a small ranged pilot experiment to analyze their sensor dependencies. Each condition state is defined as follows:

- **SA[H/M/L]**: Most of the games included in the high space requirement condition is location-based shooter games where the target has to be killed by compared virtual and real coordination. Medium accuracy will be required with casual games where players require comparatively less interaction with object on earth, such as, outdoor explorer games, where the 3D characters render in camera for providing information only.

- **SP[H/M/L]**: Highly precise location information is necessary in location-based aiming game mechanics. The requirement gradually decreases as the interaction between player and the 3D artifacts diminish.

- **SN[H/M/L]**: Play area on Earth as defined in game mechanics. Higher span includes a larger play area.

- **OP[H/M/L]**: A high orientation precision is required when the orientation span is low and an interaction among the objects and players is required.

- **ON[H/M/L]**: When the gameplay requires the player to rotate 360 degree, the game has highest span. Games played with fiducial markers have lower orientation span. The tabletop games have the lowest span.
- **TA[H/M/L]**: While playing aiming games, timing accuracy is required. Explortion games have a modest timing requirement.

Due to the game mechanics diversity, several different taxonomies could be explored. In this work, I have focused on the players perspective of gameplay experience, while playing different genre of AR games.

2.1.2 Defining Quality of Service (QoS), Quality of Experience (QoE) and Player Experience (PX)

In video games, the players' experience is affected by the game mechanics, narrative and the overall quality of the game design. This section provides the basic definition of QoS that defines the QoE in general and PX used in this thesis.

2.1.2.1 Quality of Service (QoS)

The Quality of Service (QoS) has traditionally been a measurement of network service. However, QoS can be applicable to any system that provides services to end users. A high quality system lead to a better experience of using that particular service. In the area of video games, the QoS can be defined as the accuracy and responsiveness of any of the system components which impact play including the ability of the graphics subsystem to rendering without dropping frames, the sensitivity of the network stack to latency and jitter and the capacity of input devices to provide timely and noise free representations of user intent.

2.1.2.2 Quality of Experience (QoE)

Quality of Experience (QoE) is an assessment from the user perspective of how well/easily the application meets their needs. The term QoE is broadly used in the sector or networking or telecommunication while User Experience (UX) is more commonly used in Software Engineering and Human Computer Interaction (HCI) areas.

2.1.2.3 Player Experience (PX)

An extension of UX is Player Experience (PX) which is particularly used in game research. The measurement of enjoyment during gameplay is examined while considering PX for a particular video games. In my dissertation, I have focused gameplay experience of the players while playing AR games of different genres with different spatio-temporal resolution requirements because games are a leisure activity and PX is the primary outcome.

2.2 Classifications

An elaborate taxonomy is presented in [191] by B. Thomas. The author classified AR games played in different media such as computer or handled devices. Separate views and impacts of AR games in research and commercial area were also described. A comparison of different gameplay environment were discussed. The author concluded his survey with two of his research questions regarding the compatibility of play experience and literal description and the common mistakes to avoid while engaging in this area.

While research games have various dynamics, commercial games are mostly clustered in aiming games. Table 2.2 and 2.3 represents the list of the games I will be discussing in this chapter. Listing the commercial games was challenging because a large number of AR games are listed in the app stores for both Android and iOS. However, selected AR entertainment apps are listed based on their more game-like behavior. The fourth column of table 2.3describes the effect of space and time during gameplay.

This section is divided into nine sub-sections based on the groupings of spatio-temporal behavior during gameplay. For example, location-based games require a high accuracy in location and so they are grouped into the groups where the location accuracy is higher. Later, interactions between players and 3D artifacts of the games were considered. If the gameplay required a direct interaction such as aiming, the timing requirement increases. While considering both location or non-location based games, play area was important.

2.2.1 Outdoor Shooter

This group includes location-based outdoor games that contain an action to be performed with virtual objects in play (e.g. shooting, trapping). Being location-based games, they place the highest priority for accurate and precise location information. Depending on the span of the play area and object size the orientation priorities vary. Parameters and their states for this cluster are as follows -

- Location
  - Accuracy[High] : Outdoor location-based games need higher location accuracy as the entire gameplay is directed through the location information of the system.
  - Precision[High] : Location has to be precise due to the interaction between the objects
  - Span[High] : Outdoor games are tipically played in large open area
- Orientation
  - Precision[High] : A higher orientation precision is required to target objects
  - Span[High] : Higher orientation span is needed due to the freedom of aiming
- Timing
  - Accuracy[High] : To hit a moving target, accurate timing is important

Table 2.2: Preview of Augmented Reality Research Games

Game ID	Game Name	Genre	Group
R1	ARQuake	Action/Shooter	Outdoor Shooter
R2	ARBattleCommander	Real Time Strategy	
R3	TimeWarp	Adventure/ History	Outdoor explorer
R4	Epidemic Menace	Adventure	
R5	Mad City Mistry	Educational/ Adventure	
R6	PasswARG	Treasure Hunt	
R7	Butterfly Effect	Casual	Casual Aiming
R8	Augmented Galaga	Shooter	Casual Shooting
R9	The Alchemists	Treasure Hunt	Marker-based explorer
R10	Interference	ADventure	
R11	The Treasure	Treasure Hunt	
R12	DOLPHYN Based game	Adventure	
R13	ARVe	Educational/ Health	
R14	LittleProjectedPlanet	Adventure	
R15	Tangible cubes	Edutainment	
R16	Learning Words	Educational	
R17	ARGo	Board	
R18	Impera Visko	Board Game	
R19	The Table Mystery	Educational	
R20	GARLIS	Educational	
R21	Energy Saving Game	Adventure	
R22	AREEF	Adventure	
R23	NerdHearder	Board	Casual tagged games
R24	Monkey Bridge	Adventure	
R25	ARRacing	Racing	
R26	Curball	Sport	
R27	Shelf Stack	Health	
R28	Art of Defense	Board	
R29	Smart Memory	Memory	
R30	AR Bowling	Sport	
R31	Penalty Kick	Sport	
R32	GenVirtual	Educational Health	
R33	AR Squash	Sport	Sports on table
R34	AR2Hockey	Sport	
R35	AR Tennis	Sport	
R36	AR Ping-Pong	Sport	
R37	Touch Space	Adventure	Indoor marker-based explorer and aiming
R38	Mind-Warping	Action	
R39	GeoBoids	Action	Outdoor aiming
R40	Cows and Aliens	Collaborative Adventure	Outliers
R41	ARobot	Shooter (iPad)	
R42	Human Pacman	Arcade	

Table 2.3: Preview of Augmented Reality Commercial Games

Game ID	Game Name	Genre	Group
C1	Mosquito Killer Camera	Casual Aiming	Casual Aiming
C2	Skeeter Beater	Casual Aiming	
C3	Leaf Catch	Casual Aiming	
C4	AR Balloon	Casual Aiming	
C5	Chase Whisply		
C6	Don't Get Mad Augmented Reality	Casual Shooter	Marker-based explorer
C7	AR Shooting	Casual Shooter	
C8	iPew	Casual Shooter	
C9	iSnipeYou	Casual Shooter	
C10	Real Strike	Casual Shooter	
C11	Paparazzi	Casual	
C12	Paranormal Activity	Casual	
C13	Toyota 86 AR	Casual Racing	
C14	AR.Race 2	Casual Racing	
C15	Star Trek AR	Casual Action	
C16	Augmented Reality : Size Me	Casual	
C17	Shake Fighter	Casual	
C18	AR Defender	Shooter	Casual tagged games
C19	AR Defender 2	Shooter	
C20	AR Battle Tank	Action	
C21	Augmented Reality Chess	Sport	
C22	HoopsAR	Sport	
C23	AR Pirates	Casual Adventure	
C24	Potato Augmented Reality Game	Casual	
C25	Real Maze 3D	Casual	
C26	Inch High Stunt Guy	Casual	
C27	SlinGame	sport	
C28	Table Zombie	Adventure	
C29	Zombie Room AR	Action	
C30	ARhrrrr!	Casual	
C31	Destroyer AR	Shooter	Casual Shooting
C32	Sky Siege	Shooter	
C33	Star Wars Arcade: Falcon Gunner	Shooter	
C34	DroidShooting	Shooter	
C35	AR Invaders	Shooter	
C36	Dimension Invaders	Shooter	
C37	X-Rift	Shooter	
R38	SpecTrek	Action	Outdoor aiming
R39	Pokemon Go	Action	
C40	Temple Treasure Hunt	Casual Adventure	Outliers
C41	Firefighter 360	Shooter	
C42	AR Soccer	Casual Sport	
C43	AR Basketball	Casual Sport	
C44	Augmented Reality Asteroids	Shooter	

(a) AR Battle Commander interface **(b)** AR Battle Commander pointing

Figure 2.5: Gameplay of AR Battle Commander [152]

According to Table 2.2 the game ARQuake [190] falls into this group, requiring the highest location accuracy and precision. Since it is an aiming game where the shooting is done with a virtual gun, timing has a vital role to play. ARQuake is an augmented reality first person shooter game played with a portable laptop, haptic gun and an HMD. The augmented characters of the game are spatially registered. The allowed actions in the game including walking, running, jumping and shooting one of the 16 featured monsters. The game is played both indoor and outdoor locations. The authors used a full 6 Degree of Freedom (DOF) approach with moderate tracking ability. For AR characters, AR Toolkit is used. While tracking a user's position, the authors considered three different locations - outdoors away from buildings, outdoors near buildings and indoors. Although, the GPS tracking system they used provided accurate location information, within 50 meters to building, errors occurred. Moreover, even when the distance was greater than 50 meters, orientation accuracy was an issue. While playing outdoors and far from buildings the the error of user's position was 2-5 degrees, It raised to 11-27 degrees while playing close to a building. In indoors, the degree of error remained up to 5 degrees.

The next game in this group is AR Battle commander [152]; which is a real-time strategy (RTS) AR game played in an outdoor environment. The authors address the problem of adapting RTS game in AR environment and state that there is not enough synchronization in user's movement in the real world to see all the necessary information around him/her during play. To overcome this difficulty the authors proposed a technique called 'Possesion' which allows a player to manage the line of sight during play. To validate the technique the authors developed the game AR Battle Commander where the player need to destroy the units of military of the opposing team.

There is a difference in the orientation span of the games ARQuake and AR Battle Commander. By using markers, ARQuake has a smaller potential span in orientation. On the contrary, AR Battle Commander depends on precise value of the orientation parameter. All these games have similar dependencies upon the sensor QoS.

2.2.1.1 Outdoor Explorer

This cluster contains location-based games where players gather information from digital avatars in the game rather than interacting through sensed game mechanics. The specifications are as follows:

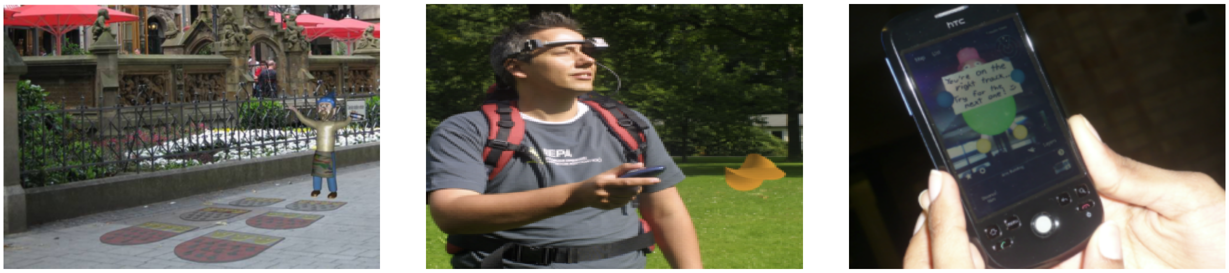
- Location
  - Accuracy[Medium] : Due to the absence of mutual interaction between the players and in-game objects, a medium accuracy can make the game playable.
  - Precision[Medium] : Medium level precision can be enough to collect information from the digital characters. Lower precision increases the amount of jitter in a player, but the game remains playable.
  - Span[High] : Played outdoor in a large area.
- Orientation
  - Precision[Low] : The digital characters remain visible with a lower accuracy orientation.
  - Span[High] : Outdoor games require 360 degree of rotation.
- Timing
  - Accuracy[Low] : Non interaction with the AR characters keeps the timing requirements low.

Epidemic Menace [117] is a cross media game with several different interfaces such as game board station, a mobile assistant and augmented reality virus tracker. With AR techniques the developers rendered a 3D representation of the virus that players need to find. The gameplay occurs outdoors and this situation increases importance of spatial accuracy. The orientation of the camera (the players wear a HMD with a laptop on their back) needs to be reasonably precise. Timing has a lower impact on the AR component of the game. Figure 2.6b shows some screenshots of the gameplay.

TimeWarp is played outside [83] where the virtual characters passively provide information and do not demand any player interaction, requiring only medium accuracy and precision. The game is played outdoors over a wide span. Thus, the orientation precision of the camera has very low impact on the game quality. Figure 2.6a shows screenshots of the gameplay.

Mad City Mystery [187] establishes the idea of learning through location based AR games. In the game, players solve a mystery by gathering data from clues as well as interviewing virtual character within the game. The system demonstrated enhanced learning outcomes for a wide variety of school aged students.

PasswARG [67] is a geo-tagged augmented reality treasure hunt game played with Android smart phones. In this game, several coordinates on the real world are defined where the player needs to go physically to get clues to solve the puzzle and move to the next level. When the player goes to a certain range of the avatar position, a 3D character renders and provides texture or graphical clue. The game was developed with the



(a) TimeWarp [83] **(b)** Epidemic Menace [117] **(c)** PasswARG [67]

Figure 2.6: Gameplay of TimeWarp, Epidemic Menace, and PasswARG

API of Layar reality browser. Although the gameplay needs GPS, lower spatial accuracy keeps the game playable. Orientation precision remains lower as the 3D artifacts provides only need to be observed to see the clue. Figure 2.6c shows a screenshot of the game.

2.2.2 Casual Aiming

The games of this group are playable in both indoor and outdoor location. Since the game mechanic includes interaction between players and in-game digital artifacts, orientation and timing have are more critical.

- Location
  - Accuracy[Low] : Non location based games do not depend on location accuracy.
  - Precision[Low] : Non location based games do not depend on location precision.
  - Span[Low] : The play area is quite small.
- Orientation
  - Precision[Medium] : Due to the in-game actions (e.g. shooting or targeting) orientation accuracy remains moderate so the targets can be hit.
  - Span[High] : The span remains high because the games require 360 degrees of rotation during gameplay.
- Timing
  - Accuracy[High] : Accurate timing is very important for targeting.

In the game Butterfly Effect [144] the player wears an HMD and holds a stick named Tornado. The player needs to collect virtual butterflies by moving towards the butterflies and using the Tornado to collect them. The game can be played anywhere the player wants. Therefore, the spatial accuracy is not required. Timing is vital since accurate aiming is needed to collect the moving butterflies. Figure 2.7c shows the game.

One of the commercial games included in the category is Skeeter Beater [157]. This is a casual game demanding a medium level of aiming accuracy. The players need to kill the mosquitoes moving different

(a) Skeeter Beater [157] **(b)** Leaf Catch [1] **(c)** Butterfly Effect [144]

Figure 2.7: Gameplay of Skeeter Beater, Leaf Catch, Butterfly Effect

direction on the camera screen by tapping them. Player earning the highest number in a given time wins. A nearly identical game is Mosquito Killer Camera [16] with same goal of killing virtual mosquitos through a camera. Leaf Catch [1] is a game where players need to collect virtual falling leaves by walking particular number of steps. The number of steps are shown in the camera and when the player walks that many steps, A leaf appears in the screen to collect. In the game AR Balloon [3] players pop virtual balloons by aiming a target towards a balloon and then tapping.

2.2.3 Marker-based Explorer

The games in this group are played both in indoor and outdoor environment. For most of these games no or minimal interaction with virtual objects is necessary. For example, with the AR artifacts, players mostly gather information with minimal interaction. Hence, these games demand the lowest sensor accuracy and precision in all dimensions. Specifications are as follows:

- Location
  - Accuracy[Low] : Being non-location based games location accuracy is lowest for this group.
  - Precision[Low] : Being non-location based games location accuracy remains lowest for this group.
  - Span[Low] : Marker-based games usually requires a very small play area. However, exceptions occur.
- Orientation
  - Precision[Medium] : A medium orientation accuracy keeps the game playable. The object needs to render precisely on top of the marker at correct viewing angle.
  - Span[Low] : Marker-based play has smaller play area.
- Timing
  - Accuracy[Low] : Since there is minimal level of interaction required, timing requirements remain low.

(a) ARGo [97]

(b) Little Projected Planet [120]

Figure 2.8: Gameplay of Little Projected Planet, ARGo

ARVe - Augmented Reality applied to Vegetal field [167] is a game for cognitive disable children. This is a non-immersive game where players match plants. The completion time is recorded to determine the winner of the game. The authors performed a user study with 93 elementary school children aged from 7 years to 9 years old. The result of the study showed that AR technology can make the disabled children more enthusiastic about their learning.

LittleProjectedPlanet [120] is an AR prototype of the famous PS3 game 'LittleBigPlanet'. Here, players interact with the virtual objects depending on the shapes created by the user. According to the authors - "Into this model the user can place several virtual objects representing items like tennis balls or bowling balls. These virtual objects then get projected into the real world by the mobile projector". The model mentioned here is the physical model calculated through the detection of the virtual shapes detected by the camera. Since the game is played based on the mini projector and a portable smart phone, orientation precision is required to observe and detect the shape from an actual viewpoint. Figure 2.8b shows a screenshot of the game.

Tangible Cubes [101] is an edutainment game for elementary summer school children. The children are given a cube with black and white marker on each side of it and asked to find animals from the pictures that appears on each plane of the tangible cube. Authors have used an HMD to render the virtual artifacts of the game. They compared the AR game with an equivalent real game and completed a survey with 46 children from the Summer School of the Universidad Politecnica de Valencia and showed a result that children enjoyed AR version of the game more than the real one.

Similar to Tangible Cubes, Learning Word [100] is a game for younger children to learn words through the game. Different markers are used to render virtual letters on its surface. The authors ran an experiment on 31 children who enjoyed playing the AR game while learning words.

GenVirtual [76] an educational musical AR games designed for people with learning disabilities. The authors targeted specific skills such as creativity, attention, memory (storage and retrieval), planning, con-

(a) Tangible Cubes [101]
(b) Learning Words [100]
(c) GenVirtual [76]

Figure 2.9: Gameplay of Tangible Cubes, Learning Words, AR Racing, and GenVirtual

(a) AR Shooting[125]
(b) MindWrap [170]
(c) Impera Visco [170]

Figure 2.10: Gameplay of Tangible Cubes, Learning Words and AR Shooting

centration, ready-response, hearing and visual perception, and motor coordination. GenVirtual uses AR technology to help disable peopled learn music. The objective of the game is to follow the sequence of the notes in a song. According to the authors - " GenVirtual is a musical game on which the user follows a sequence of sounds and colors emitted from virtual objects." A musical sequence is generated from a MIDI file and specific notes appear on top of the fiducial markers. The player touches the notes of different colors associated with different markers. Figure 2.9c shows a screenshot of the game.

ARGo [97] is the augmented reality version of the board game Go - commonly played in Asian countries. The hardware components needed for this game are - a laptop computer, ARGo board, stones, a stationary webcam and a mobile projector. Through the projector, the game view is projected on top of a table, where the players on each team place rocks to occupy most of the blocks of the AR board. The one with more occupied blocks wins. Figure 2.8a shows an overview of the gameplay of ARGo.

Mind Wrap, Impera Visco, and Penalty Kick are three different games implemented to demonstrates the user interface for handheld AR games [170]. For this purpose, the authors created three different prototypes of AR games with minimal infrastructure support. All these games consolidate both physical and virtual objects. The game Impera Visco is a board game where players win by mining, trading, fighting and cultivating land.

(a) Energy Saving [52] **(b)** GARLIS [197] **(c)** The Table Mystery [46]

Figure 2.11: Gameplay of Energy Saving, GARLIS and The Table Mystery

Players take different actions based on the different markers placed on a table top.

Energy Saving [52] is a casual adventure educational game to support the awareness of reducing energy in the environment. It is an indoor game played in groups. Players go to a station and perform the given task. At the same time a clue is given to reach to next station. AR markers provide the 3D clues rendering in the camera screen. To make the gameplay interesting a virtual garden is provided to each team. Whenever a task is performed, the team earns a point which leads the garden to improve (e.g. the trees grow and become more green). Figure 2.11a shows the screenshot of the game.

Two educational games GARLIS[197] and The Table Mystery[46] are included in this group. GARLIS (Game-based Augmented Reality Library Instruction System) provides an AR system in a real world library. According to the authors - "The aims of the proposed system are to enhance learner impressions and interest in learning the Chinese library classification scheme, and enhance library instruction performance using the situational learning approach supported by AR techniques that can be connected to a real library environment." Based on the information provided, the players need to find their required books in the library. With a large scale user experiment, the authors reached the conclusion that GARLIS could provide help with library classification within a game environment.

The Table Mystery is a collaborative AR game for chemistry students with a rich game design for three to four players in a group. Each group receives instruction from a character experiencing amnesia. Players need to follow the character's instruction to find information using the handheld device rendering on top of a periodic table. This game demands a highly collaborative environment as the members of a particular group play individual roles and they need to combine their findings to solve the riddles.

AREEF - an Under Water Augmented Reality (UWAR) game is the other game that falls into this group of sensor resolution [148]. AREEF is an underwater multiplayer AR game played with handheld tablet. Each player carries on tablet device with waterproof shield and swims through the pool to find markers that show different content. The players are suppose to collect information showing an AR technique above the markers. At the base station a player receives new missions. Another underwater AR game is proposed using DOLPHYN - an underwater-computerized display system [36]. While diving under water, with this system

(a) Real Strike[95] **(b)** Toyota 86 AR[86] **(c)** AR.Race 2[94]

Figure 2.12: Gameplay of Real Strike, Temple Treasure Hunt, Zombie Room AR, Toyota 86 AR and AR.Race 2

(a) iSnipeYou [127] **(b)** Paranormal Activity [93] **(c)** Paparazzi [128]

Figure 2.13: Screenshots from the game TagThis, iSnipeYou, Paranormal ACtivity, and Paparazzi

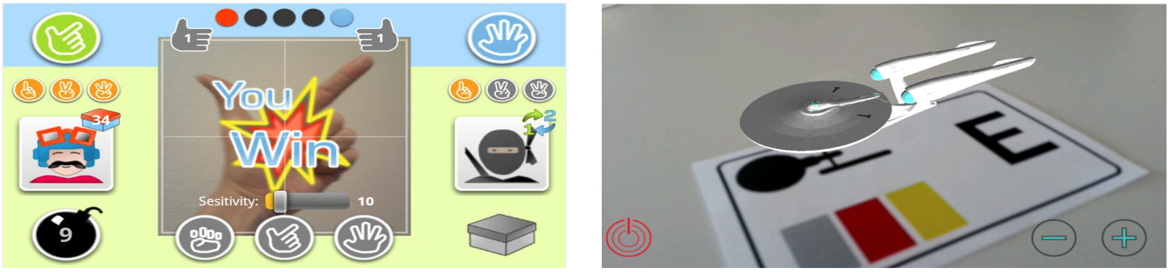
the divers can have an AR gaming experience. Markers are used to render 3D objects.

AR Shooting [125] is a casual shooting game made for the Android Platform. In AR Shooting, the player can choose their gun from available options such as handguns, shotguns or pistols. Then, the player shoots a black and white silhouette. Depending on the shooting position, they earn points. Figure 2.10a shows screenshots of the game.

The next game comes into this category is iPew [185] also made for iPhone. This is a casual shooting game where the player can fire at a person in the camera. iSnipeYou [127] is the game where the player can view the world through a shooting target and can shoot objects to earn points. The Paranormal Activity [93] (based on the famous movie Paranormal Activity), players are suppose to discover the ghosts in the real world through the camera. The last commercial game falling into this category is Paparazzi [128]. This is a simple game played both in Android based smart phones and iPhones. In this game, a virtual character - the paparazzi tries to take photograph of the player. ARhrrr! [71] is a shooter game played on a tabletop. The gameplay includes shooting the zombies to save the civilians before they are eaten by the zombies.

Real Strike [95] is a first person shooter game available in iOS. Figure 2.12a shows the screenshot of the game. Two casual racing games are in this group. In these games single cars race against the clock. In Toyota 86 AR[86] the car is visible on top of a marker whereas AR. Race 2 [94] is a first person racing experience. Figure 2.12b and 2.12c shows the screenshots.

Size Me! [20] is an AR game where players feed a virtual cocoon to make it grow into a butterfly. The



(a) Shake Fighter[156] **(b)** Star Trek AR[22]

Figure 2.14: Gameplay of Shake Fighter and Star Trek AR

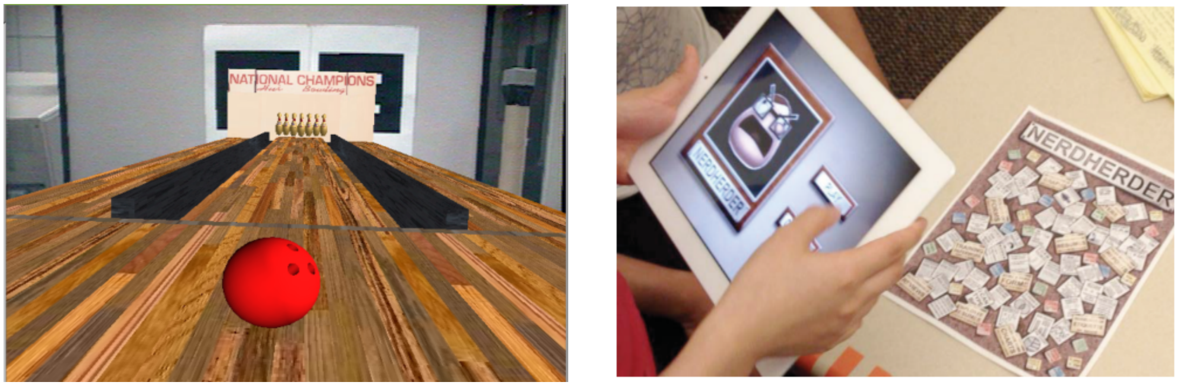
game is playable in both outdoor and indoor environments. Shake Fighter [156] is an AR version of the classic game Rock, Paper, Scissor. Players do hand gestures for each of these elements which is identified by the camera sensor. Don't Get Mad, Augmented Reality [155] is a casual shooter game where players can shoot anywhere the camera is facing. In the game Star Trek AR [22], different Star Trek characters, ships and weapons are shown on a marker.

2.2.4 Casual Tagged Games

This cluster mostly includes game that are played using stationary markers. Unlike the previous group, the gamplay in this group requires more sophisticated player interaction with the digital artifacts that appears on top of the marker visible through handheld camera.

- Location
  - Accuracy[Low] : Being non-location based games location accuracy remains lowest for this group.
  - Precision[Low] : Being non-location based games location accuracy remains lowest for this group.
  - Span[Low] : Marker-based games usually requires a very small play area. The games in this group mainly played on a table top.
- Orientation
  - Precision[High] : Orientation needs a greater precision due to the interaction between the player and AR objects appearing on marker.
  - Span[Low] : Marker based play has smaller play area.
- Timing
  - Accuracy[Medium] : A medium level of timing accuracy is needed to perform the interactions.

NerdHerder [133] is an AR game where the player acts as an IT manager - the NerdHerder at the technology firm MicroNerds. Using different techniques, the player must send all the other nerds back to



(a) AR Bowling[130] **(b)** NerdHarder[133]

Figure 2.15: Gameplay of AR Bowling and NerdHearder

(a) Monkey Bridge [33] **(b)** AR Racing [145] **(c)** Curball [103]

Figure 2.16: Gameplay of Monkey Bridge, Curball and AR Racing

work. The game levels involve both puzzle-solving and motion-based actions. The game runs on both Android and iOS platform including iPhone 4S and iPad2.

AR Bowling [130] is an augmented reality bowling game played with a see-through HMD as one of the input devices. To render the AR elements, optical markers are used with ARToolkit. The action of the game is performed with the hand gesture and to track the hand gesture, Pinch Gloves from Virtual Technologies were used. The orientation of the camera decides the view of the plane and so, it has a moderate effect on the game. Figure 2.15a shows the screenshot of the gameplay.

Monkey Bridge [33] is a collaborative AR game where players are suppose to develop a virtual bridge using their own 'monster-like' characters using virtual and physical pieces of rock. The goal of the game is to reach to a specific position over the ocean. To implement the game the authors used a middleware technique for developing AR games: the Studierstube AR platform. They developed three different demos of the game where the first version is played in desktop and the other prototype is the AR version developed with ARToolkit optical marker recognition system. The third setup was built using a magnetic tracking system to track two HMDs and two Plexiglas puks used to place the virtual tiles. Figure 2.16a shows a screenshot of the game.

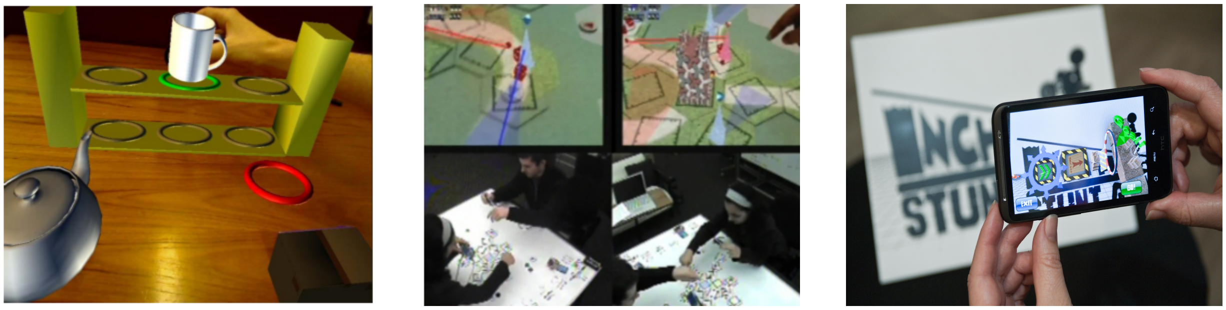
Liarokapis [115] demonstrated a multimodal tracking interface to enhance gameplay. To validate their interface design the authors developed Pervasive Racing Game-AR Racing [145]. This is a modified AR version of an existing XNA game, where a single player needs to finish the lap as quickly as possible without going off the track. In the AR version of the game, instead of following a specific track, cars are allowed to go anywhere inside the zone defined by an optical marker. The driver sees the game through the HMD display with an attached camera. The players finish the lap while avoiding the obstacles define in the game zone. Figure 2.16b shows a screenshot of the game.

Curball [103] is an AR game with a combined combination of Curling and Bowling. The game has two players - one is a senior player and the other one is junior. The senior player sits in front of a computer screen with a physical tangible ball on his/her hand. He/she is able to see the playground and based on this view, and needs to do a hand gesture towards where he/she wants to throw the ball. The junior player plays on a field with the physical obstacles with optical markers on top. He/She needs to move the obstacles based on the instruction of the helpers since He/she cannot see the ball. He/she needs to move the obstacle to keep the ball on the game surface. If the ball touches any of the obstacles, the senior player gets points and the level ends. The game employes a stationary camera. Figure 2.16c shows an overview of the gameplay of Curball.

According to the previous research/surveys, Augmented Reality games are an effective support for limb stroke rehabilitation. Burke et. al. described three aspects of AR games for limb-stroke rehabilitation named Shelf Stack [53]. They are - meaningful play, challenge and conservative handling of failure. Based on these constraints, the authors demonstrated two of their AR games named Brick a' Break and Shelf Stack. Both of these games were developed using Microsoft XNA and ARTag. This game has very low spatial and temporal impact since the game is played stationary sitting on a table. The orientation matters to a moderate level since the view of the objects depends on the orientation of the camera. Figure 2.17a shows a screenshot of the game Shelf Stack.

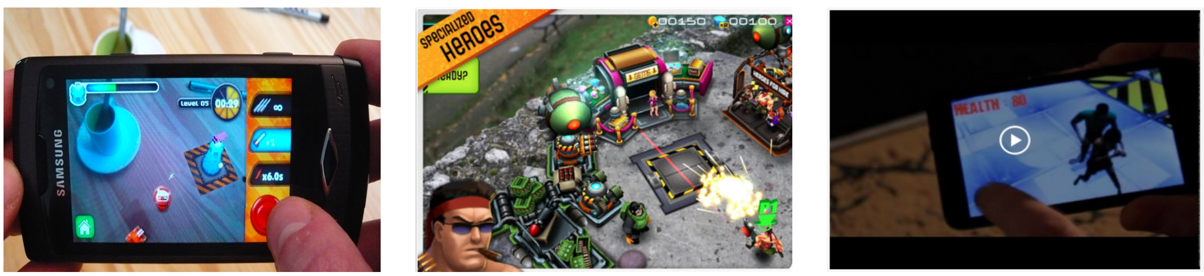
Art of Defense [87] is a tabletop AR representation of the desktop game named Tower Defense. Its Authors named the game Art of Defense (AoD). The main research goal of this work is to explore the user experience of a collaborative AR game. In the game, the player needs to save a tower from the enemy waves by placing different blocks with optical markers on top of it through which the virtual barriers can be created. The authors developed the game in a Symbian platform using OpenGLES. Later they a small user study and measured the level of engagement through the AR handheld experience. They conclude that AoD is fun to play and involves the players more than a regular table top game. Figure 2.17b shows the screenshot of the game.

Smart Memory [170] is a card AR game combination of the classing version of game "Memory" and "Minesweeper". Black and white markers have been used to implement an AR version. Unlike Minesweeper, the game Smart Memory does not use time to decide the winner. AR Defender [88] is a tabletop shooter



(a) Shelf Stack [53] **(b)** Art of Defense [87] **(c)** Inch High Stunt Guy [62]

Figure 2.17: Gameplay of Shelf Stack, Inch High Stunt Guy and Art of Defense



(a) AR Defender [88] **(b)** AR Defender 2[91] **(c)** Zombie Room AR[161]

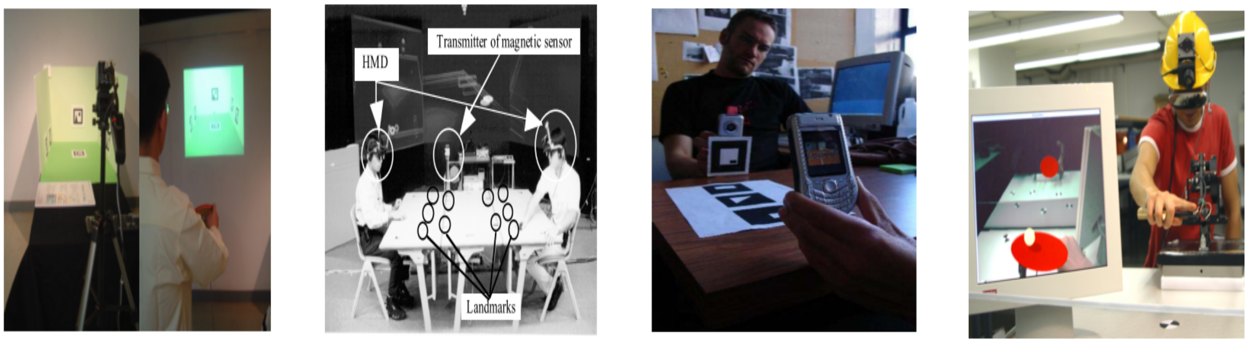
Figure 2.18: Gameplay of AR Defender,AR Defender 2 and Zombie Room AR

game played on both iPhone and Android platform. During the gameplay, the player needs to shoot a virtual tower that appears on top of an associated fiducial marker. Figure 2.18a shows a screenshot of the game. A sequel of this game was released on iOS[91]. Figure 2.18b shows a screenshot of AR Defender 2.

Inch High Stunt Guy [62] is a casual racer AR game played on tabletop. This game is available for both android and iPhones. With the AR markers a game environment is created on top of a table. A game character is capable of performing stunt based on the player's actions. AR Pirate [121] is a casual shooter game played on iPhone and some available Android platform.

Zombie Room AR is a table top role playing game that uses AR. Players must save themselves by killing zombies. Figure 2.18c shows the screenshot of the game. A very similar concept is observed in the game Table Zombies AR [23]. Penaly Kick is a game comes with a pack of cereal. At the back of the package there is a photo of green field with a fiducial marker. If the user aims the camera at it, a virtual goalie and a soccer ball renders and the player scores by pushing the ball into the goal.

In the AR Battle Tank [153] game, a tank needs to be controlled on top of marker. Augmented Reality Chess [4] is an AR version of regular chess game played on top of marker. Hoops AR [13] is an augmented reality basketball game. The play area is created using marker with necessary components (e.g. ball and basket). Players target is to score by throwing the ball into the basket. Real Maze 3D [19] is a maze game played on top of marker. Players find a way out of a given maze with a defined start and end point. A similar conceptual marker based game is SlinGame [21]. The Potato Augmented Reality Game [18] is played



(a) AR Squash [113]

(b) AR2Hockey [146]

(c) AR Tennis [82]

(d) AR Ping-Pong[105]

Figure 2.19: Gameplay of AR Squash, AR2Hockey, AR Tennis, and AR PingPong

on marker where players need to guide a potato through a given path displayed on top of a marker.

2.2.4.1 Sports on Tables

Although the games in this group need markers to play, player-player interaction must also be supported.

- Location
  - Accuracy[Low] : Being non-location-based games location accuracy remains lowest for this group.
  - Precision[Low] : Being non-location-based games location precision remains lowest for this group.
  - Span[Low] : Marker-based games usually requires a very small play area. The games in this group mainly played on tables.
- Orientation
  - Precision[Medium] : Medium accuracy of orientation sensing is required as the markers reference reduces the noise.
  - Span[Medium] : Marker-based play has smaller play area.
- Timing
  - Accuracy[High] : Timing accuracy is an important factor because the players conduct player to player interaction via the AR aftifacts.

Lee et. al. [113] presented the augmented reality squash game using estimated geometric information from images taken using a stationary camera. The geometric location of the markers in the world coordinate system was estimated to register the motion tracker's coordinate system. Finally, motion modeling was performed to allow interaction with the ball. Based on phone orientation, players can locate the ball in phone screen and thus perform their action.

The game AR2Hockey (AR AiR Hockey) [146] is a collaborative real time AR game played where players sit at a table with see-through head mount display communicating with a virtual world. In the game area, each player is visible to the other player. The game requires a higher rate of time frequency to avoid the dynamic error. According to the authors - "This simple application challenges to the following problems of the collaborative AR. Firstly, more than two persons share a single physical and a virtual space. Secondly, since the puck moves fast, the response time becomes severe and the synchronization problem should be solved. Thirdly, since the virtual puck is hit by an physical hand, the positioning error must be minimized."

The next game that falls into this category is AR Tennis, a face to face collaborative AR game [82]. The game is developed on the Symbian platform integrated with ARToolkit on a handheld device. The main goal of the research was to analyze the face to face collaboration between the two players in AR games. For communications, the authors used Bluetooth peer-to-peer connections between the two handheld device where one of the phones acts as a server and the other as client. Similar to the games AR Squash and AR2Hockey, AR Tennis is also played stationary, sitting on the two alternative edges of a table.

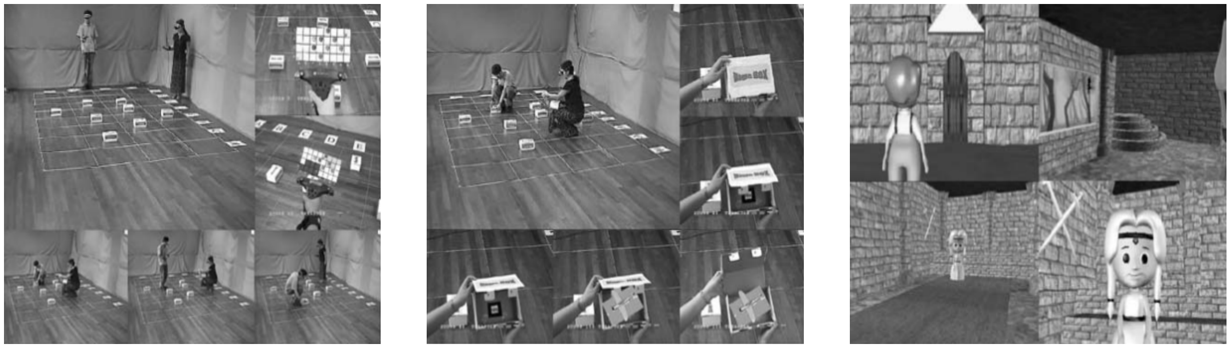
B. Knoerlein, G. Szekely, and M. Harders [105] developed a collocated visuo-haptic augmented reality environment. To determine the reliability of their system the authors developed an augmented reality table tennis game named AR Ping-Pong. Similar to the aforementioned games, AR PingPong is also played stationary with two players. The players interact with the virtual ball holding a real table tennis bat's handle attached to the haptic device. To make the virtual ball collide with the bats, the positioning of the system is mapped to the real world coordinates. To control the bat, haptic devices are used.

Figure 2.19 represents the system setup and overview of the games for AR Squash, AR2Hockey, AR Tennis, and AR Ping-Pong.

2.2.5 Indoor Marker-based Explorer and Aiming

The two games in this group are played in a specified indoor space. The specifications are as follows:

- Location
  - Accuracy[Low] : Being non-location-based games location accuracy remains lowest for this group.
  - Precision[Low] : Being non-location-based games location precision remains lowest for this group.
  - Span[Medium] : Since the game is played in a room area, the span of play area is medium.
- Orientation
  - Precision[High] : A higher accuracy in needed due to the interaction between the player and a portion of gameplay includes interaction without marker.
  - Span[Medium] : Since a part of the games include non marker dependent play, the span remains medium



(a) The game space

(b) Finding treasure from the tangible objects

(c) Navigation in the virtual world

Figure 2.20: Gameplay of Touch Space [59]

- Timing
  - Accuracy[Medium] : Due to the communication among player's a medium level of timing accuracy is required.

Touch Space [59] is a mixed reality AR-VR (Virtual Reality) game played by interacting with tangible objects as well as other players. Players communicate with their co-players in an augmented reality environment. The main actor is supposed to rescue a princess from a mysterious island from a witch by following information hidden as AR in the markers in different points of the room, and as tangible objects as the squares of the grid.

Mind-Warping [188] is an AR Kung-fu fighter game developed on a platform named 'Warping' available with two different platforms - an augmented desktop and a body-centered augmented reality. In this indoor game, fighters fight against evil magician who directs the monsters. With a wearable head mounted display, the players see their next stage of the game. In this game three levels of monsters attack from floor, ceiling and middle zone and the player needs to fight them with hand gestures and kung-fu-like sounds (i.e., heeee-Yah).

2.2.6 Casual Shooting

This group includes a large number of the commercial aiming games. The aiming needs to be done with a defined weapon or button and this particular feature differs the game from the group of casual aiming although the parameter dependencies remain same. Compared to 'aiming with hand tap' these games have higher demand on orientation precision because the entire viewplane must be rotated for aiming.

- Location
  - Accuracy[Low] : Being non-location based games location accuracy remains lowest for this group.
  - Precision[Low] : Being non-location based games location precision remains lowest for this group.
  - Span[Low] : Location-wise the play area is small.

(a) Sky Siege [96] **(b)** Star Wars Arcade: Falcon Gunner [28]

Figure 2.21: Gameplay of Sky Siege and Star Wars Arcade

- Orientation
  - Precision[Medium] : With medium accuracy of orientation, the games remain playable.
  - Span[High] : The span is high because these games requires 360 degrees of rotation during gameplay.
- Timing
  - Accuracy[High] : Due to the aiming actions, timing needs to be accurate.

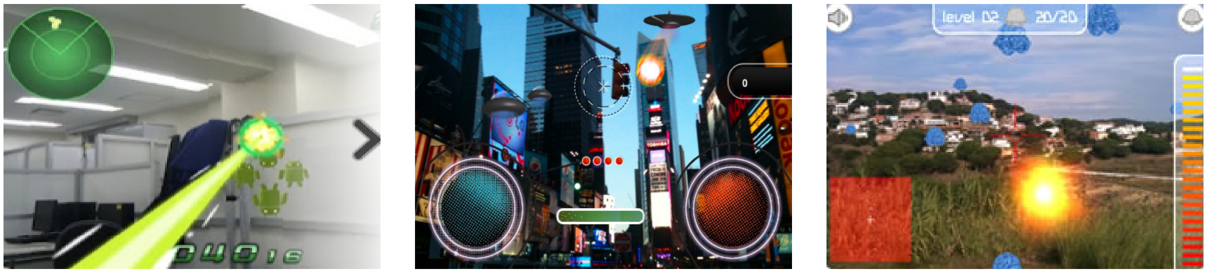
Sky Siege [96] is an AR shooter game played on the iPhone. The players shoot virtual helicopters that appear around them and earn points. If more than one player is playing at the same time with different devices, the highest point achiever wins and Figure 2.21a shows a screenshot of the game.

Star Wars Arcade: Falcon Gunner [28] is another game from Apple iTunes played in iPhone. This is a first person shooter AR game developed around the renowned movie Star Wars. Player need to shoot the TIE fighters and earn points. Figure 2.21b shows a screenshot of the game.

DroidShooting [126] is a shooting game made for the Android Platform. In DroidShooting, the player shoots the virtual Android robots appearing around the player. Figure 2.22a shows screenshots of the games. A similar shooting game played outdoors is X-Rift. It is a multiplayer game to protect the world from alien monsters [160]. This category includes another game Territory Defense Augmented Reality [159]. Similar to other games of this group, this is playable both indoor or outdoor locations where players earn points by hitting the enemy aircraft.

By killing virtual UFOs players earn points in the game AR Invaders [90]. There are two controlling buttons - one is to fix the aiming target and the other one is for shooting. In the game Dimension Invaders [165], players kill UFOs to earn points. Unlike AR Invaders, this game has one controlling event. Figure 2.22b and 2.22c shows the screenshots of the games.

In the game Destroyer AR [8], the player needs to save fighter planes by tilting the phone to avoid enemy air craft appearing from various directions.This category includes Augmented Reality Asteroids [154] and Territory Defense Augmented Reality [159] - both these games include shooting enemy airplanes to gain points.

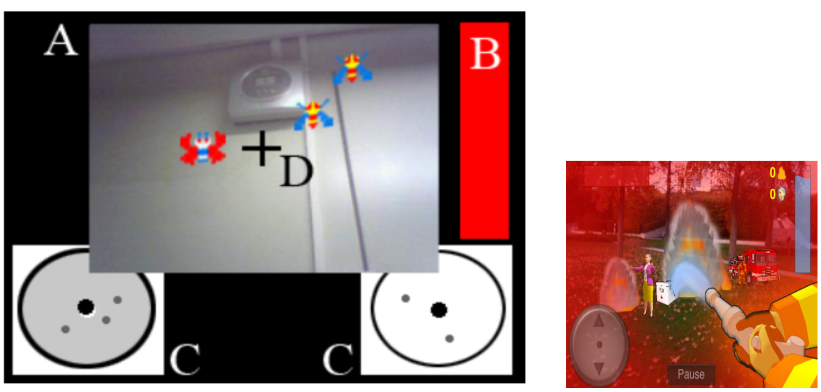


(a) DroidShooting[126] **(b)** AR Invaders [90] **(c)** Dimension Invaders [165]

Figure 2.22: Gameplay of DroidShooting, AR Invaders, and Dimension Invaders

Firefighter 360 [192] is developed specially for iOS platform. In this game, the player acts as a fireman whose goal is to extinguish fire around him. If he goes too close to the fire, it effects his health and it might cause him death. There is an opportunity to take virtual medical packs appearing around him by walking into that place. Players have to move around 360 degree to spread the water thoroughly. Figure 2.23b shows a screenshot of the gameplay.

The only research game in this group is Augmented Galaga [150]. This is an AR version of the famous arcade game Galaga. In Galaga, players shoot spaceships and aliens in a galaxic environment. In Augmented Galaga, the spaceships are superimposed on top of the real world while looking through the handheld device's camera. An object tracking method is included to track specific object in the real world around which the spaceships appear. Players need to shoot the spaceships by pressing a button the handheld device. Figure 2.23a shows gameplay of Augmented Galaga

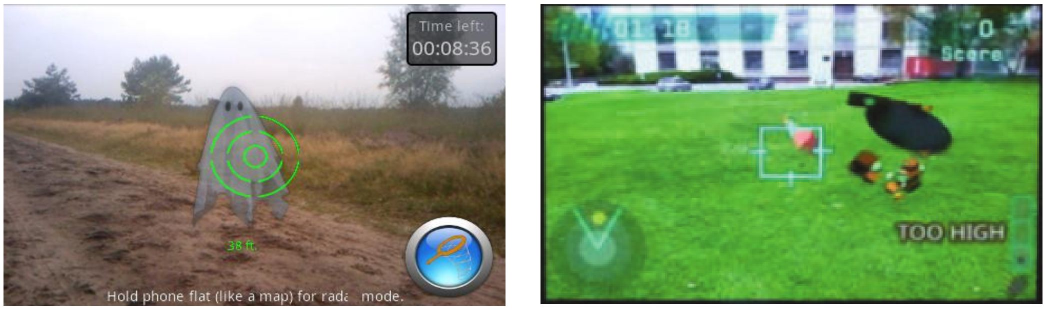


(a) Augmented Galaga[150] **(b)** Firefighter 360 [192]

Figure 2.23: Augmented Galaga and Firefighter 360

2.2.7 Outdoor Aiming

Both the games in this group are played outdoors. The difference between these two games are their type of aiming. Details as follows:



(a) SpecTrek [129] **(b)** GeoBoids

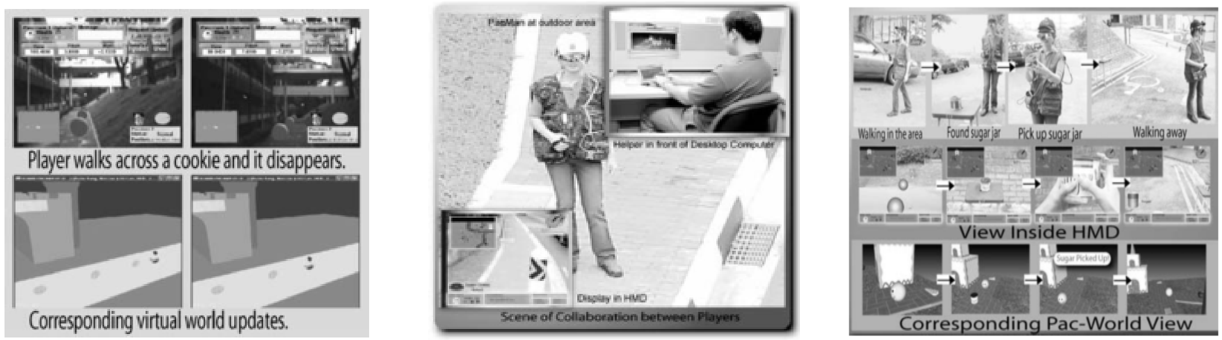
Figure 2.24: Gameplay of GeoBoids and SpecTrek

- Location
  - Accuracy[High] : Outdoor location-based games need higher location accuracy
  - Precision[Medium] : Location has to be precise moderately due to the interaction among the objects
  - Span[High] : Outdoor games are played in big open area
- Orientation
  - Precision[Low] : A lower orientation precision is sufficient to target objects due to non marker based rendering
  - Span[High] : Higher orientation span would be needed because orientation is a constrained
- Timing
  - Accuracy[High] : To kill target in a high span play area, accurate timing is much important

SpecTrek [129] is an AR shooting game specially designed for the Android platform. The developers describe the game as a ghost hunting game where the players need to find virtual ghosts and shoot within a given time. Since the ghosts are stationary, timing and orientation requirements are relaxed. Figure 2.24a shows a screenshot of the gameplay.

Pokemon Go [17] is location-based aiming game where players need to hunt for different characters of Pokemon series. Following the map, players need to find the points of interests with the possibility of finding maximum numbers of Pokemon. Once a Pokemon is found, players thrwo balls at the Pokemon in an AR environment. While the initial map investigation requires position accuracy, the AR targeting component only depends on orientation and is similar to the casual shooter games, making Pokemon Go the only hybrid game.

characters and reach there to collect them with a targeting object named pokeball.



(a) Pacman Collecting Cookies

(b) Collaboration between Pacman and Helpes

(c) Collection of Special cookies

Figure 2.25: Gameplay of Human Pacman[58]

A similar game is GeoBoids [116]. The player must first identify and then run to a point of interest in the real world to grab the flocks of virtual characters (Figure 2.24b). The player has to repeat this procedure until the time expires. This is designed as an exergame and played outdoors.

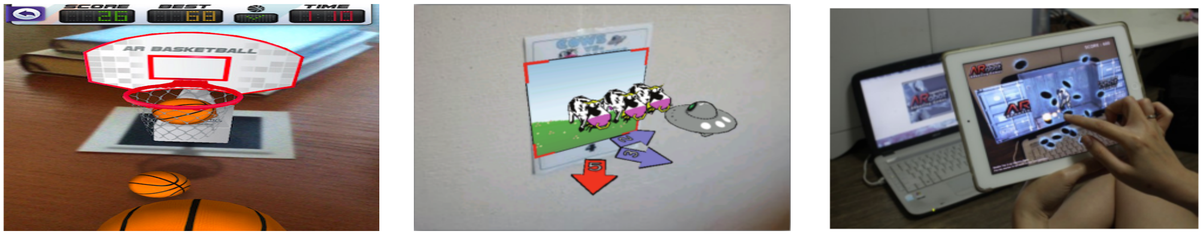
2.2.8 Outliers

This groups includes all the games which did not neatly fit into any of the other categories. Due to variations in gamplay it was difficult to include the games in a particular group.

Adventure game Temple Treasure Hunt Outdoor [158] is in this cluster. This game is playable both in indoor and outdoor modes. In the outdoor version, the player is given a map and a treasure is located on a geo-location point on earth. The players go to exactly that point to reveal the treasure which appears as a form of 3D avatar on handheld device's screen. This game demands highly accurate and precise location information to visualize the 3D artifact.

Human Pacman [58] is a role playing AR game the brings human-social and mobile game under the same roof. The focus of this game is collaboration among the team members and within the virtual 'Pac-World'. The game is divided into two teams - the first team is the Pacmen and his/her Helpers and later is the Ghosts and their helpers. In the game, the Pacman needs to collect all the cookies in certain area that he/she can see through his/her HMD. At the same time Ghosts are suppose to devour the Pacmen. In the visible map, the Ghosts do not see the actual position of the Pacmen but they can see a sequence of vanishing cookies. Pacmen can collect cookies by walking through it but for special cookies, the Pacmen need to touch Bluetooth-embedded objects placed in different sections of the game defined zone. The Pacmen receive hints through the communication with their helpers and based on the clue, the players look for the physical bluetooth object in the game area. If the Ghost finds any Pacman he/she has to tap physically on the the Pacman to devour him/her. Figure 2.25 shows some screenshots of the game Human Pacman.

Cows and the Aliens [137] is a collaborative competitive AR game where players need to collaborate while exploring the game area. The goal of the game is to save virtual cows by bringing them to a stable. Initially,



(a) AR Basketball[89] **(b)** Cows and the Aliens [137] **(c)** ARobot [175]

Figure 2.26: Gameplay of AR Basketball, Cows and Aliens and ARobot

the cows will be scattered in the game space associated with the fiducial marker. The player need to move physically to perform the game actions. There are two actions that a player can do while playing - taking the cow to a stable or request for a UFO (Unidentified Flying Object) to shoot the cows. If the players send the cow to the stables, the cow vanishes from the previous position and reappears into a corner- the virtual display of the stables. While shooting the cows a flash occurs onto the screen. Figure shows 2.26b the interface of the game.

A commercial game AR Soccer fall into this category [92]. This is an extremely casual game released by the iPhone app. Players need to view the floor to find the soccer ball which can be kicked. One similar game is AR Basketball [89]. There's a virtual ball and stand where the player need to through the ball in the stand. The player scores the best within the lowest time earns the highest points. None of these two games uses any of the sensors but camera and requires very little interaction.

ARobot is a 3rd person shooter (TPS) mobile AR game played with iPad. What is new in this game the position of the avatar of the player. While in traditional TPS games, the player's avatar is visible from it's back, in ARobot, the player's avatar faces the player. The other objects of the games such as objects to shoot stays in front of the Avatar. In spite of being a shooter game, ARobot falls in the outlier is because other than shooting the objects on time, no other movements required for the game play. Figure 2.26c shows the screenshot of the game. Another similar game is Augmented Reality Asteroids [154] where fighter plane appears on camera while holding the phone towards the marker and the players need to shoot then to gain points.

2.3 Effectiveness of QoS on QoE and PX

Quality of Service (QoS) is a key component of the Quality of Experience (QoE). A user can have a positive or negative experience of using a particular service depending on its quality. In video games, the QoS of gameplay inputs can impact on player experience (PX). In this section, an overview of User eXperience (UX) evaluation is provided from canonical reference within the Human Computer Interaction (HCI) literature. Because I am proposing a technique linking sensor behavior to PX inputs in AR games, an overview of the existing evaluation techniques impacting AR games is provided. A brief literature review on game PX evaluation techniques is also is provided.

Over the last two decades, User eXperience (UX) has become one of the most prominent research areas in Human Computer Interaction (HCI). Mike Kuniavsky defined UX as - "The user experience consists of all of the factors that influence the relationship between the end user and an organization, especially when a product mediates that relationship" [108]. In other words, positive UX can be explained or defined as the range of user satisfaction while using a product or service. On the other hand, a low level of user satisfaction may drive the UX in a negative direction. Boehner et. al. has defined a term 'dynamic feedback' where the performance analysis is derived not only from the evaluator's analysis but also from the reaction of the specific user of the service [45]. In the explanation of experience evaluation Joseph et. al. posed central questions including 'What do I mean by evaluation in experience-focused HCI? What are the goals of evaluation in experience-focused HCI?' or 'What novel evaluation methods (from inside and outside HCI) might I appropriate for evaluating experience-focused HCI?' [102]. In this research, the authors' main goal was bring the diverse audience under the same umbrella. On the other hand, to deal with UX in HCI, Fallman and Waterworth defined a the Repertory Grid Technique (RGT), representing a relationship between a construct and its elements [72]. The authors defined RGT as a communication bridge between qualitative and communicative research. There are several more recent research contributions exploring the content and impact of UX in HCI [135] [49] [131] [199] [196]. Wright and McCarthy [199] evaluated the user experience based on 'empathy'. The authors states that, with the technology enhancements, HCI is concerned with human's feelings, expectation, and experience, using empathy to justify the methodological development of service and products. According to the authors - "I have emphasized the dialogical character of empathy, empathy as communicative performance built on responsivity to others." Figure 2.27 shows the framework of meaning according to D. Vyas [196]. The authors described the framework in three steps - the interaction between the user and the system creates experience, the appearance and interactional instructions are achieved from designers narration, and the coherent combitionation containing sensual, cognitive and emotional practices developed by the users.

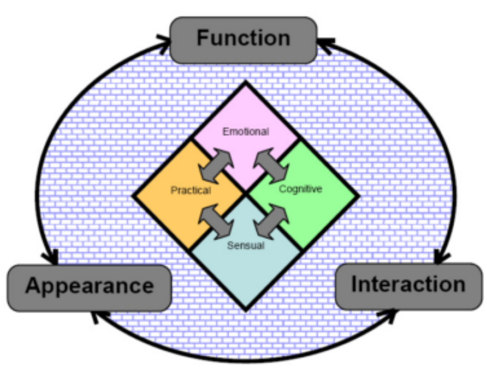


Figure 2.27: Framework of the experience as meaning according to D. Vyas [196]

Mcnamara and Kirakowski describes the term UX as a combination of functionality, usability and experience [132]. The authors also mentioned these three key factors as the content of the usage of the technology. However, the term has different connotations for different technology use patterns. For example, functionality describes the ability to perform certain task with a system while usability defines the user-friendliness of the prototype. Nonetheless, functionality depends on the quality of underlying mechanism. The authors included performance, reliability, and durability as components of functionality. Later, they argue that, a higher user satisfaction rate does not always depend on the highest quality of the service.

Forlizzi and Ford made an attempt to provide a standard for user experience [73] to ease designers' effort. The authors explained three ways of explaining experience- the experience that people usually gather from his/her conscious state of mind, explaining a previous experience and telling a story explaining the experience. They mentioned 'product' as a factor of influence on the user experience. However, several different terms such as context or usage might impact the experience as well. As a framework for user experience, the authors defined four dimensions - sub-consciousness, cognition, narrative, and storytelling. They defined the sub-consciousness experience as habituated behavior whereas cognition is the state of conscious activity. The term narrative experience, applies to the techniques that users learn by themselves by gaining instruction from the narration. L. Alben defined the user experience as a combination of management, user understanding, learning, need, mutability, effective and appropriate design patterns, and finally aesthetic sense [25].

Gaggioli et. al. provided a 'methodological approach of presence' [74]. In addition, the authors considered the motivational as well as the cognitive aspects of user experience. In other word, presence is considered as experience. The research question of the experiment is - "what goes on in people's minds when they interact with computer-generated, three-dimensional environments and how does the content of their consciousness at such times is related to the rest of their goal- oriented behaviour." Later, the authors proposed a method named the Experience Sampling Method (ESM) which is shown in figure 2.28. Here, the SM indicates the Subjective Mean [61].

In the area of pervasive computing, QoE has been analyzed. Li-yuan et. al. proposed an algorithm that reduces the context and parameters effecting the quality of the user experience [114]. The authors discussed two major factors of QoE - to observe the user's real-time activity and the reliability of the system to gain maximum satisfaction. Furthermore, the authors mentioned three aspects that impacted the experience, the quality of sensors, the capability of sharing stored information, and processing time.

Providing simple explanations Hassenzahl and Tractinsky provided a long discussion on 'what is UX' [79]. Figure 2.29 shows a graphical representation of the facets of UX. The concept of UX behaviour is explained in [34].

Law et. al. depicted a shared definition of UX in the concept of HCI [110]. The authors limited UX to the emotional, psychological or behavioural attachment of the user. A survey has been provided similar concepts by Law et. al. in [111].

The aforementioned discussions provide a clearer view of the diversity of the term User eXperience in HCI research. However, in the area of computer games - a leisure activity, UX is not only important but also the

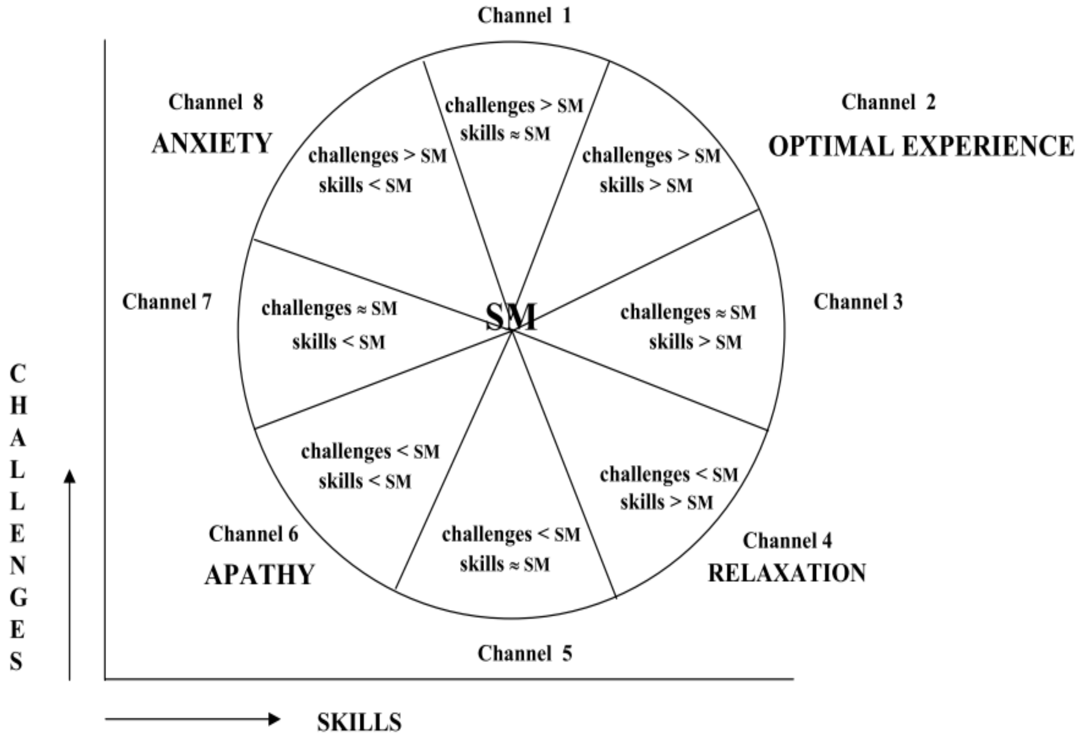


Figure 2.28: The Experience Fluctuation Model by Gaggioli et. al.[74]

primary outcome. Initially, there was a hypothesis that the measurement of user satisfaction after a game play is the key to determine the quality or quantity of UX [193]. To measure user experience R. Bernhaupt described methods for all phases of game production. The concept of a game plays a vital role in making the game playable. The storyline and setup of the game can impact the flow of gameplay.

To evaluate PX, criteria that commonly come forward are immersion, flow, playability, fun, presence, involvement, and engagement [179]. However, there is a long lasting debate between immersion and involvement when considering a playability of a computer game. Brown and Cairns depicted an analysis describing the three levels of immersion - engagement, engrossment, and total immersion [50]. With an investigation based on the existing immersion theories, the authors interviewed gamers to examine the level of engagement during game play. Experimentally, they concluded that the immersion varies with time and flow during play, with complete immersion the most difficult level to achieve.

A scientific methodology to examine player's experience has been described by Nacke et. al. [140]. The authors advocated for a technique to be established to improve the relationship between player experience and game itself. Sanchez et. al. provided an argument stating usability alone is insufficient to achieve flawless playability [174]. They defined the term 'playability' as effectiveness, learnability, immersion, satisfaction, motivation, emotion, socialization and associated these with different attribute of video games. Figure 2.30 describes the model in detail. An approach to measure PX is a self-report questionnaire filled by the players after playing. Nacke and Lindley provided a pilot study to measure player's involvement based on 3 param-

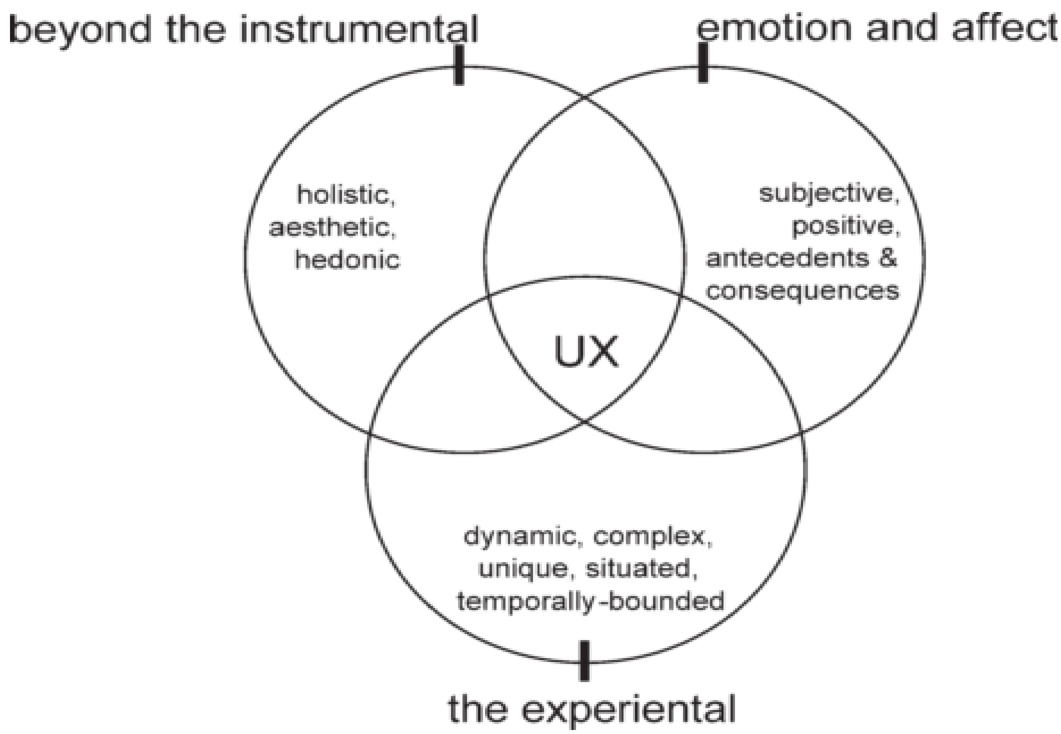


Figure 2.29: The Facets of UX according to Hassenzahl and Tractinsky [79]

eters - boredom, immersion and flow [138]. A set of stimuli levels were designed using Half-Life 2 Source SDK to focus the described parameters. Through the Games Experience Questionnaire (GEQ) authors reach to a conclusion that - "the absence of enough challenge leaves the players in a negative emotional state, while more challenge provides a much better experience in general, rating high on positive affect and flow." Therefore 'competence' is another important factor that influences player's behaviour. Przybylski et. al. describes that along with a level of competence, relatedness is necessary to boost player experience [163]. They performed an empirical analysis to evaluate the procedural fact of continuous and longer engagement, by applying self-determination theory (SDT).

An effective ludology based on flow and immersion of players while playing an FPS game is presented in [139]. The authors set up an experimental study through playing three different level of the game Half Life 2 followed by subjective and objective enquires. The authors found between 'valence' and 'arousal'. Results of GEQ analysis demonstrated compelling inequity in challenge and tension. A data driven computational model has been proposed to predict player state and actions performed [151].

2.3.1 Quality of Service (QoS)

In multi-player ubiquitous games, the term QoS is mostly used to represent factors describing network quality during game play. For example Budke et. al. describes an analysis of the quality of services of a mobile ad-hock network for multiplayer games through simulation [51]. Improvements were demonstrated for different

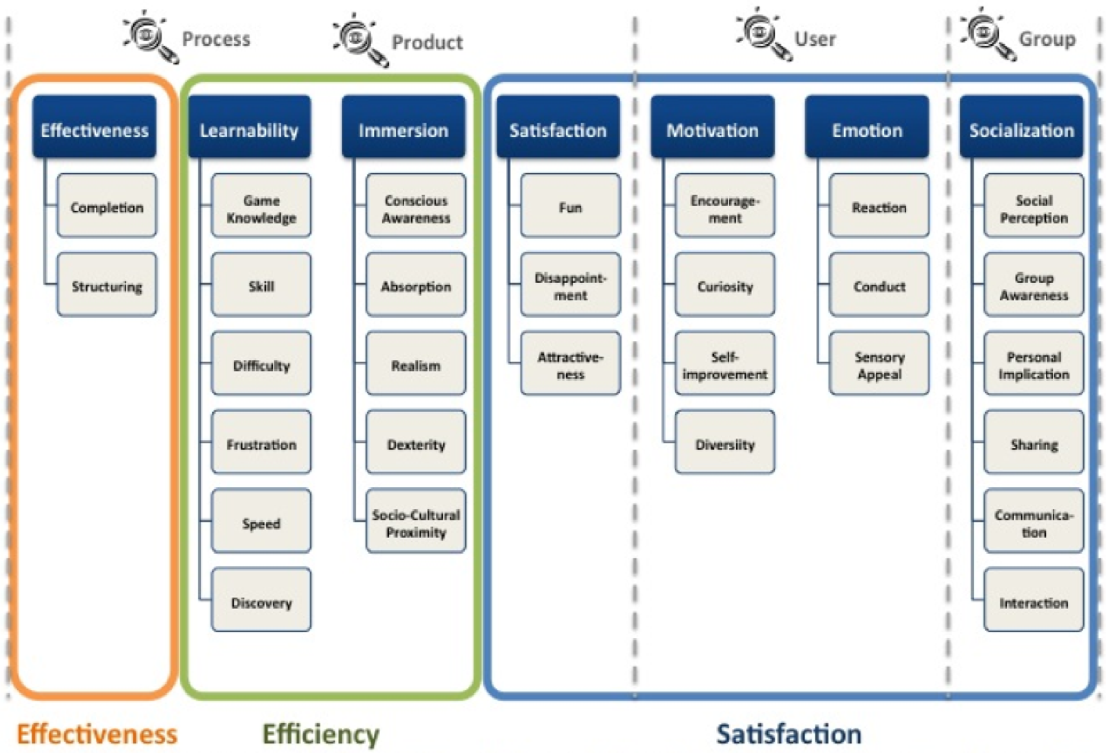


Figure 2.30: Playability Model according to Sanchez et. al. [174]

routing protocols. A similar work was presented by Carrig et. al. [54]. The authors proposed a technique based on the concept of Consumer Surplus (CS) that distinguishes the difference between the satisfaction of a specific 'good or service and the cost of the good or service'. Issues that might hamper the QoS in multiplayer games are described by A. Spurling [186] who described different types of multiplayer network games (e.g. client-server, Peer-to-peer, mirrored-server), and their impact on latency and jitter.

When considering online games, the network quality effects the game play experience. Oliveira and Henderson demonstrated an analysis on the impact of network quality on online games [147]. According to the authors, to improve an online game's quality, a better quality network is preferred. Due to the volatile nature of the internet, the quality of online gameplay may vary with time. The result demonstrates the player's various reactions of playing online games. As a result of their analysis several issues were identified such as time distortion, prediction or buffering. Moreover, the authors provide possible solutions to deal with such network issues. After an online survey with 23 online questions, the authors reached to the conclusion that the users are aware of network issues during gameplay. In authors' words - "Assuring specific network QoS for an online game would be a possible solution to improve the gaming experience of the users, but the issue is who will pay for the service".

Considering the periodic loss of data, also known as jitter in a networked first person shooter game (FPS), Armitage and Stewart delivered an analysis in [30] while using a public server on game network. The analysis examines user satisfaction in the under network delay. Their methodology demonstrates that since

2004, Quake III was played a total 11750 days. For the qualitative experiments, the experimenters the data were filtered whose latency and jitter fell in the boundary of 15%. Players considered disqualified who were not accurately playing for 15 minutes over the network. In their analysis, correlation between jitter and latency was shown the aspect of relative jitter of isolated latency.

A similar work dealing with network delay and jitter in FPS games was publishrd in Bhatti and Henderson [40]. With statistical analysis of 'session-level traces' of multiplayer network games they authors demonstrated that -"Players duration times fit an exponential distribution, while interarrival times fit a heavy-tailed distribution."

Quality of Experience is the term which relates how a user perceives the quality of a specific application. The definition of QoE is explained by Wu et. al. in [200]. However, different techniques to evaluate QoE were illustrated by Kuipers et. al. in [107]. The terms the authors mentioned here are -

- Quality of the framework
- Quality of the audio of the application
- Quality of interaction during the gameplay
- Quality of the visual quality, audio synchronization and its transmission over the network
- User synchronization
- The start-up and ending time

While most networked games' QoS depends upon the network quality, AR games are different. In order to play AR games the OS or engine need to provide pose estimation services to register the camera in the game world. While talking about service quality, the first thing to be identified is -'What are the services required for AR games'. For AR games, the sensor services which impact the quality of gameplay are the spatio-temporal pose parameters, more easily understood as the position, orientation and timing as described earlier in this chapter. Typical quality measures for spatio-temporal sensors are accuracy, precision and span (as described in table 2.1). The game design dictates the level of service required for each sensor parameter as fully described for a wide variety of AR games in chapter 2.2.

The taxonomy presented in section 2.2, provides a detailed description how 'sufficient' the accuracy, precision or span is needed to make the game playable. For example, while playing location-based games such as ARQuake, 'good quality' requires high accuracy, precision and span of the services (space, timing, orientation) due to the expansive game design and precise interaction modalities. On the other hand, while playing games like Droid Shooting, sufficient quality of experience can be ensured with a higher precision of orientation and timing service, neglecting the spatial service because the game design is camera-centric (see section 1.4.1).

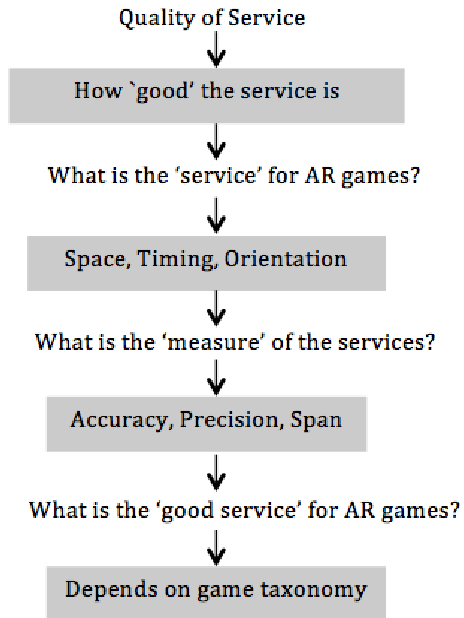


Figure 2.31: Quality of Service flow in AR games

2.3.2 QoE and QoS

Quality of Service (QoS) impacts of Experience (QoE). For gaming perspective, a good quality game is able to provide good experience to the players. Although QoS is casually analyzed in network gaming [99], regular AR game experience can also be affected by the service quality of the game mechanics.

T. Seller addresses the research question 'How can usability methods and approaches be adapted and extended to evaluate and improve the user experience of gaming systems?' in [180]. This research investigated the ways to engage the user with a flawless gaming experience. According to the author, the social environment, need, and perception dynamically effect the user experience. To investigate the hypothesis, Seller chose to go through 'interviews, observations, usability evaluations, focus groups and questionnaires'. Additionally, a case study was performed in collaboration with a game company. For this, both contextual and lab-based approaches were undertaken. To evaluate the online game QoE, Chang et. al. provided an analysis with three first person shooter games [56]. The main purpose of this work was to find a standard to raise the QoE of the players during play which directly benefits the game developers, game servers and gameplay. With the indication of the drawbacks of MOS (Mean Opinion Score) rating techniques, the authors used a 'crowdsourceable framework based on paired comparison'. Another approach with similar goal (online game QoE evaluation) is proposed by Chen and Zarki evaluating an objective simulation of QoE based on the network hazards in online games. The work in [98] describes the QoE evaluation of online cloud games. For a location-based massively multiplayer online role-playing game (MMORPG), an empirical study was made by Verdejo et.al. [194]. The authors stated that, a physical involvement has a positive impact on the

QoE in the MMORPG category games. Some experimental evaluation of the QoE based of specific games were made in [27] [164] [183].

2.3.3 Play Experience and Usability Analysis Techniques

The psychological impact of playing games can be significant. Playing games can impact the player both physically and emotionally. The game world takes a player to the virtual world to 'live' the life [169]. For example, games require players to make decisions, and take actions accordingly. Still, the inquisitive nature of human might always demand the answer of 'why do we actually play games?' [169] The first and foremost answer appears to be- 'having fun.' Rigby and Ryan [169] defines 'fun' as a very broad and superficial word in gameplay. Rather, they preferred to shift the 'fun' to 'need satisfaction' that includes - competence, autonomy, relatedness, consistency and density.

Competence is an intrinsic need satisfied by achieving mastery in game. Higher levels of competence could be achieved with optimal challenges and feedback. While competence improves the mastery of accepting challenge, autonomy enhances the power of performing actions in game. According to the authors - "feeling autonomous means that we are pursuing things that interest us and that we want to pursue. By contrast, we feel controlled when we are not interested in what we are doing and are simply taking action as a stepping stone to some other goal." With limited choices, games could be autonomous if the players find it interesting. Relatedness is the reflection of meaningful connection combined with competence. The relatedness leads to consistency to achieve the destiny of the game. According to authors - "Because of this immediate ability to bring people together in shared worlds, video games supply a novel and efficient vehicle for people to experience relatedness." All these intrinsic motivation factors of players during gameplay can be analyzed through PENS (Player Experience of Need Satisfaction). The authors also examined how PENS [169] can impact on larger spectrum of personal such as vitality and well-beingness of the broader game community The PENS scale is an important tool in this thesis. Several other techniques to analyze play experience have been proposed by researchers. A short description is provided as follows -

2.3.3.1 Traditional Usability

This traditional technique was one of the approaches employed in the Microsoft games user research (GUR) group [69]. The key difference of the term usability between productivity applications and games is productivity applications exist to improve productivity while the main goal of gaming is fun. To analyze this Amaya et. al. used the Playtest technique, a survey-based methodology useful for large-scale experiments. This technique is capable of quantifying players' cognitive behaviour towards the game. The authors mentioned three reasons that made the method important.

- Reliability is achievable through the result
- Iterative testing demonstrates the effect of specific changes on the players' enjoyment

- Score comparison is possible between games

A sufficient number of participants (depending on the game design) as well as facilitators are needed for a successful analysis. Moreover, the experimenter should posses good usability and statistical analysis expertise.

2.3.3.2 Think Aloud Sessions

While running an experiment to analyze play experience the experimenter often needs to understand what the player is thinking or feeling to understand their reasoning and motivation. Under this circumstance, 'Think Aloud' is one of the approaches applied in usability testing. Henriette (Jettie) C.M. Hoonhout mentioned this issue while dealing with game environments [84]; such as - "is the game challenging enough or will it stay challenging till it is over?, are the players' having fun?, how learnable the game is or how does the social interaction develops." To analyze such phenomena, a verbal protocol analysis could be used. To conduct the experiment, several (often 3-5) iterative sessions are needed with 1 user and 1 facilitator. In addition, recording equipment, and a prototype or version of the game are required. Once the data collection is completed, time should be available to review the recorded data and prepare the final report. Similar to the traditional playtest, both facilitator and observer need usability and experimental expertise.

2.3.3.3 Heuristics with Experts

Guideline-based methodologies are applied to facilitate analysis of play experience, which is known as the heuristic evaluation technique [181]. According to Noah Shaffer -"Usability heuristics are shortcuts to finding usability problems quickly and cheaply...these methods are very effective when the point is to come up with feed-back for improvement of a specific interface." In game research, several guidelines have been proposed for heuristics [181]. Melissa Federoff prepared the first set of usability heuristics for games where a list of 40 guidelines were provided. Federoff's heuristics were concentrated on game design issues. To analyze game experience while applying heuristics with experts, 2-3 experts are needed to select heuristics, review game, make a report, present the report, and finally make changes to game accordingly.

2.3.3.4 Heuristics with Non-experts

If experts are not affordable, applying this technique is a potential alternative to the previous technique. However, the same sets of resources would be necessary as with experts; only the experts would be replaced by a larger pool of non-experts. A moderate level of knowledge in heuristic evaluation is necessary.

2.3.3.5 Design Standards

Dr. Eric Schaffer demonstrated how design standards can improve user experience in gameplay [176]. Game mechanics developed using design principles, design standards and methodological standards can provide better consistency, and also can improve the speed and lower the cost of application development up to ten percent. To pursue this experimental procedure, sufficient time is required to meet and discuss the designing standards. The experimenter should posses expertise in design, management and usability techniques.

2.3.3.6 Instrumentation and Metrics

This technique digitally loggs the play experience by recording detailed records of the games states. At the initial level of instrumental testing, Schuh et. al. [68] used a clickable method to log experience and found the approach to be problematic (e.g. some people forgot to click and some clicked too many times). Later, he applied built-in instrumentation within the game design and was able to record a promising set of data. To apply instrumentation and metrics techniques, a prototype of the game is required. A large-scale representative sample of participants is also important. The experimenters should have time and resources to develop and run an automated testing. The experimenter has to have considerable expertise to develop and automated analysis tools and interpret the result.

2.3.3.7 Physiological Measures

Regan Mandryk et al. proposed this technique in [123]. According to the author - "The goal was to develop an evaluation methodology for games that: captures usability and playability through metrics relevant to ludic experience; accounts for user emotion; is objective and quantitative; and has a high evaluative bandwidth (continuous measurement)."

This method is able to demonstrate the approximate emotional state of players in interactive game environment based on the players' physiological responses. The authors provided an overview of three different experiments conducted prior to the comparison. The first one demonstrated how the players interact psychologically with different play technologies. The second experiment examined the difference in physiological signals based on the play condition. Finally, the author presented a mathematical model of players' emotional state based on physiological measures.

Choosing appropriate sensors is important when conducting such experiments. For example, to compare the positive and negative experience while playing a game, 'valence of an emotion' can be measured using EMG face to detect frowning or smiling. This methodology requires additional sensing. A reasonable amount of time is required for calibration and data interoperation. The experimenter should have enough expertise in physiological sensing equipment handling and interpretation.

2.4 Summary

In past decade the scope of AR gameplay has spread due to the evolution of handheld devices. People can play various genres of AR games on smartphones. However, a lack of sensor resolution in such devices can cause poor game behavior resulting in negative play-experiences. Different genres of AR games react in different ways towards sensor Quality of Service (QoS). For example, a location-based AR game will highly depend on the accuracy of sensors like GPS where as a casual shooting game would rely more strongly on orientation sensors.

The survey provided here includes both research and commercial games in a taxonomy based on their dependency of sensor QoS during gameplay. In the second portion of the chapter, a general description of QoS and its impact on Quality of Experience (QoE) on gameplay is provided.

Quality of Service (QoS) in AR games has impact on the the QoE or more precisely on PX. QoS is a term traditionally used in networking, however, depending on game genre, the components of QoS varies. For example, while playing an online shooter game, network delay hampers the quality of the game effecting the user experience. Gutwin wrote about this issue while dealing with groupware systems [77]. The author discovered a close relationship between delay and task performance. On the other hand, unlike shooter games, an online treasure hunt game is not as impacted by network delay. Geo-tagged target-based games played outdoors require high position accuracy whereas, a treasure hunt game can provide satisfactory PX with much less spatial accuracy.

The relationship between QoE and QoS of ubiquitous computer games is obvious. Elaborating on this Wijnants et. al. described the correlation between the QoS and QoE of a multiplayer location-based game [198]. The authors developed a GPS based game 'World War I (WW I)' where players interact each other over server. The game is defined as a Role Playing Game (RPG) with characters such as Commander, Soldier, Media, and Spy. Later, to investigate the correlation between the QoS and QoE of the game, a small user study was performed. However, no firm effects could be identified due to the small sample size.

I chose three most important sensor phenomena - Space, Time and Orientation and examined their impact on different genres of AR games. Here, space indicates the player's (i.e. device) position on earth, time refers to timing of object interaction (e.g. trigger) and orientation is the pose of the device. I divided the sensor parameters (each having three possible states) as follows -

- Space - Accuracy (Low, Medium, High), Precision(Low, Medium, High) and Span(Low, Medium, High)
- Timing - Accuracy(Low, Medium, High)
- Orientation - Precision(Low, Medium, High) and Span(Low, Medium, High)

Throughout the chapter, the fundamental purpose was to relate the existing AR games and their sensor dependencies to their impact on players throughout the gameplay. The key intention behind this was to provide a wider view of the available AR games' behavior with the sensor parameters and propose a novel technique to overcome the issues impacting PX. With the parameters and their states, an explicit taxonomy is presented and potential sensor resolution dependency can be identified.

Chapter 3

Manuscript 1

Title: The Impact of Sensor Noise on Player Experience in Magic Window Augmented Reality Aiming Games

Venue: IFIP International Conference on Entertainment Computing (ICEC), Trondheim, Norway

Citation: Eishita, Farjana Z., and Stanley, Kevin G. "The Impact of Sensor Noise on Player Experience in Magic Window Augmented Reality Aiming Games." Entertainment Computing-ICEC 2015. Springer International Publishing, 2015. 502-507.

Author's Contribution: The research presented in this manuscript is my own, conducted under the supervision of Dr. Kevin G. Stanley. Ideas and techniques that are not products of my own work are duly cited, or, in cases where citations are not available, are presented using language that indicates they existed prior to this work.

Summary: Augmented reality (AR) requires superimposing digital artifacts on real world scenes. Unfortunately, sensors used to render digital artifacts are subject to noise and imprecision, making the registration difficult in practice. Using a modified version of the Android operating system, we experimentally examined the impact of orientation sensor noise on player experience in three commercial AR aiming games employing different mechanics and input techniques. The aiming techniques included were - tapping an object, shooting an object and tapping an object with a reticule. A total of 24 participants were recruited to play the games using the modified Android OS. After each gameplay, participants completed online surveys to record their play experience. The result demonstrated that noise variance differentially effected their gameplay depending on different aiming techniques. Players were more sensitive to noise when playing the game by tapping objects as oppose to aiming.

Relationship to the Thesis: This manuscript demonstrates players' sensitivity towards different levels of input sensor noise while playing different aiming AR games. This manuscript contributes to the central research goal by examining the differential impact of sensor QoS upon the PX while playing AR games that deploy different techniques in aiming.

Aiming is the most common interactive technique in AR games. Making the analysis of QoS variation on PX is an inevitable component of my dissertation. The experimental design and statistical analysis performed in this experiment demonstrated the fact that in spite of leaving the same gross categorization in the taxonomy, different aiming mechanisms within the same broad game category impact player experience under varying sensor noise. The findings of this experiment are significant because aiming is a primary interaction technique in video games mechanism. This manuscript demonstrates how sensor noise sensitivity can create significant difference in PX in AR games.

Experimental Analysis: The research question for this experiment was - "Does different levels of input sensor noise impact the PX while playing AR games with different aiming techniques?". Experimental design had three different noise levels (e.g. Low, Medium, High) with a control as the primary independent variables. The magnitude of noise was defined through different standard deviation. To analyze the PX, dependent variables were derived from the standard psychology surveys PANAS (Positive And Negative Analysis Surveys) and IMI (Intrinsic Motivation Inventory). PANAS aided us to investigate the variation of experience in terms of positivity and negativity. Through IMI, the experience of players' interest/enjoyment, competence, tension/pressure and efforts were recorded. Therefore, for IMI the dependent variables were interest/enjoyment, competence, tension/pressure and effort. Overall, a repeated measure ANOVA was adopted to analyze the statistical significance of the experiment.

Relationship with the taxonomy: The primary goal of this experiment is to investigate the differential impact of sensor QoS upon PX while playing different kinds of AR 'aiming' games. Hence, while selecting commercially available AR games, search for aiming games were preferred. Rationally, the selected games were from the casual aiming/shooting group of our defined taxonomy.

These games of this group have a medium precision and a high span requirement of orientation; timing accuracy requirement is high and all the states for location parameters have requirement of low precision as these games do not depend on position. based on our results the 'medium' precision requirement can be further subdivided. Our experimental outcomes demonstrated that player experience varied significantly while playing the game with tapping object technique, but significantly lower the least impact was observed in aiming with a button.

Game Input Mechanics: The following three commercial AR games were used in this experiment -

- **Droid Shooting**: Primary sensor used in this game is accelerometer. The target of this game is 3D robots. The players need to shoot the robots with a virtual trigger located at the bottom right corner of the screen. There is a fixed reticule at the center of the screen which needs to be targeted on top of the robots to make a successful hit. The robots keep moving around making the device the center of gameplay and do not shoot back.
- **Skeeter Beater**: This game retains direct tap and hit technique on the digital mosquitoes that appears on a 360anner around the device. There is no particular hit button or reticule assigned. The players need to look around for moving targets and tap exactly on it to earn points in the given one minute time. The initial sensor used in this game is orientation.

- **Chase Whisply**: In this game, the main target is the virtual ghosts that appear on to the screen and needs to be tapping onto a fixed reticule located on the center of the screen. The ghosts do not hit back and there is no fixed timing technique attached. Primary sensor used in this game in rotation vector.

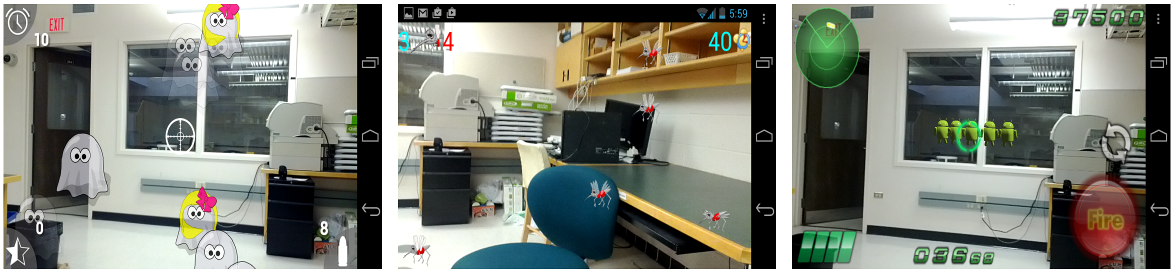
3.1 Introduction

Game developers have always been early adopters of new technology, pushing the limits of what was technically feasible to craft new experiences for their audiences. With the mobile revolution, electronic play has moved away from the computer console or couch to permeate aspects of everyday life. However, the display area and processing power of handheld devices are limited, meaning players cannot inhabit virtual worlds that are as deep or richly textured as their desktop counterparts. A plausible workaround is to employ the real world as a game board, viewing the world through a smartphone camera, and rendering digital artifacts upon it. We call such games augmented reality (AR) games.

Augmented reality offloads much of the rendering load to the real world. Play environments no longer have to be drawn, they are viewed directly through a digital camera. While the rendering load is much lower, digital artifacts must be correctly placed within the scene, and viewed from the appropriate angle. To accomplish this, sensors initially developed to approximate a phone's position on Earth for navigation and determine phone orientation for screen rotation must now approximate the precision of a virtual camera in a video game. However, unlike the virtual camera used to render scenes in digital worlds, physical sensors are subject to noise, drift and error. In particular, determining the pose of the camera in space so that digital artifacts can be rendered from the appropriate angle, and aiming tasks within the game can be appropriately resolved, is of particular import. In this paper we present an experimental study of the impact of sensor noise on three different aiming games, and show that both noise and input type have an impact on the subjective play experience of participants.

3.2 Related Work

Location based games employ both orientation for aiming, and fixed real world coordinates. ARQuake [190] is a location-based AR shooting game. The digital artifact rendering occurs based on fiducial vision-based tracking. AR Battle commander [152] is a real-time strategy (RTS) AR game played in an outdoor environment. PasswARG [67] is a geo-tagged treasure hunt game where players find clues provided by the 3D characters located on POIs (Points of Interest) to find the password to unlock next level. Aiming AR games which soley employ accelerometers or gyroscopes are a significant game research area. Butterfly Effect [144] is an AR game dependent on orientation precision where player wears an HMD and wields a stick rendered as a tornado to collect virtual butterflies. Augmented Galaga [150] is an AR version of the famous arcade game Galaga. ARVe - Augmented Reality applied to Vegetal field [167] is a game for cognitive disable children. LittleProjectedPlanet [120] is an AR prototype of the famous PS3 game 'LittleBigPlanet'. Mind Wrap, Impera Visco, and Penalty kick are games implemented to demonstrate the user interfaces for handheld AR games [170].



(a) Chase Whisply (b) Skeeter Beater (c) Droid Shooting

Figure 3.1: Screenshots of Games Employed in the Experiment

3.3 Methodology and Experimental Setup

Many current commercially available AR smartphone games employ aiming with a handset as their primary mechanic. We chose three different games, each employing free aiming - aiming without the aid of visual marker tracking - to ensure that the comparisons reflected differences in aiming modality and not sensing technique. All three games require that players orient the phone to find targets, they differ in how players interact with those targets. All three of these games would be classified as casual arcade games, as they are meant to be played opportunistically and for short durations.

- Chase Wisply [7] is a ghost hunting game using a targeting crosshair.
- Skeeter Beater [157] makes players kill mosquitoes by tapping on the mosquito.
- Droid Shooting [126] requires players shoot robots with a trigger button.

There are several different methods for accessing phone orientation within the Android SDK. These games each use a different software interface. Zero mean Gaussian noise was inserted in a scaled manner in each of these interfaces. Droid Shooting uses accelerometer, Skeeter Beater uses the abstract Orientation sensor which fuses accelerometer, gyroscope and compass readings, and Chase Whisply uses the abstract Rotation Vector, derived from the abstract Orientation sensor.

Table 3.1: Game Descriptions

Game	**Aiming Type**	**Ammo Type**	**Default Time**	**Using Sensor**
Chase Whisply	set target and tap anywhere	Limited/ Reloads	30 sec	Rotation vector
Speck Trek	tap on the object	No ammo	60 sec	Orientation
Droid Shooting	shoot robots with defined trigger	Unlimited	60 sec or shooting all robots	Accelerometer

Zero Mean Gaussian Noise (ZMGN) is a textbook noise model for physical sensors. As multiple small disturbances at various levels of the physical sensor and data acquisition are applied, Gaussian distributions tend to emerge. As the noise is zero mean, it can be added directly to the sensor signal without impacting the average performance. Sensor data error was injected at the operating system level as described below for each of the respective sensors. Through pilot testing we configured the standard deviation of sensor error to be at most 2.8% of the span of the input signal.

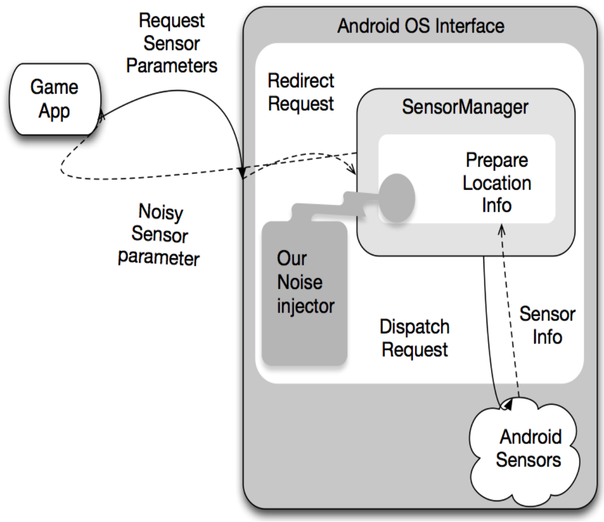


Figure 3.2: Android OS Manipulation Process

We used the Android Galaxy Nexus with AOSP 4.1 in all experiments. We recruited 24 participants (13 male, 9 female; aged from 20-35 years) After each experimental condition, participants completed the PANAS (Positive and Negative Affect Schedule) [60] survey, which measures positive and negative affect, and the IMI (Intrinsic Motivation Inventory) [172] survey, which measures perceived interest, competence, effort and tension.

3.4 Results

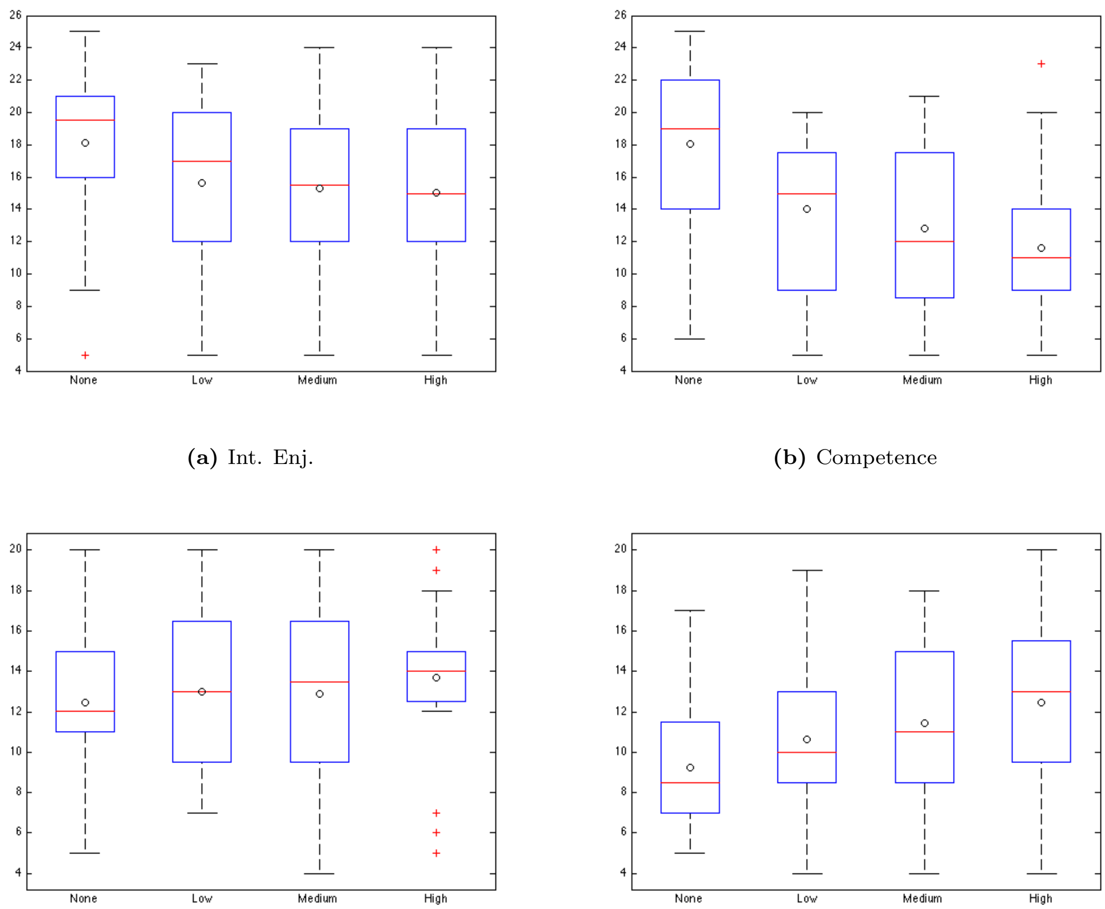
Both PANAS and IMI results were analyzed using a multivariate ANOVA. There was a significant difference among the games for players' positive in-game experience ($p = 0.033$, $F = 4.001$) and with noise level ($p = 0.001$, $F = 9.637$). While examining players' negative play experience, both game and noise level effects showed significant difference in variance (game: $p < 0.001$, $F = 11.645$; noise: $p < 0.001$, $F = 11.242$).

Interest and enjoyment of different gameplay was significant between games ($p = 0.025$, $F = 4.381$), and more so with noise ($p < 0.001$, $F = 12.407$). Competence displayed the highest significant difference among all effects (e.g. game, noise level, game-noise level) (game: $p < 0.001$, $F = 11.075$; noise: $p < 0.001$, $F = 33.591$, game-noise: $p < 0.001$, $F = 9.415$). Effort only differed by game ($p = 0.044$, $F = 3.611$). Players' tension had significant differences with noise level effect ($p = 0.001$,$F = 17.149$), but not with game.

Although there was no significant difference between Low and Medium level in SK, competence showed significant difference in rest of the levels ($p < 0.001$ for relevant pairs). According to the pairwise comparison between subjects, other than Medium and High level of play, the tension/pressure variation was significant

($p = 0.006$). Subjective effort increased with each noise level ($p < 0.006$ for relevant pairs). As a result, there was a significant fall of interest and enjoyment of the gameplay with increased noise($p < 0.016$ for relevant pairs) [Figure 3.4].

For the game Skeeter Beater, almost all the parameters of IMI and PANAS showed significant interaction. In pairwise comparison of between parameters measured by PANAS and IMI, all of them showed significant difference, except for the difference between Medium and High noise. Noise impact appeared to saturate after a moderate amount of added noise. Although there was no significant difference between Low level and Medium level plays in SK, competence showed significant difference in rest of the levels ($p < 0.001$ for relevant pairs). According to the pairwise comparison between subjects, other than Medium and High level of play, the tension/pressure variation was significant ($p = 0.006$). Subjective effort increased with each noise level ($p < 0.006$ for relevant pairs). As a result, there was a significant fall of interest and enjoyment of the gameplay with increased noise($p < 0.016$ for relevant pairs). Figure 3.4 provides a box plots of players' experience with SK.



(a) Int. Enj.

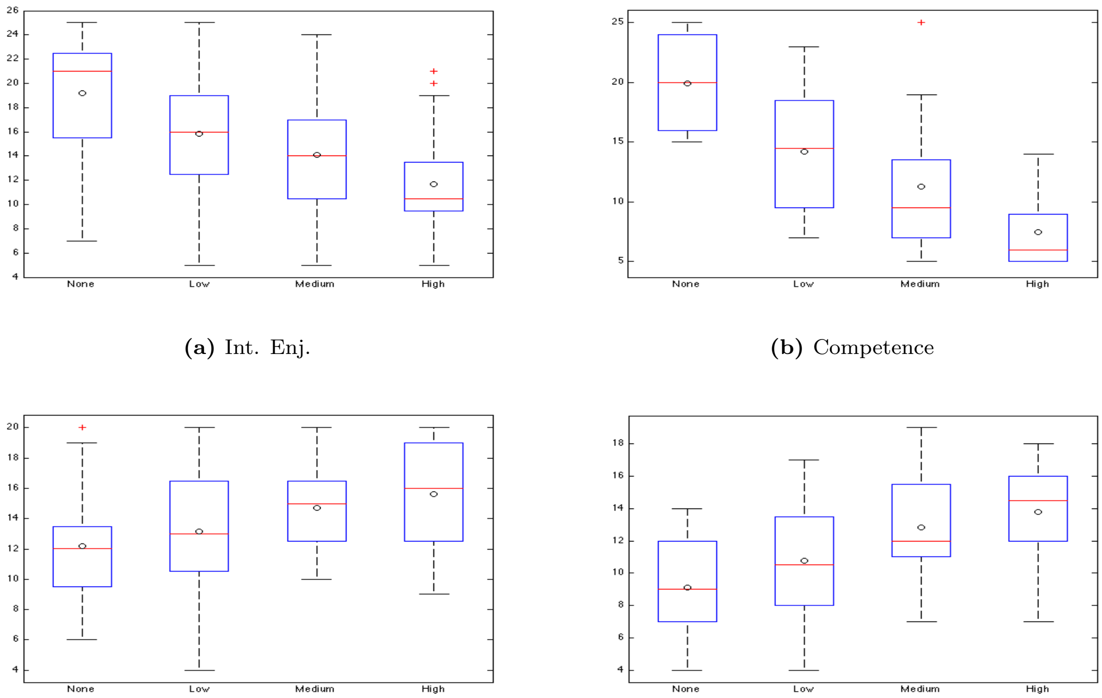
(b) Competence

(c) Effort

(d) Tension/Pressure

Figure 3.3: IMI Responses from Chase Whisply

For the game Chase Whisply, the most significant difference among the different noise levels was observed



(a) Int. Enj.

(b) Competence

(c) Effort

(d) Tension/Pressure

Figure 3.4: IMI Responses from Skeeter Beater

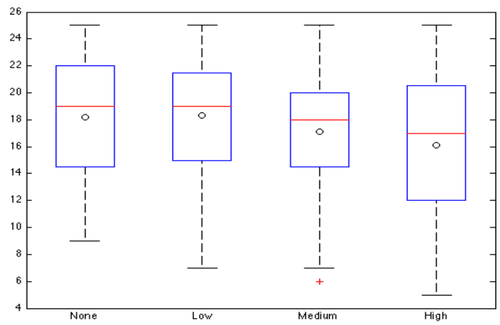
in competence (pairwise always $p < 0.04$). Tension and pressure also increased pairwise with noise for No, Low and Medium ($p < 0.013$). For PANAS, only negative feelings were more pronounced with higher noise ($p < 0.0106$).

The least variance was observed in the game Droid Shooting. A noticeable variance was observed in competence ($p < 0.0144$) that went slightly lower with the increment of noise. Overall, a higher tension ($p = 0.0191, \chi^2 = 9.93$) was observed during DR gameplay with increasing noise [Figure 3.3].

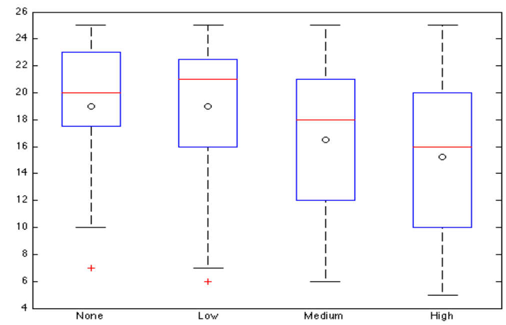
3.5 Discussion and Future Work

Our primary findings indicate that noise can have a significant impact in MW AR aiming games, that this impact generally increases with increasing noise, and that the magnitude of this impact depends on the type of aiming mechanic and game mechanics. We suspect a combination of the more difficult aiming technique, which required aiming the phone like a camera while simultaneously tapping the screen, and the negative scoring mechanic caused greater levels of frustration and decreasing competence.

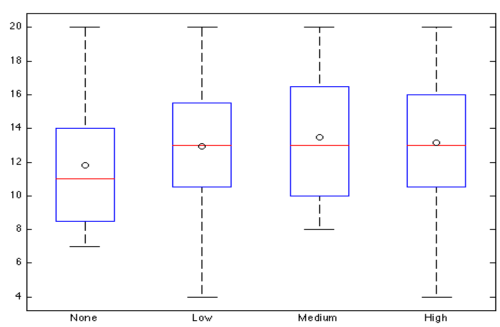
Players suffered more significant decreases in affect and competence in SK than in the other two games. We suspect a combination of the more difficult aiming technique, which required aiming the phone like a camera while simultaneously tapping the screen, and the negative scoring mechanic caused greater levels



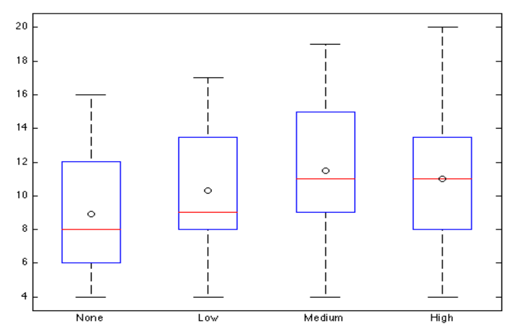
(a) Int. Enj.



(b) Competence

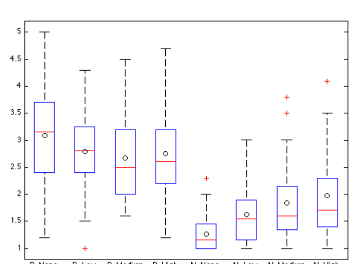


(c) Effort

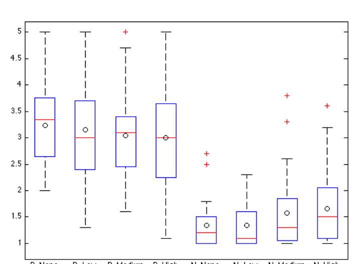


(d) Tension/Pressure

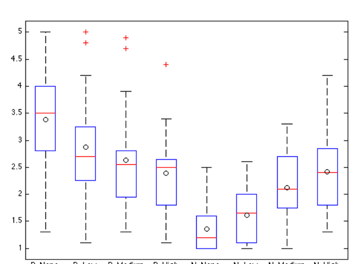
Figure 3.5: IMI Responses from Droid Shooting



(a) Chase Whisply



(b) Droid Shooting



(c) Skeeter Beater

Figure 3.6: PANAS Results of all three games

of frustration and decreasing competence. Because both DR and SK featured moving targets, but DR experienced a much smaller impact with respect to noise, we do not feel that moving targets in these cases were a dominant cause.

The uniformly decreasing competence observed in our experiments is particularly troubling for game designers, as it was noted in [163] that feelings of competency are one of the primary motivators for playing games. The sensitivity observed is particularly important because aiming is fundamental to almost all AR interactions.

While this work has made important contributions to the literature, there are several shortcomings that could be addressed in future work. First, we only focused on aiming games and magic window AR. Second, the games considered, while commercial, were limited in mechanic complexity, narrative scope and artistic design. Finally, while our sample size was large enough given to determine the primary effects, it was skewed towards the university community.

3.6 Conclusion

In this paper we have presented an experimental comparison between the impact of orientation sensor noise on commercial AR games on player experience. We have noted significant impacts of noise in all games tested, but more importantly differential sensitivity to noise. Game developers should consider the interaction mode carefully when designing new interactive experiences to either avoid or masks the noise sensitivity observed, employ more sophisticated filtering techniques and integrate the potential for noise into the overall game design.

Chapter 4

Manuscript 2

Title: : Quantifying the Differential Impact of Sensor Noise in Augmented Reality Gaming Input

Venue: 7th IEEE Consumer Electronics Society Games, Entertainment, Media Conference, Toronto, Canada

Citation: Eishita, Farjana Z.; Stanley, Kevin G.; Esquivel, Alain, "Quantifying the differential impact of sensor noise in augmented reality gaming input," in Games Entertainment Media Conference (GEM), 2015 IEEE , vol., no., pp.1-9, 14-16 Oct. 2015

Author's Contribution: The research presented in this manuscript is my own, conducted under the supervision of Dr. Kevin G. Stanley. Ideas and techniques that are not products of my own work are duly cited, or, in cases where citations are not available, are presented using language that indicates they existed prior to this work. Allain Esquivel has made is contribution through coding the experimental game and assisting in the user experiment.

Summary: Augmented reality is an exciting new medium for game designers, enabling them to craft the latest round of innovative interactive experiences. Commoditization of both high performance smartphones, and head mounted displays have provided compact high fidelity cameras and displays, and enough computing power to put compelling augmented reality into the hands of consumers. However, significant work remains in codifying the design space, and the relative sensitivity of different modes of display and interaction on user experience. In particular, the role of sensor noise in gameplay across different displays and input techniques has not been evaluated. In this manuscript, a user study was conducted with 48 individuals playing both head mounted and magic window variants of the same game with different input techniques, under different orientation sensor noise conditions. Evaluating user experience using both game logs and standard experiential surveys, differential effects of the introduction of noise on different systems were found. Among the four different kinds of control types - fixed or flexible reticule on smartphone and fixed or flexible reticule on head mounted display control, players were more sensitive while playing on smartphone under different levels of of sensor noise which was the key finding of this particular experiment. The findings also demonstrated how the other play experience criteria such as competence, effort, tension/pressure or interest-enjoyment varied under different noise levels while conducting with different game control. Through these findings, several design recommendations were provided.

Relationship to the thesis: This manuscript demonstrates that the player experience varies under different levels of sensor input noise while playing an AR games using different input techniques. This relates to the central contribution of this dissertation by quantifying the differential impact of sensor QoS upon PX; in this case isolating game genre and analyzing input techniques. This work is significant because for the AR game development community it is crucial to understand how noise can affect PX for game mechanics and interface which elevate or suppress the impact of noise. Through the findings of this research work, the developers can obtain a guideline a smarter development path which can achieve the highest possible PX while playing different kinds of AR games.

Experimental Analysis: The research question about this experiment was - "Does different levels of input sensor noise impact the PX while playing aiming AR games with different input modalities?". The Experimental design had two different noise levels (e.g. Low, High) with a control as the primary independent variable. The noise was injected into the Android OS orientation sensor. The noise level values varied with different standard deviation. Two different analysis were made - log analysis and PX analysis.

To analyze the variation in players' outcomes in the game, log analysis were made. In this analysis, the noise levels were defined as the independent variables. The dependent variables included are -

- Score in all conditions
- The Euclidean distance traveled by the center of the phone in all conditions
- The number of shots and hits in all conditions
- The distance distribution of the reticule from center during free-aiming conditions
- The distance distribution of the reticule from center when an object was hit during free-aiming conditions

Analysis of these dependent variables allowed us to demonstrate the differential impact of input sensor noise on players' performance while playing with different input techniques.

To analyze the PX, dependent variables were derived from the standard psychology surveys PANAS (Positive And Negative Analysis Surveys) and IMI (Intrinsic Motivation Inventory). PANAS aided us to investigate the variation of experience in terms of positivity and negativity. Hence, the dependent variables for PANAS included positive and negative experience. Through IMI, experience of players' interest/enjoyment, competence, tension/pressure and efforts were recorded. Therefore, for IMI the dependent variables were interest/enjoyment, competence, tension/pressure and efforts. Overall a repeated-measure ANOVA technique was applied to investigate the statistical significance.

Relationship with the taxonomy: This game was developed in our lab as a platform to investigate the differential impact of sensor noise for different input modalities both in players' subjective behavior and intrinsic motivation. Hence, the game MonstAR was not included in the taxonomy. However, if it were included, it would have fall in the group of casual aiming/shooter with a medium precision requirement of orientation. Although, it was a single game, but was played with different input modalities, the players' experience varied under different levels of sensor QoS.

Game Input Mechanic: In this experiment customized AR game MonstAR is used. The game was developed in our lab to examine the differential impact of different aiming technique with different input controls. The primary sensor used in this game is orientation. The players need to hit the flying monsters. Two different aiming techniques were - hitting with locked reticule and hitting with unlocked reticule. Both this techniques were implemented for two different versions - 1) Magic Window (MW) version and 2) Head Mounted Display (HMD) version. The monster did not hit back the player and there was no fixed timing mechanic included.

4.1 Introduction

Game developers have always been quick to adopt and adapt new technologies to create novel user experiences. The cheap 3D graphics driven by commoditized GPUs owes much to the creative drive of game designers harnessing the new technology. Smartphones are used as much to play Angry Birds as to check email. The Wii, with its motion control input, is still one of the best selling console of all time. With every new technological innovation comes new barriers which must be overcome with changes to game mechanics and design, or increased technical fidelity. Those designers who can create compelling game play experiences which hide the inadequacies of early technologies, such as the block-cartoon 3D anime of Final Fantasy VII, the stylized motion interaction of WarioWare Smooth Moves, or the simple swipe-to-destroy interface of Angry Birds, have a significant early mover advantage, as their games can occupy evolving niches before more traditional designs can leverage the technology. Designers who can provide a compelling player experience (PX) with novel but unrefined technology have a significant advantage.

Augmented Reality (AR), is an offshoot of virtual reality (VR) where digital images are overlaid on the real world. There is increasing commercial interest both amongst indie and mainstream game designers for this novel gaming modality, as it allows grounding fantastical events in real world environments. Sony and Oculus have both announced AR functionality for their upcoming head mounted displays (HMDs), Nintendo has implemented AR in versions of its 3DS and a number of small AR titles are available on iPhone and Android App stores as magic window (MW) games. In HMD AR games, view orientation is tied to head orientation, which is a natural mapping for humans. In MW AR Games, a handheld screen provides a "magic window" through which digital artifacts can be viewed, almost like a magnifying glass, which is slightly less natural, but can still be compelling. As the sector matures, it is likely that developers will wish to cross develop for both HMD and MW deployments, particularly for casual games, to maximize their potential install base.

Unlike many of its gaming forebearers, AR titles can be significantly impacted by sensor accuracy, as the digital artifacts must often be rendered in a manner that is anchored to the real world. Even in the case of randomly moving targets such as planes, mosquitoes or robots in simple AR shoot-em-ups [157][154], where the targets are not anchored to specific real world locations, the apparent location of the target within the rendered display should not appear to jitter or drift against a stationary real world background. Depending on the game, sensors for detecting real world position might be employed, or optical fiducial markers used to localize objects. However, in almost all cases, screen orientation from accelerometer and gyroscopic sensors is required to align line of sight, and often ordinance, with digital artifacts.

For studios developing AR games, understanding how noise can affect player experience is critical for designing game mechanics and interface designs which ameliorate or hide the impact of noise. Furthermore, companies wishing to cross develop titles for both high-end HMD, and lower power, but ubiquitous, smartphones should understand the tradeoff between aiming techniques and interface type, to allow for smarter development paths which achieve the highest possible user experience across systems with the smallest amount of code refactoring.

Few studies have addressed the impact of noise on aiming in augmented reality games, and no studies have specifically looked at the impact of noise on view-mapping augmented reality games [144], although some work has been done in pervasive games [136]. Additionally, few studies have addressed the relative impact of quality of service (QoS) on PX, and most of those are focused on network related issues such as latency and packet loss [54] [186]. Currently, designers of AR games have nothing to draw on when attempting to understand the relative impact of sensor noise on aiming tasks in HMD and MW AR games.

In this paper we present results of a lab-based user study of 48 individuals comparing the impact of artificially injected and controlled sensor noise in HMD and MW versions of the same game, with different aiming mechanics, on participant performance - measured through game logs - and experience - measured through standard survey instruments. We find that MW AR games are more sensitive to noise than their HMD counterparts, that players (at least initially) prefer aiming the entire screen rather than a reticule within a screen, particularly in noisy environments, and even moderate levels of noise can impact participant performance and enjoyment.

4.2 Literature Review

Augmented reality games using both head mounted and magic window displays have been both reported in the literature and increasingly sold through app stores. These games have often employed simple mechanics, partly to limit experimental confounds in the case of research games, but also because of the limited reliability of the sensor-based input.

4.2.1 AR Games in Academia

A large number of AR games are played with HMDs due to their potential for immersion. ARQuake [190] is a location based AR game that used GPS, digital compass, and fiducial vision-based tracking to convert the desktop version of Quake to a mobile AR game, played with HMD (Head Mounted Display). Similar to ARQuake, Human Pacman [58] is a location based AR game. Team members collaborate in a virtual outdoor 'Pac-World'. Epidemic Menace [117] is a cross media game with several different interfaces such as a game board station, a mobile assistant and augmented reality. Players must find a virus that is spread by an evil scientist. Game play is primarily outdoor and dependent on GPS accuracy. In the game Butterfly Effect [144] player wears an HMD holding a stick named Tornado. The player needs to collect virtual butterflies by moving towards the butterflies and using the Tornado to collect them. Touch Space [59] is a mixed reality AR-VR (Virtual Reality) game played by interacting with tangible objects as well as other players. Players communicate with their co-players in an augmented reality environment.

Table AR games usually depend on fiducial markers for AR rendering. Several sport games are played on this table top approach. Lee et. al. [113] presented the augmented reality squash game using 'estimated geometric information of images'. AR Tennis [82] is a face to face collaborative AR game. The game is developed on Symbian platform integrated with ARToolkit [70] on a handheld device such as PDA. The main goal of the research is to analyze the face to face collaboration between the two players in AR games. Similar to the games AR Squash, AR Tennis is also played stationary, sitting on the two alternative edges of a table. Liarokapis [115] developed AR Racing [145], a modified AR version of an existing XNA game, where a single player finishes the lap as quickly as possible without going off the track.

The ubiquity of smartphones has increased the potential install base for MW AR games. Augmented Galaga [150] is an AR version of the famous arcade game Galaga, where the spaceships are superimposed on top of the real world while looking through the handheld device's camera. An object tracking method tracks specific object in the real world around which the spaceships appear. Energy Saving [52] is a casual adventure game to support the awareness of reducing energy in the environment. Completing tasks at stations earns points which leads players' virtual gardens improving (e.g. the trees grow and become more green). GARLIS [197] (Game-based Augmented Reality Library Instruction System) provides an AR system in a real world library. The game play centers on a 3D character who provides information regarding the Chinese library classification scheme. The Table Mystery [46] is a collaborative AR game for chemistry. Each team in the game receives instructions from a character with amnesia, who provides clues which are rendered on top of a periodic table. GenVirtual [76] is an educational musical AR game specially designed for people with learning disabilities. The objective of the game is to follow the sequence of the notes leading to a song. Burke et. al. described three aspects of AR games (meaningful play, challenge and conservative handling of failure) for limb-stroke rehabilitation named Shelf Stack [53]. Based on these constraints, the authors demonstrated two of their low cost developed AR games named Brick a' Break and Shelf Stack. Both Shelf Stack and GenVirtual games were developed using Microsoft XNA and ARTag.

4.2.2 Commercial AR Games

Most commercial AR games are played on smartphones, although technical demonstrations for new head mounted displays such as the Oculus Rift exist. The very first AR aiming game is known as Mozzies [2] played on Motorola SX1 where players kill virtual mosquitoes. Sky Siege [96] is an AR shooter game played with iPhone. The player's goal is to shoot virtual helicopters and earn points. Star Wars Arcade: Falcon Gunner [28] is another game from for iPhone. Players need to shoot the TIE Fighters to earn points. DroidShooting [126] is a shooting game made for the Android Platform. In DroidShooting, the player shoots waves of virtual robots appearing around the player. In AR Invaders [90] and Dimension Invaders [165] the player shoots virtual spaceships. In the game Destroyer AR [8], the player needs to save fighter planes by tilting the phone to avoid enemy air craft appearing from various directions. This category includes Augmented Reality Asteroids [154] and Territory Defense Augmented Reality [159] - both these games include shooting enemy airplanes to gain points. In the game Augmented Reality Asteroids [154] where fighter plane appears on camera while holding the phone towards the marker and the players need to shoot then to gain points.

4.3 Experimental Setup

Our experiment involves testing user performance and experience in a custom-made AR endless shooter, called MonstAR. Players shot waves of enemies in four different experimental configurations with three levels of additive noise to sensor readings. Players' in-game performance was logged, and in-game experience probed with retrospective questionnaires immediately after each condition.

4.3.1 AR Game Testbed

MonstAR is a simple AR game in the genre of endless shooters inspired by early arcade games such as Galaga, which have seen a recent resurgence in MR AR commercial titles such as Droid Shooting by Quest-Com, and iSnipeYou by Sense8. This sub genre is particularly appealing as a test bed because the simplicity of the mechanics and design inherently limit the confounding effects found when evaluating more complex games, because the aiming mechanics are fundamental to almost all AR games (at least for mapping line of sight), and because the existing install base on app stores provides an immediacy of impact.

The game itself is based on shooting waves of flying monstrous birds. The birds appear to move with the addition of sensor noise, as the AR engine renders them in different positions based on apparent but erroneous changes in viewing angle and position. Players must target waves of these enemies. Points are awarded for successfully hitting a monster.

The experiment probes two display and two aiming types. Players are provided with the same game on two devices, an HMD and a smartphone. For consistency of presentation we employed the Durovis Dive Head Mount HMD, which employs a Galaxy Nexus Samsung smartphone as the computational and display element, by physically mounting the smartphone in an HMD chassis, and providing adjustable lenses for viewing stereo images. The smartphone condition uses an identical smartphone to the one in the HMD, ensuring that there are no differences in processing or rendering speed, pixel count, or screen size. However, because the HMD renders objects in 3D using a split screen technique, the field of view in the HMD case is limited compared to the MW case. In one condition for each of the HMD and MW cases, the aiming reticule is locked to the center of the screen (called the locked case). Players must move the entire field of view to put the reticule on a particular target, reminiscent of classic First Person Shooter (FPS) aiming mechanics. In the second input type, players can move the view screen, as before, but can also move the aiming reticule within the plain of the view screen (called the unlocked case), reminiscent of classic Third Person Shooter (TPS) aiming mechanics. In the HMD case, on-screen reticule movement was driven using a handheld controller (Madcatz CTRL), whereas in the MW case it was driven using a soft joystick. Screenshots of each condition can be seen in Fig. 4.2. The MonstAR system was built in Unity using a set of third party SDKs for AR and input functionality. The Durovis Dive Open Dive Sensor SDK was to build the AR portion of the game.

Game controls were encoded using TouchScript and Ultimate Joystick.

Orientation is supplied by the Android abstract orientation sensor which provides the world-frame rotation of the device, which is mapped to camera orientation(s) in Unity. The reading is performed by a plugin named divesensor which is included in the Durovis Dive SDK. Gaussian white noise was randomly drawn from a 100 element histogram approximating the Gaussian distribution, multiplied be a scaling factor and added to the rotation parameters about the x, y and z axis prior to those data being forwarded to the game engine.

Figure 4.1: Durovis Dive HMD system

Logging was implemented by using the SystemIO of C-sharp. We used the PlayerPrefs function of Unity to keep track of the players ID and score across conditions. We placed the log writing functions inside the Update() function of Unity so that it records every parameter of the player frame by frame, which had no appreciable impact on frame rate. Firing and enemy hits were logged asynchronously. The following parameters were logged with timestamps:

- Start/End of a level
- Trigger pressed
- Target killed
- Phone pose in game coordinates (x,y,z)
- Reticule position in game coordinates (x,y,z)

4.3.2 Gaussian Noise Distribution

We employed a zero mean Gaussian additive white noise model, commonly used to represent an accumulation of independent random processes underlying the overall sensor noise. Other noise models are possible, for example simulating temporary signal disruption, but we have limited our investigation to a single noise model to manage experimental scope. Additional noise models will be addressed in future work. We defined three different levels of noise, determined through pilot testing and corresponding to reasonable levels of noise given the performance of the orientation sensor systems (shown in Table 6.1). Noise values were drawn and added to all three parameters of the orientation. As far as the game was concerned, the player was moving the device, and it attempted to render the 3D artifacts with respect to the device's apparent position.

(a) HMD with Locked Reticule

(b) HMD with Unlocked Reticule

(c) Magic Window with Locked Reticule

(d) Magic Window with Unlocked Reticule

Figure 4.2: MonstAR Screenshot

Table 4.1: Standard Deviations (σ) for Noise Levels

Level	**SD(σ) in percentage**	**SD(σ) in rad/sec**
None	0	0
Low	0.75	0.367
High	2.8	0.977

4.3.3 User Study

We evaluated 48 adult participants ranged from 18-60 years of age (14 female). Among these, 29 were familiar with AR, and of those 23 had experience playing AR games. All participants have used smartphones, and 22 spent at least an hour per week playing mobile games in their smartphone.

The entire experimental setup included 4 different segments of gameplay each having 3 different levels of sensor noise (none, low and high) for a total of 12 conditions arranged in a Latin Square design. A practice play session of 3-5 minutes prior to each game type (MagicWindow locked reticule or HMD unlocked reticule) were provided to the participants to reduce the learning impact on performance and experience. In accordance with our ethics approval, before beginning the entire process participants were provided a consent form explaining the experiment. Once they signed the consent form, the experiment began.

When starting the HMD portion of the experiment, personalized physical adjustment of the lenses was required for proper viewing for each participant. Once the were comfortable wearing the HMD, an introduction to the game controller and the specific controls were demonstrated. After the successful completion of a practice session, the actual experimental sessions took place. After each condition, the participants were asked to fill standard and validated surveys recording their play experience: the PANAS (Positive and Negative Affect Schedule) [60] and IMI (Intrinsic Motivation Inventory) [172] surveys; standard instruments for evaluating user experience in games. With practice sessions, play sessions, and survey completion, the overall experiment took approximately one hour per participant.

4.4 Results

Our results are comprised of two main data sources: log analysis of points scored in each condition as a performance metric and statistical analysis of the results of the IMI survey as a player experience metric. We are primarily interested in the differential performance of input type, view type and noise level on player performance and experience.

4.4.1 Log Analysis

We analyzed the logs to determine the amount of effort and outcomes for each condition. We wanted to determine the game state output that corresponded to the players' subjective experience as recorded by the surveys. We analyzed:

- Score in all conditions
- The Euclidean distance traveled by the center of the phone in all condition
- The number of shots and hits in all conditions
- The distance distribution of the reticule from center during free-aiming conditions

- The distance distribution of the reticule from center when an object was hit during free-aiming conditions

Players scored points for each monster killed. The total number of points after each condition were aggregated into distributions across participants and are shown as boxplots in Figure 4.3a. Unsurprisingly, noise depresses score, with no noise significantly different from low and high noise ($F = 229, p < 0.001$). Interestingly, maximum score in the MW case is achieved with FPS mechanics, where the reticule is locked. There is a main effect for view type, with the HMD performing better than the MW ($F = 282, p < 0.001$). We also observed significance by lock type ($F = 11, p = 0.001$). We also observed two way interactions between view type and lock type ($F = 45, p < 0.001$), game and noise level ($F = 7.9, p = 0.001$), and a three way interaction between all factors ($F = 80, p < 0.001$). There was no significant interaction between lock type and noise level, possibly because users performed uniformly poorly in the unlocked MW case, independant of noise. From this analysis, we can conclude that the trends clearly visible in Figure 4.3a can be taken at face value.

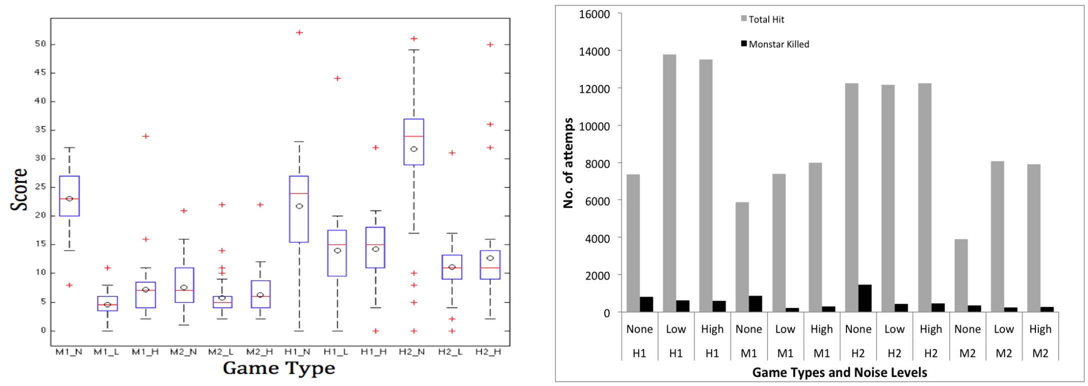
Participants performed better with HMD, and no noise. The introduction of even low noise depressed performance significantly, but there is little difference between the impact of low and high noise. Players achieved higher scores in the HMD with the unlocked system, but this performance degrades more substantially in the presence of noise than the locked case. For the magic window condition, users were universally better in the locked case, than in the unlocked case, and saw a larger drop with the introduction of noise.

We considered the Cartesian displacement (x,y,z) of the center of the screen and aiming reticule to estimate the extent to which participants used the two methods of aiming with and without noise. The most obvious trend in Figure 4.4 is the difference in participant motion under the noise conditions. It appears that participants were trying to chase the monsters with the aiming reticule rather than adopting a wait-and-shoot strategy, pulling the trigger when a monster crossed a stationary reticule. Movement without noise was significantly different than motion with noise ($F = 82, p < 0.001$). Players moved the HMD more than the MW in low noise conditions ($F = 82, p < 0.001$). We suspect this is due to the kinematics of head mounted versus hand held displays, but cannot confirm with the experimental data we have.

To gain a sense for attempts versus scoring in all cases we plotted the sum across all participants of shots versus hits for all conditions. As these data are summed, statistical comparison is not possible, but broad insight can be achieved. Players took a total of more shots in noise conditions and hit cumulatively fewer targets, as we already knew from the score. Fig. 4.3b reinforces our earlier contention that under the influence of noise, participants were still trying to track the objects, but succeeding less.

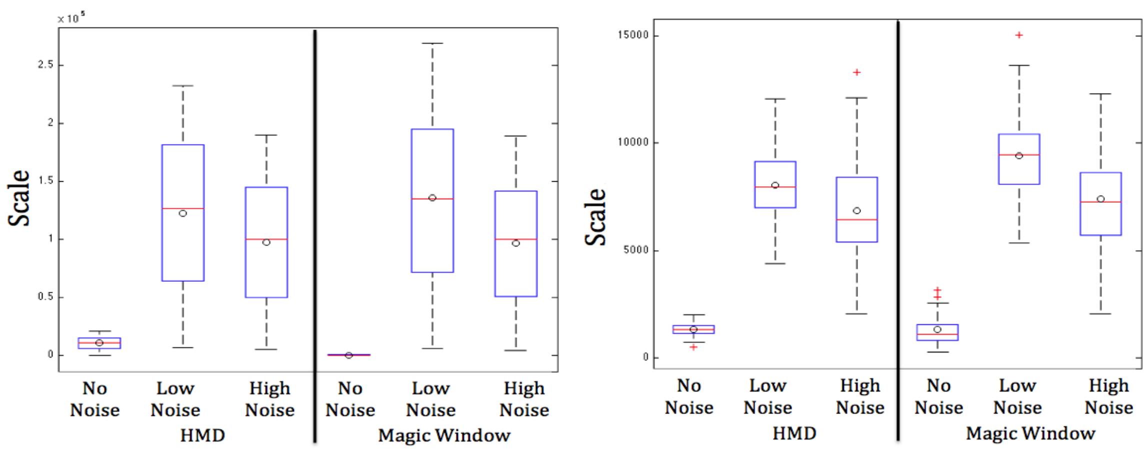
4.4.2 Player Experience Analysis

Successful gameplay design depends on player satisfaction, and enjoyment, not productivity as the primary purpose of a game is leisure activity. Nacke et. al. [140] state that a technique needs to be established to improve relationships between the player experience and game itself. The scale of a good or bad play



(a) Scores in different game state **(b)** Attempted hits vs. kills

Figure 4.3: Players' attempted hits and scoring scenario. The labes are named as GameType_ReticuleType_NoiseLevel as in game type varies H=HMD, M=Magic Window Reticule Type varies 1=locked, 2 =unlocked and noise level varies as none(N), Low(L), High



(a) Locked Reticule State **(b)** Unlocked Reticule State

Figure 4.4: Players' movement during different gameplay condition

experience depends of players' overall positive or negative play experience as well as the interest/enjoyment or level of competence during gameplay. To examine these, our participants completed surveys after each condition. From the IMI survey results we evaluated:

- Interest/Enjoyment
- Competence
- Tension/pressure
- Effort

Boxplots of each of the conditions for each of the IMI survey results are plotted in Fig. 4.5. Boxes are grouped by view type at the highest level, then input type, leaving sequential results for noise as side-by-side triplets.

We performed an ANOVA using SPSS with three factors: two binary - view type and lock type - and one ordinal - noise level. We found main effects for view type for interest ($F = 22.5, p < 0.001$), competence ($F = 39.5, p < 0.001$) and enjoyment ($F = 8.6, p = 0.005$); main effects for lock type with interest ($F = 12.1, p = 0.001$) and competence ($F = 4.2, p = 0.046$); and main effects for noise type with interest ($F = 27.6, p < 0.001$), competence ($F = 32.9, p < 0.001$) and tension ($F = 7.7, p = 0.001$). Participants had lower competence and interest with higher noise, additional aiming mechanics and less immersive displays. Players had increasing tension with increasing noise, and greater enjoyment with more immersive displays. In short, our main effects confirm what an experienced designer would conclude: that noise harms game engagement, that more immersive displays are better, and that often simpler input regimes are preferable.

However, this work is not primarily about confirming general design insights, but understanding how those design insights interact with each other. To understand how the different factors of display, lock type and noise level interact, we compared the pairwise interactions of the IMI responses. Looking at interactions of view type by lock type by noise level, we were able to uncover several key insights into the PX impacts of AR game design considerations.

There is a differential sensitivity to noise with view type. Mean competence decreases with increasing noise, independent of lock type for HMD displays ($p < 0.015$ for all none-to-noise pairs). Noise makes the game more challenging, beyond the point were players felt they were achieving mastery. Competency with MW display exhibits a joint dependency on input type and noise. In the unlocked case, the introduction of any noise causes mean competency to fall ($p < 0.001$ for all none-to-noise pairs). In the unlocked case competence falls more dramatically with noise. In the magic window case, mean competence falls more dramatically in the locked case. This result may be due to sample bias within our population as the means for the MW locked case show decreasing competence with noise, but the medians show increasing competence with noise. We take this incongruity to indicate that there was strong heterogeneity in our subject population, leading to significant differences in rating. In the unlocked case, median competence decreases but not significantly. There was a significant difference in interest between low and high noise levels for the different games and input types.

Participants found that both lock types were more interesting/enjoyable without noise than with noise ($p < 0.003$ for all none-to-noise cases) for the magic window case. This was moderately interesting, as we had initially hypothesized that participants might find the low noise case more interesting as it imparted pseudo-motion on the monsters. For the head mounted case, there were significant pairwise differences between high noise and no noise for the locked case ($p = 0.003$), and between all none-to-noise cases in the unlocked case ($p < 0.001$).

From a pairwise comparison over effort, the only significant difference noted was in the head mounted view, with unlocked reticule, where high noise was considered more effort than low noise ($p = 0.035$). However, given the small effect size in the graph and the fact that none of the other condition combinations were considered effort-heavy, we do not place a great deal of weight in this finding.

Players felt differential tension with noise in the MW locked case ($p = 0.035$), for either low or high noise with no noise. None of the other pairwise relationships with tension were significant. As the game was not designed with tension in mind, this outcome is not unexpected. The relationship in the locked magic window case may indicate that the noise levels have inadvertently hit a "sweet-spot" of difficulty and accessibility, causing differential tension to be reported.

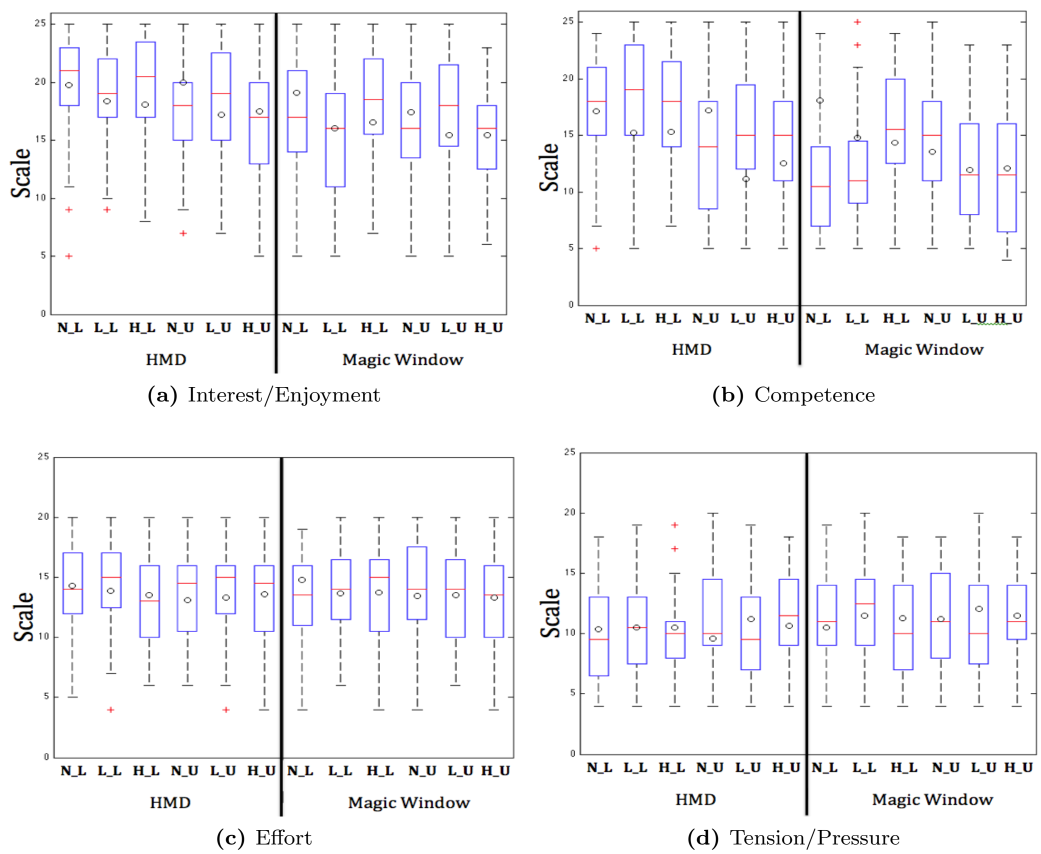
4.5 Discussion

Our results indicated that there was cross dependency between how AR games were presented to the user, how they interacted with the game, and the amount of noise present in the sensor inputs. In particular, noise decreased feelings of enjoyment and competency, but more sharply in the head mounted case, indicating a greater sensitivity to noise in HMD games than MW games. However, mean and median competency was always lower in the MW case compared to the HMD case, indicating that the MW interface was overall more difficult for users to manipulate and less engaging to interact with.

4.5.1 Findings and Design Guidelines

Through this study we have made a series of findings about the differential behavior of performance outcomes and player experience for simple AR shooting games. These findings are based on the large and statistically significant effects we have observed in our experiments. Our recommendations attempt to provide guidance on possible game design techniques to ameliorate the impact of the effects we have observed, but are by no means the only possible solutions. We have paired these findings with design recommendations for developers wishing to enter this space. This guideline list is not an exhaustive one for AR shooters, as it pertains only to the findings from our experimental analysis presented here.

Finding 1 : *Noise matters* Introducing simple Gaussian sensor noise with modest standard deviation had a significant impact on the players' performance, interest and competence. The amount of noise did not



(a) Interest/Enjoyment

(b) Competence

(c) Effort

(d) Tension/Pressure

Figure 4.5: Players' Intrinsic Motivational Inventory during different gameplay condition. Bar names are labeled in a format of `NoiseLevel_ReticuleState`. Noise Level can vary as none(N), low(L), high(H) and the reticule state can vary locked(L) and unlocked(U).

seem to matter, as little difference was noted between the high and low noise conditions for the players' experience.

Recommendation 1 : *Add adaptivity to game engines.* Because noise matters, noise compensation should be part of the fundamental game mechanics for multiplayer AR games, particularly if they are cross platform. This is already possible for network shooting games, where hit determination takes latency into account. For example, increasing noise increases difficulty, so it may be necessary to increase hitbox size in shooters, or change environmental variables to compensate as in [141].

Finding 2 : *Players do better with HMDs, but not much.* Scores with HMDs were pairwise higher than with the equivalent magic window condition. Players were more interested and felt more competent with HMDs. We suspect but cannot prove that this was a novelty effect as commodity HMDs are still in the alpha or beta testing stages. However, there is a plausible argument that the more immersive and natural interaction and display afforded by HMDs will almost always produce a more interesting experience.

Recommendation 2 : *Build the Magic Window version first.* If our immersion hypothesis is correct, then compelling experiences on a HMD game might not translate to a MW. For cross-platform titles, particularly in the casual genre, it is sensible to test the game mechanics and balance on the less compelling platform first.

Finding 3 : *Players chase monsters.* The addition of sensor noise caused apparent motion of the monsters against the camera-fed background. When confronted with this apparent motion, players still attempted to target monsters by moving either their head or reticule. Players travelled farther, and fired more often in noisy cases than non-noise cases. While this was not problematic in our short test cases, it could be an ergonomic issue for longer play sessions, particularly in the locked HMD condition, as players attempt to make rapid, short, random movements with their neck to aim.

Recommendation 3 : *Provide targeting assistance.* Targeting assistance that is either hidden (e.g. hit box expansion) or integrated into the narrative (e.g. target-seeking ordinance) could remove the need for the rapid, short motions induced by the Gaussian noise model. Alternatively, the unlocked reticule case could be employed for HMDs to allow find motion with finger controls, leaving only gross aiming motions to the head pose.

Finding 4 : *Players perform poorly in MW shooters with unanchored reticules.* We noted lower performance across score for larger distances moved under all noise conditions for MW with an additional degree of freedom. In the HMD case, performance improved when using the movable reticule, but degraded under noise conditions. Players felt significantly more competent and interested in the low noise conditions in both the HMD and MW cases.

Recommendation 4 : *Use FPS Mechanics*: Unless you, as a designer, have another compelling reason to do so, fixing the reticule will provide greater platform extensibility and lower noise sensitivity, compared to the movable reticule. As FPS mechanics are widely employed in existing computer and video games, little if any training overhead would be incurred.

4.5.2 Shortcomings and Future Work

While this work represents a significant contribution to the gaming literature, it does have some shortcomings which should be addressed in future work. First, our experiment only considered one type of game - chosen because of its current relative popularity to other AR games on app stores - and one noise model - chosen because it is the most common and generic model of sensor noise. However, other game genres and noise models are possible. Future work should investigate the extent to which different noise models differentially impact different game mechanics in HMD and MW implementations. Furthermore, the noise variance was selected a priori. A more theoretically rigorous noise model derivation might be desirable. Second, the game we tested with, while consistent with the early offerings on app stores, had simple mechanics and stylized interactions. Understanding the more nuanced impact of noise and interaction type in games with more complex interlocking mechanics would require creating new more complex games. Finally, like many preliminary studies, our sample size was biased towards the university community. Larger and more broadly sampled participants could better ground the generalizability of the work.

4.6 Conclusion

Through a controlled user study we examined user performance and experience under different input, display and sensor noise conditions for an augmented reality game. We found that users reacted differently to the introduction of noise depending on the type of display and input technique. These results will help inform development in this rapidly evolving area. Studios developing for single systems can adopt mechanics that suite their game design. However, studios looking at cross platform deployment must be concerned about the potential for differential effects of sensor noise providing inconsistent experience across different platforms. Our finding suggest that multi-platform HMD titles could use either locked or unlocked reticules, but that cross platform magic window deployments should by default use locked reticules. This research represents a first step in a rapidly evolving area, and significant and impact further research can build upon these findings.

Chapter 5

Manuscript 3

Title: Analyzing Play Experience Sensitivity to Input Sensor Noise in Outdoor Augmented Reality Smartphone Games

Venue: British HCI, Lincoln, United Kingdom

Citation: Eishita, Farjana, and Stanley, Kevin. "Analyzing play experience sensitivity to input sensor noise in outdoor augmented reality smartphone games." Proceedings of the 2015 British HCI Conference. ACM, 2015.pp. 56-64.

Author's Contribution: The research presented in this manuscript is my own, conducted under the supervision of Dr. Kevin G. Stanley. Ideas and techniques that are not products of my own work are duly cited, or, in cases where citations are not available, are presented using language that indicates they existed prior to this work.

Summary: The act of overlaying digital artifacts on a real environment requires detailed information about the relative pose of the player and digital artifacts be accurately sensed and computed, which is often beyond the capacity of sensor systems deployed on commercial devices such as smartphones. Game developers are adept at creating compelling experiences from a limited or noisy palette of interactions, but have limited guidance in the case of augmented reality games. In this paper, we present a novel technique for evaluating the sensitivity of augmented reality games and game mechanics to input noise by modifying the sensor input stream of an open source operating system in a controlled manner. Any game, commercial or academic, that runs on that operating system can be systematically tested for the user experience impact of differing levels of sensor input noise. We perform such an experiment on two commercial and one academic game and determine that similar levels of input noise have very different impacts on user experience depending on the game design, input modality, and narrative. We found that players were more sensitive to the hunting mechanism than the other two. Unexpectedly, while playing a targeting game, player experience was increasingly positive as the noise increased. For the trivia game, play experience was consistent for all levels of noise.

Relationship to the thesis: This manuscript explores the players' sensitivity to sensor QoS for location-based AR games of different genres. This paper contributes to the central research question by identifying the criteria that impacts the PX while playing different AR games with different levels of sensor noise. The findings can provide concrete guidelines on noise impact mitigation. This contribution is significant because the differential impact of noise on user experience is important as it indicates that proper design decisions can be used ameliorate or mask sensor noise issues. In stabilizing the differential impact of sensor noise on location-based games, we have further validated our central hypothesis that the QoS impacts PX in AR games in subtle and important ways. Additionally, this manuscript contains the most complete description of the technique used to inject sensor noise into any game, the primary technical and methodological contribution of the thesis.

Experimental Analysis: The research question for this experiment was - "Does different levels of input sensor noise impact the PX while playing location-based AR games and does the noise differentially impact our games based on genre?".Experimental design had three different noise levels (e.g. Low, Medium, High) with a control as the primary independent variables. The magnitude of noise was defined through different standard deviation. To analyze the PX, dependent variables were derived from the standard psychology surveys PANAS (Positive And Negative Analysis Surveys) and IMI (Intrinsic Motivation Inventory). PANAS aided us to investigate the variation of experience in terms of positivity and negativity. Through IMI, the experience of players' interest/enjoyment, competence, tension/pressure and efforts were recorded. Therefore, for IMI the dependent variables were interest/enjoyment, competence, tension/pressure and effort. Overall, a repeated measure ANOVA was adopted to analyze the statistical significance of the experiment.

Relationship with the taxonomy: This experiment demonstrates the PX sensitivity of playing location-based AR games under different levels of input sensor QoS. Because location-based AR games use GPS as their primary sensor to detect location on Earth, we injected different levels of noise (e.g. None, Low, Medium, High) to latitude and longitude of the GPS readings. The games chosen for this experiments were - SpecTrek (group: outdoor aiming), Temple Treasure Hunt (group: Outliers) and PasswARG (group: Outdoor explorer). Although all three games are location-based AR games, due to their different game mechanics and play techniques, the spatio-temporal requirements were different. The taxonomy describes that outdoor aiming games such as SpecTrek requires high location accuracy but a medium precision. Our experimental results partially confirms the expected behavior for the class, however, the game remained playable at higher noise levels.

Game Input Technique: Two commercial games and one research location-based AR games were used in this experiment. The game mechanic is as follows -

- **SpecTreck:** The players need to find digital ghosts anchored on real-world positions. After the game initiates, 3-5 ghosts around the player's location appears on the map. When looking through the camera towards the particular direction, the ghosts appear on screen. The size of the ghost increases as players walk closer to it. To catch the ghosts, when players reach within 100 meter of radius, the reticule located at the center of the screen turns green from red indicating that the ghosts are catchable. Then the players need to tap a button located at the bottom right of the screen making sure the reticule is placed on top the the digital ghost.

- **Temple Treasure Hunt:** Only one treasure in one particular level is loaded every time the game is initiated. The location of the treasure can be viewed through the map mode. Once the player reaches around approximately 5 meter of the physically anchored treasure, the camera view is loaded and the treasure appears onto the screen. Then the player needs to tap on the treasure to capture it. If the player is not within necessary proximity, the augmented view is not initiated.
- **PasswARG:** This is a strict location based games where players need to only look at the digital artifacts providing letter clues to unveil the password. The characters are loaded on screen when the game is initiated and necessary clue is provided at the bottom of the screen.

5.1 Introduction

Augmented reality (AR) is a technology where digital artifacts are overlayed on a rendering of reality, usually captured through a camera. While augmented reality has been researched for some time, advances in smartphone technology have begun to bring these techniques into the mainstream, either by enabling novel technologies such as the Occulus Rift through hardware commoditization, or directly through the phones themselves as magic-window AR apps. AR technology has applications over a wide variety of fields including maintenance, design and entertainment. A particularly salient application area for AR is games, where players can interact with fantastical elements overlaid on actual spaces. Games are distinct from many of the other application areas as the primary outcome for a game is user experience, and not performance in completing a digitally mediated task.

From a technical standpoint, AR display is already a reality. Simple AR applications can be readily created to provide the user with information on specific locations, directions, or a digital overlay of an object, providing for example digital notes on a physical model. However, providing this kind of feedback requires detailed and accurate knowledge of the pose of the display in physical space to allow the digital artifacts to be properly rendered on the scene. Computing where on the image to display the digital artifact is sometimes called the registration problem. While the registration problem can be adequately solved for course-grained digital artifact display, like overlaying a direction arrow based on GPS coordinates, accurate pose estimation, particularly including location on the Earth is still not reliably available on mainstream commercial devices.

Despite these shortcomings developers have begun to release AR apps for smartphones, for example Layar, which allows simple GPS tagging, or simple AR games. AR games are particularly interesting because the registration problem can be weakened through clever game design. While a user would be disoriented if an AR label for coffee shop was applied to an adjacent bank due to sensor error, the same cannot be said for the location of a target in an aiming game, as the location of the target does not have to be tied as strongly to the semantics of the space it inhabits. However, different games have, presumably, different sensitivities to sensor error. One might expect a shooting game, where aiming was the primary mechanic, to be more sensitive to sensor error than an Easter egg hunt, where simply finding the digital treasure is required.

Currently, AR game designers do not have specific guidance as to the trade-offs that exist between input modality, game design, narrative, and sensor reliability. Game designers have a great deal of experience in hiding input shortcomings behind game design using traditional control techniques, but, to the best of our knowledge, no concerted effort has been made in this regard for AR games, which must rely on a different set of sensors as input.

Tackling this problem in general is difficult, as it requires creating a wide variety of game types, narratives, and input modalities, and user-testing them in a controlled environment against different levels sensor noise. Creating games can be a time-consuming activity, and controlling for sensor noise can be difficult in practice. In this paper, we employ a novel technique, whereby we modify the sensor data stream within the Android operating system to corrupt incoming sensor data in a controlled, and experimentally configurable way. By modifying the operating system in this manner, we can deploy any publicly available AR games as potential experimental testbeds, dramatically decreasing the development overhead. Furthermore, we are able to ensure that the games we are testing are of commercial quality, as they can be downloaded directly from the Android store.

Specially, we demonstrate this technique by performing a user study of two commercial and one academic AR game, which employ GPS location as the primary game input, using our modified operating system. We find that increasing sensor error has differing impacts on user experience based on the game mechanics, and narrative. In some cases, players perceive increased error as cumbersome, and in others as an increase in the game difficulty. These findings are extended to recommendations for AR game development and future research.

5.2 Related Work

Significant prior work has been done both in academia and industry on augmented reality games. In the past, AR game research has focused on dedicated systems using early head-mounted displays to provide immersive feedback. More recently, the explosion of smartphone technology has opened the door to research and innovation in magic-window AR games. A number of different authors have examined the role of user experience in games, providing standardized survey instruments for evaluating play.

5.2.1 Research Games

ARQuake [190] is a location based AR game that used GPS, digital compass, and fiducial vision-based tracking to convert the desktop version of Quake to a mobile AR game, played with a laptop, haptic gun and an HMD (Head Mounted Display). AR characters were deployed using ARToolkit [70]. Similar to ARQuake, Human Pacman [58] is a location based AR game. The main focus of this game is collaboration among the team members in a virtual 'Pac-World'. Being an outdoor game, localizing the players has large effect on game play. Epidemic Menace [117] is a cross media game with several different interfaces such as game board station, a mobile assistant and augmented reality. Players must find a virus that is spread by an evil scientist. Game play is primarily outdoor and dependent on GPS accuracy.

The ubiquity of smartphones has increased the scope of application for AR games. Energy Saving [52] is a casual adventure game to support the awareness of reducing energy in the environment. AR markers anchor clues at different stations. GARLIS [197] (Game-based Augmented Reality Library Instruction System) provides an AR system in a real world library. The game play centers on a character who provides information regarding the Chinese library classification scheme. The Table Mystery [46] is a collaborative AR game for chemistry with a rich game design. Each group in the game receives instructions from character with amnesia. This character provides clues and the players need to follow the instruction and achieve information using the handheld device rendering information on top of a periodic table. GenVirtual [76] is an educational musical AR game specially designed for people with learning disabilities. The objective of the game is to follow the sequence of the notes leading to a song. Burke et. al. described three aspects of AR games (meaningful play, challenge and conservative handling of failure) for limb-stroke rehabilitation named Shelf Stack [53]. Based on these constraints, the authors demonstrated two of their low cost developed AR games named Brick a' Break and Shelf Stack. Unlike the location-based games, these games rely on orientation of the phone, typically detected through accelerometers and gyroscopes.

Table AR games usually depend on fiducial markers for AR rendering. Lee et. al. [113] presented the augmented reality squash game using 'estimated geometric information of images' taken using a stationary camera. The game AR2Hockey (AR AiR Hockey) [146] is a collaborative real time AR game demanding both high fidelity and high response rate from the input sensors. Like ARSquash, AR Tennis [82] is a face to face collaborative AR game. The game is developed on Symbian platform integrated with ARToolkit [70] on a handheld device such as PDA. Similar to the games AR Squash and AR2Hockey, AR Tennis is also played stationary, sitting on the two alternative edges of a table. This setup decreases the dependency on spatial accuracy of the game and at the same time increases the impact of orientation sensitivity.

5.2.2 Commercial Games

Most commercial AR games are played on smartphones, although technical demonstrations for new head mounted displays such as the Occulus Rift exist. Sky Siege [96] is an AR shooter game played with iPhone. The player's goal is to shoot the virtual helicopters and earn points. Star Wars Arcade: Falcon Gunner [28] is another game for iPhone. Players need to shoot the TIE Fighters to earn points. DroidShooting [126] is a shooting game made for Android Platform. In DroidShooting, the player shoots waves of virtual android robots appearing around the player. In AR Invaders [90] and Dimension Invaders [165] the player sees virtual spaceships which they need to shoot and earn points. All of these games employ sensors to determine the orientation of the screen for aiming. Skeeter Beater [157] is a casual game demanding lower aiming accuracy. The players need to kill the mosquitoes by locating them with the camera, then tapping. ARSoccer [92] is an casual game where players need to view the floor to find the soccer ball which can be kicked. AR Basketball [89] is a similar game featuring a ball and hoop.

While significant work has been done in AR Games and some simple games are entering the market through app stores, few authors have addressed the issue of the differential impact of sensor noise by interaction type or narrative.

5.2.3 Related Tools and Approaches

Analysis of a player's experience, including fun, staisfaction, immersion has been he been investigated for games [104][174][138]. Combining eight elements: 'concentration, challenge, skills, control, clear goals, feedback, immersion, and social interaction' Sweetser and Wyeth proposed a model to find player's enjoyment in a game [189]. Competency in particular can play a large part in games; for example, player's with same extent of competency, a stronger player might feel bored where as a weaker player can be frustrated [195]. Failing to achieve the goal in a repeated manner can easily frustrate a player in video games. To overcome the issue, the necessity of creating an 'ideal' environment where any player can enjoy playing the game regardless of their category (e.g. expert, casual) has been discussed in [75]. As aforementioned, inappropriate narratives can direct players to an inaccurate mindset during gameplay. Hence, context-awareness [81] has been taken as decisive sector to prepare AR game modality.

As players learn the gameplay and the control mechanisms a deeper immersion is achieved [55]. Uncertainty can be influential to hamper player's satisfaction while playing location-based games. To overcome the issue a couple of approaches such as hiding (by filtering the unreachable location caused by GPS error) or revealing (where players are aware of the probable uncertainty) were applied in [37]. However, an overall statistical analysis for player's satisfaction rate was not provided. To overcome issues with tracking in virtual or augmented reality environment framework named OpenTracker has been proposed proposed [166]. This approach is applicable in the 'pipes-and-filter architectural' pattern that provides adjustable platform to deal with tracking data.

While some authors have already considered the role of sensor noise in games, no one has looked at differential impacts of noise using standardized instruments.

5.3 Methodology

In our experiment, we evaluate the impact of additive sensor noise to the user experience of three augmented reality games available for Android phones. Sensor noise was added to the GPS sensor stream at the operating system level, so all games received exactly the same stimuli. Players played each game under four noise conditions. User experience was measured using standard validated instruments, and compared using standard statistical techniques.

5.3.1 Adding Noise to GPS

To limit the experimental degrees of freedom, we chose to examine a single sensor, GPS-based location, typically reported as latitute and longitude on the surface of the Earth. The location-based AR games we consider all rely on the GPS sensor to localize the player with respect to the digital artifacts. The accuracy of the GPS location estimate can depend on the number of satellites visible, the atmospheric conditions, and the existence of natural or man-made canyons. These failure modes can be modeled using different noise models, but we chose to examine a canonical noise model, additive Gaussian Zero Mean Noise (GZMN), again to limit experimental complexity. In most smartphones, a nominal accuracy of 10 m can be obtained under favorable circumstances, but errors up to kilometers can be reported, particularly during initial satellite acquisition.

For experimental purposes, we injected zero mean Gaussian white noise to the actual GPS readings with three different standard deviations (SD). The Gaussian distribution was chosen as a standard model of cumulative sensor error, where multiple random noise events, when summed, tend to converge on a Gaussian distribution. Because the distribution is zero mean, it can be directly added to the incoming GPS signal without effecting the average performance of the system. Other noise models reflecting sporadic changes in accuracy due to local topology, or intermittent failure due to lost satellites are possible, and can be easily implemented in our system, but are left to future work.

5.3.2 Game Descriptions

Three games were chosen for this experiment. While many AR games exist on the Google App store only a few use GPS as input (orientation is much more common), and fewer still have sufficient stability and user interaction to warrant testing. After eliminating unsuitable games, we then chose two commercial AR games with similar mechanics, but different design, a ghost hunting game and a treasure hunting game. We included an academic edugame based on an Easter egg hunt mechanic as the third game. We then had three games centered on the idea of finding a digitally tagged location in space, but with different interaction mechanics and narrative. THe selected games are breifly described in the following subsections. Screen shots of each game are shown in Fig. 6.5.

5.3.2.1 SpecTrek (ST)

SpecTrek is a casual AR game where players hunt for digital ghosts in a given area. At the beginning, a circular play area is defined by selecting a radius. We employed the lowest radius (467 meters). A number of ghosts (from 3-5, default 3) are randomly placed within the play area and can be located through the map as points of interest (POI). A map interface is visible when the phone is held parallel to the ground. To find the ghosts through camera, the player must hold the phone perpendicular to the ground, as if taking a picture, in the direction indicated on the map. If pointed in the right direction, the digital ghost is displayed. The size of the ghost depends on the distance of the player from the ghost. To catch the ghosts, the players must walk towards the ghost holding the phone in hand. When the player is within 175 meters of the ghost's location, the ghost could be caught by aiming the reticule at the ghost, and tapping the net located on bottom right corner of the screen.

5.3.2.2 Temple Treasure Hunt (TT)

Temple Treasure Hunt is a scavenger hunt game where players hunt for virtual treasure located using at points in the physical world. Similar to SpecTrek, players need to walk towards a POI displayed on a map, visible while the device is held parallel to the ground. Unlike SpecTrek, the digital avatar is not loaded until the player reaches the precise position of the treasure. Once the label of player's location and treasure matches (demanding higher precision), the the digital character is loaded, and visible through the camera,

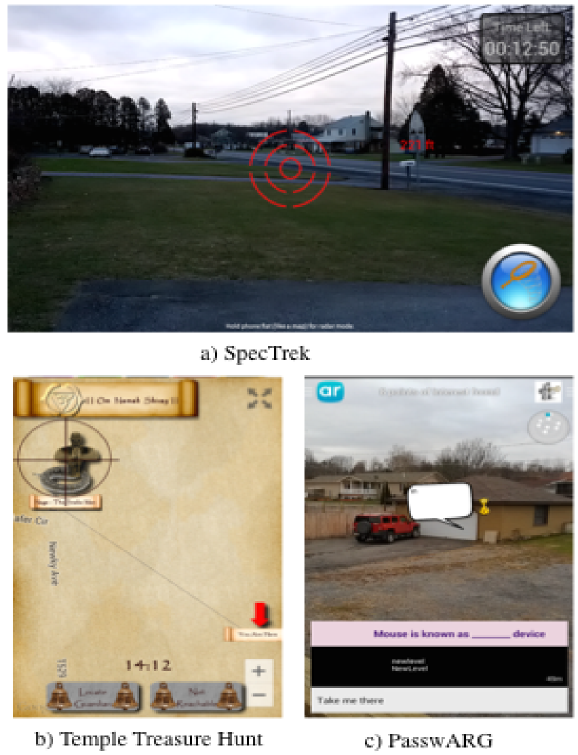


Figure 5.1: Game Screenshots

when held perpendicular to the ground. The last task of the player is to tap on the treasure; if successful, that level is over.

Table 5.1: Game Descriptions

Game	Default Play Area	Default Time	Target
Temple Treasure Hunt	500 m (approximately)	15 minutes	Find treasure guardians
Speck Trek	407 m	15 minutes	Capture as many ghosts as you can
PasswARG	450 m (approximately)	Defined by the experimenters	Find the passwords from given clue

5.3.2.3 PasswARG (PW)

PasswARG [67] is an AR game that employs the Layar reality browser [85], and can be played on iPhones and Android smartphones and tablets. The PassWARG game is based on an Easter egg hunt mechanic, where players navigate a given area to find clues held by virtual characters [64]. Players were given a sentence with a blank word in it. The answer was hidden as a form of scrambled letters. Players search for geo-located digital characters who have the scrambled letters in the form of a speech bubble. Players must physically approach a character for the clue it holds to be visible through the magic window AR. Solving the puzzle by unscrambling the letters reveals a password. A correctly-deciphered password completes the level.

5.4 Experimental Setup

5.4.1 Software Configuration

To implement the noise variation in system, we employed the Android 4.1 AOSP (Android Open Source Project) provided by Google. Because Android is open source, changes can be made to the sensor data serving components of the system. Because of the architecture of Android, this can readily be accomplished by changing a single set of method calls within the appropriate sensor classes.

Most Android smartphones or tablets are equipped with built in sensors to measure motion or location. The Android API divides sensors into three major categories: Motion, Environmental and Position. The sensor frameworks are available with classes and interfaces to allow apps to interact with sensor data. However, sensor availability varies depending on API version as well as hardware configuration [26].

Our experiments were conducted with GPS sensors. Although most of the motion sensors were defined in the `SensorManager` class, location sensors are located in the `android.location` package and becomes operational with supported hardware. `LocationManager` is the key component of location framework that provides the location determination facility. An instance of `LocationManager` needs to be requested from the system with `getSystemService(Context.LOCATION_SERVICE)` call to handle a new `LocationManager` instance. Noise is added by adding values randomly drawn from a 2D Gaussian distribution within the `getLat()` and `getLng()` method in this class. Additional lines of code which query the current noise level (standard deviation) and draw values from a zero mean Gaussian distribution with that standard deviation were added to these methods. Apps that employed the sensor then received the noise-corrupted data. Parameters for the Gaussian distribution could be adjusted through a separate app interface, which modified the parameters retrieving values from an array checked by our noise injection module at startup. This process is illustrated in Fig. 5.2.

We defined four different level of noise, determined through pilot testing and corresponding to reasonable levels of noise given the performance of GPS systems (shown in Table 6.1). Noise values as drawn and added to both latitude and longitude, generating a two dimensional noise-perturbed reading centered on the value returned from the sensor. As far as the game was concerned, the player was moving, and it attempted to render the view of the digital object with respect to the player's new apparent position. However, from the player's perspective, they know they have not moved in real space, so the re-rendering appears as motion of the digital asset.

5.4.2 Experimental Protocol

An open field experimental area was selected to minimize the potential for GPS interference. On each day participants reported to the area individually, and played one game. The order of the games was not randomized for experimental consistency, but the presentation of noise levels within the games was

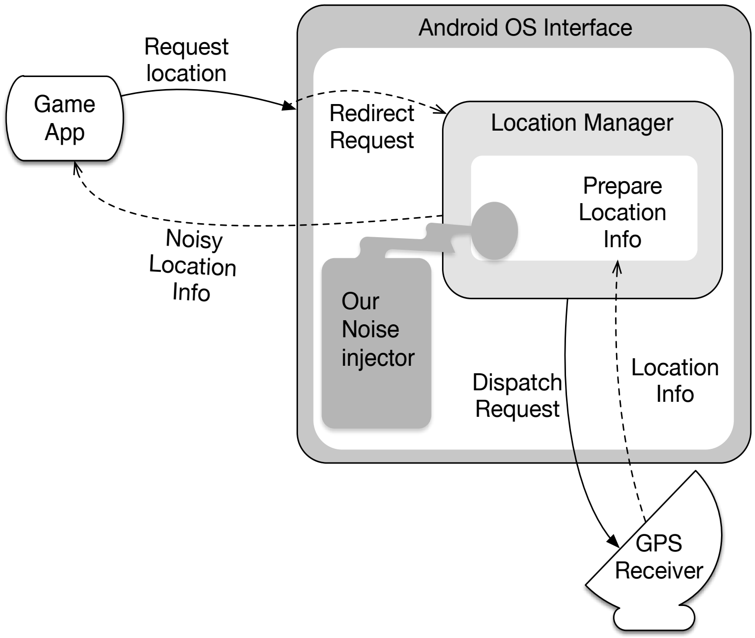
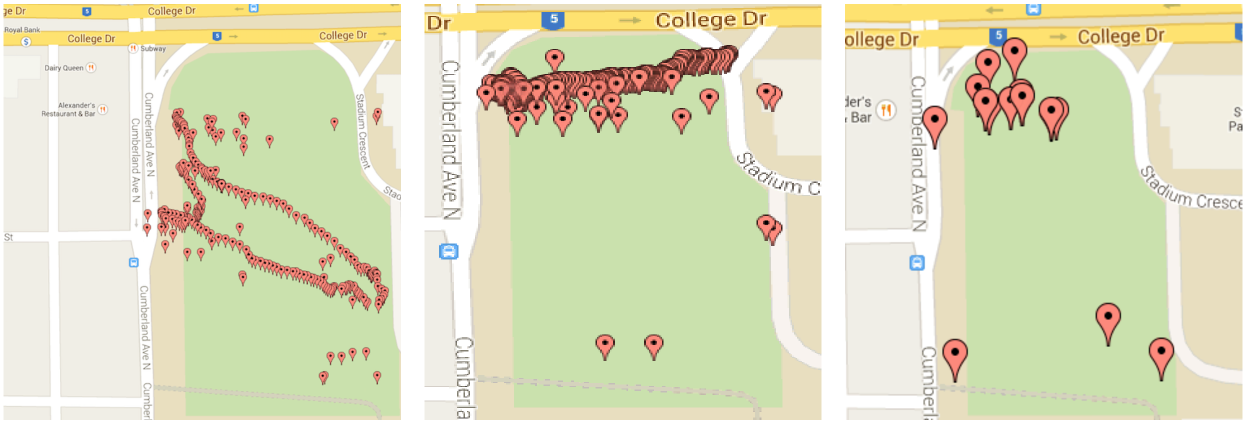


Figure 5.2: Android OS Manipulation Process

Table 5.2: Standard Deviations (σ) for Noise Levels

Level	SD(σ) in Degree	SD(σ) in Meter
None	0	0
Low	2.5^{-6}	2.77
Medium	5^{-5}	5.53
High	10^{-4}	11.07

randomized based on a Latin square design. Two rounds of 12 participants (for a total of 24) aged from 18-32 took part in the experiment. Prior to engaging in the experiment, players were briefed on the purpose of the experiment and signed informed consent forms, in keeping with the approval from our Ethics Review Board. To allow participants to familiarize themselves with the game, we provided a 5 minute learning period, for players to play the game and ask questions, prior to beginning the experiment. Each day the players were given a specific game and asked to play the same game for four times associated with four different types of noise levels for 2-3 minutes. After each experimental condition, participants completed the PANAS (Positive and Negative Affect Schedule) [60] and IMI (Intrinsic Motivation Inventory) [172] surveys, standard instruments for evaluating user experience in games. With practice sessions, play sessions, and survey completion, each game condition took approximately one hour per participant, so each participant provided a total of three hours worth of work. Players also provided a verbal ranking of difficulty level that was recorded after completing all four conditions for a single game. A demographic survey was administered on the last day of experiment. Differences between conditions were evaluated with a Friedman test.



(a) Temple Treasure Hunt **(b)** Speck Trek **(c)** PasswARG

Figure 5.3: Moving locations of Players During Game Play

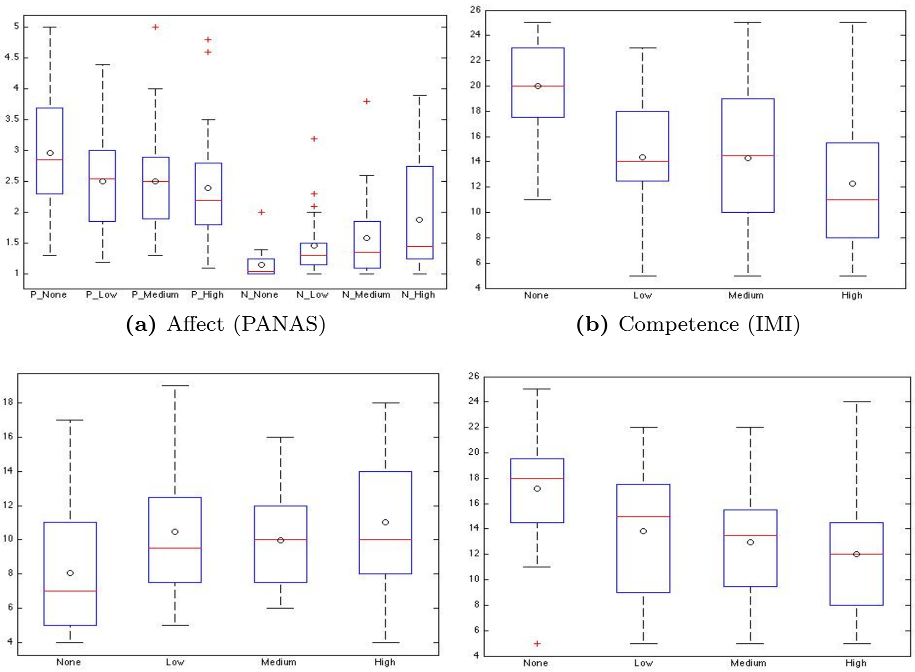
5.5 Results

Players were generally able to complete the games. Exceptions occurred in Temple Treasure Hunt when they were unable to locate the guardian and treasure. Although players occasionally expressed having difficulty with the SpecTrek because the ghosts were moving quickly, most completed successfully. PasswARG play proceeded uneventfully. Anecdotally, players were often frustrated with Temple Treasure Hunt, but were able to complete PassWARG and SpecTrek challenges, in spite of the additional noise.

Each of the phones logged player's movement during play. Since the deployment of the treasure (in TT) or ghost (in ST) was randomly generated, we were unable to make any pattern comparison with the change of noise level. Figure 5.3 shows movement patterns of play in each game without any added noise for reference.

Most parameters for both the PANAS and IMI did not show significant interactions with noise level. However, several key parameters showed interactions which explain our qualitative observations. Data were examined with the Friedman Test [182]. From IMI, the Competence and Tension/Pressure metrics displayed significant differences with noise level for some metrics. From PANAS, only Temple Treasure Hunt displayed significant interactions with noise level. Box plots showing the distributions of responses for competence, interest/enjoyment are showing in Fig. 5.4 and Fig. 5.5. Here, the whiskers and boxes represent the quartiles, the inner line represents the mode, and the mean is indicated by the small circle. Outliers are plotted as individual points (crosses) on the top and bottom of the upper and lower whiskers. The y-axis in all graphs corresponds to the unnormalized score for the labels experience critereon according to the survey instrument guidelines.

Players had a lower feeling of competence with sensor noise in Temple Treasure Hunt ($p<0.001$, $\chi^2=24.75$). Pressure varied in a complementary fashion to competence in Temple Treasure Hunt ($p=0.026, \chi^2=9.21$), with individuals feeling more pressure as noise increased. While competence playing Temple Treasure Hunt varied consistently with increasing noise, pressure increased from baseline to low and remained at that



(a) Affect (PANAS) **(b)** Competence (IMI)

(c) Tension/Pressure (IMI) **(d)** Interest/Enjoyment (IMI)

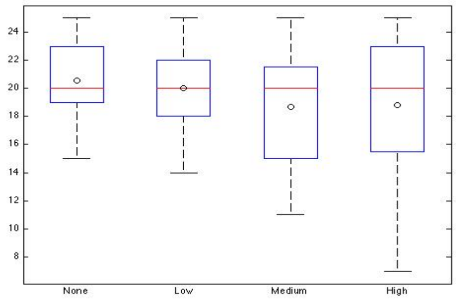
Figure 5.4: Temple Treasure Hunt Responses

value. Player's enjoyment playing Temple Treasure Hunt decayed significantly with noise, in keeping with the feelings of increased pressure and decreased enjoyment ($p<0.001, \chi^2=27.68$). If we consider the overall positive and negative play experience analyzed through PANAS, the positive experience goes down with the noise increment and the vice-versa with negative feeling. Although the average level of positive experience varies, in the case of negative feelings, the highest level of noise holds highest variance (pos:$p=0.01, \chi^2=11.31$; neg:$p<0.001$, $\chi^2=26.45$). These finding would seem to indicate that increasing sensor noise had a predictably negative effect on player experience. However, these effects are not consistent across games.

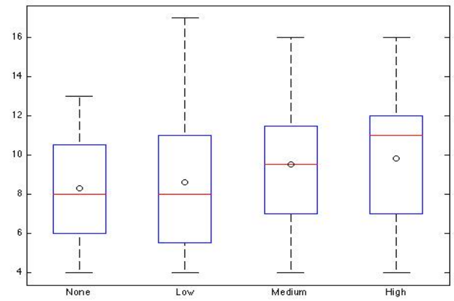
PasswARG demonstrated a minor decrease in competence with increasing noise ($p=0.05$, $\chi^2=7.68$), showing while that the manipulation had some effect, the effect size was relatively small, and the direction was inconsistent. No other significant changes in enjoyment, pressure, or any other player experience parameters were noted for PasswARG. In SpecTrek, players experienced greater pressure or tension ($p=0.028$, $\chi^2=9.12$) and exerted significantly more effort ($p=0.0065$, $\chi^2=12.27$) with higher noise levels, indicating a greater degree of challenge with no significant impact on competence or enjoyment.

5.6 Discussion and Future Work

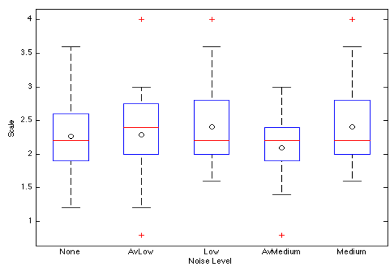
The work we have described here has two primary benefits: first it acts as a demonstration of the efficacy of using a modified operating system to examine user experience impacts on individual apps, and second it provides an initial look into the tradeoffs associated with different input modalities, game design, and narrative in magic window AR games under differing levels of sensor noise. Both of these contributions will



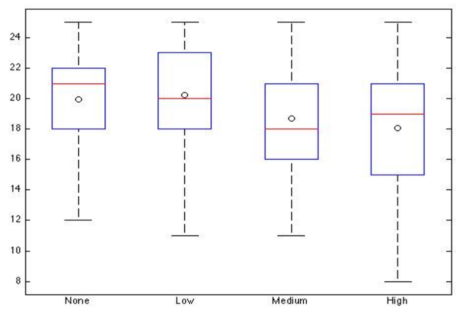
(a) ST Competence (IMI)



(b) ST Tension/Pressure (IMI)



(c) ST Effort (IMI)



(d) PW Competence (IMI)

Figure 5.5: Passwarg and SpecTrek Responses

help game designers and developers move AR gaming forward, the former by providing design insight, and the later by providing a new tool for evaluation.

The modified operating system itself is not terribly complex. Only a handful of lines of code within the operating system needed to be altered to engender this behavior; however, the overall impact could be quite significant. We can now test AR applications for their sensitivity to sensor noise disruption without having to create those apps ourselves. Commercial games, with established play experience and professional design can now be used as a testbed, allowing games researchers to be more certain that effects are due to the manipulation and not the game. This approach also permits testing a wider variety of game designs and interaction techniques, as new games do not have to be built each time. While our work has focussed on game experience, the system could be used to probe user experience with any number of AR apps in conjunction with sensor noise. Again, the apps can be commercial packages sourced from an App store. By employing PassWARG as a testbed we have demonstrated this is feasible, as it rests atop Layar, a commercial reality browser used for a number of purposes outside of gaming.

Our findings from the user study demonstrated that the players felt that the treasure hunt game was the most sensitive to noise. Participants expressed frustration that they could not complete the game because the final selection task of picking up the treasure became tedious and difficult as noise increased. Little impact was observed for the clue finding game, most likely because the clue could be read quickly by most participants before the noisy signal moved it off screen in all but the highest noise condition. Contrary to our initial intuition, the ghost hunting game, where target selection is the primary game mechanic, had a user experience that was far less susceptible to the introduction of noise in the signal. In a sense, the ghost games primary mechanic was a repeated selection task; the same task that caused frustration within the treasure hunting game. While some of this might be due to geometry (players could target the ghost from farther away than the treasure, subtending a smaller angular displacement on screen), other effects also are likely at play.

Authors have recently proposed that people play computer games to engender a feeling of competence [163]. This model of user experience in games fits well with our results. When playing the treasure-hunting game, the final step of the game is picking up the treasure should be a trivial exercise, as the narrative and structure of the game privilege finding the treasure in the first place. Having obtained a feeling of competence from locating the treasure, players are then denied the satisfaction of completing the game by what appears to be a glitchy interface. On the other hand, having the ghost in the ghost hunting game moving randomly with the sensor error provides the appearance to the player of a more difficult to capture ghost. Completing a more difficult challenge, tends to lead to a greater feeling of accomplishment as a simple smaller scale test, our system can uncover unintuitive interactions between sensor error and design, providing support for the utility of the technology and approach.

As a guideline, game designers should be encouraged to incorporate sensor error into the design of their games by minimizing the number of digital objects that are logically rigidly anchored to the real world. This will allow for compelling AR games to be built without the potential for frustration. In a sense, this is an application of seamful design [48], where the shortcoming of a sensor medium is used as a game feature or mechanic. Specifically, for aiming games, selection tasks should, if possible, be made on objects which are plausibly mobile, aiding in the suspension of disbelief for players when noise induced movement is observed.

While this work has made a significant contribution to the study of AR games, it does have some shortcomings. The study group was modest, and biased towards university students. A broader demographic should be tested to understand if these trends generalize. Secondly, we only tested the sensitivity to GPS error. Additional work testing the system with other sensor modalities such as orientation will be undertaken. Finally, we only tested single player games. Multiplayer games are much more likely to be sensitive to sensor error, as players must agree where objects are in the real world. A multiplayer study should be undertaken in the future.

5.7 Conclusion

In this paper, we have presented a novel approach for investigating the sensitivity user experience of different AR games to noisy sensor input. By modifying the sensor services in the operating system to provide structured noise disruptions, we were able to test commercial games not designed with experiments in mind. After performing a user study over three AR games employing GPS as a primary input, we found that game design, narrative and interaction technique all contribute to the sensitivity of user experience on noise. Based on our findings, AR games which can provide feelings of competence in the face of variable noise are likely to more successful than those that do not. In the future we intend to investigate new games, sensors and demographics to understand the generalizability of these findings.

Chapter 6

Manuscript 4:

Title: Player Experience in Augmented Reality Outdoor Games of Different Noise Models

Submitted To: Journal of Entertainment Computing Elsevier

Citation: Eishita, Farjana, and Kevin Stanley. "Player Experience in Augmented Reality Outdoor Games of Different Noise Models." Journal of Entertainment Computing Elsevier., Under review.

Author's Contribution: The research presented in this manuscript is my own, conducted under the supervision of Dr. Kevin G. Stanley. Ideas and techniques that are not products of my own work are duly cited, or, in cases where citations are not available, are presented using language that indicates they existed prior to this work.

Summary: Augmented reality gaming is leaving the lab and entering the general population with a combination of high-end headsets from the likes of Microsoft and Facebook, and magic window AR games for commodity smartphones like Pokemon Go. Unlike traditional video games, AR games must solve the registration problem to map objects in the real world to the screen via the camera. Sensors are typically employed to provide the real world pose of the physical camera. However, like all sensors, the location and orientation sensors are subject to noise processes. While the interaction between noise processes and player enjoyment has been studied in networked games, limited work has been done examining the impact of sensor noise on player enjoyment in AR games, and that work has been largely confined to simple noise models. In this paper, we present an empirical analysis of the impact on location based AR games of GPS noise on player experience. Our analysis shows that different games are impacted differently by noise. Multimodal noise processes can have a lower impact on player experience than equivalent unimodal processes, when players can time their interactions.

Relationship to the thesis: Previous contributions in this thesis have examined unimodal noise models. This paper further generalizes those findings for more complex and variable noise models. This manuscript shows the players' sensitivity upon the different QoS level of the sensors particularly for location-based AR games of different genres under different kinds of noise models. This paper contributes to the central research question by identifying the criteria that impacts the PX and their variation under two different types of noise models - the Zero-mean Gaussian Noise Model (ZMGN) and Sequential Noise Model (SNM) while playing different kinds of location-based AR games. This contribution is significant because the differential impact of noise on user experience not only depends on noise level and game genre but also on noise structure. Moreover, the differential impact of noise on user experience is important as it indicates that proper design decisions can be used to ameliorate or mask sensor noise issues by leveraging the structure if the noise itself.

The findings demonstrate differential impacts which can be leveraged for effective guidelines to confront sensor noise. Also, the findings provide a useful guideline while making such decisions about sensor resolution requirements for this particular genre of location-based AR games. Additionally, this manuscript contains the most complete description of the technique used to design different types of sensor noise and inject it in any game, which is the primary technical and methodological contribution of the thesis.

Experimental Analysis: The research question about this experiment was - "Does noise structure differentially impact PX while playing location-based AR games?". The primary goal of this experiment is to distinguish the differential impact of sensor QoS in AR games under different kinds of sensor noise models. PX in location-based magic window AR games depends on prayers' overall positive or negative instinct to play a particular game. In addition, PX can be explained with players' intrinsic motivation of cognitive gameplay. To investigate that the standard IMI factors - interest/enjoyment, competence, tension/pressure and efforts were incorporated as dependent variables. By analyzing these IMI factors, players' autonomous behavior towards gameplay under different levels of sensor QoS consisting both ZMGN and SNM was examined which ties the outcome with the research question of this experiment.

Our experimental design used five conditions of noise levels and three Games as the independent variables. The noise was injected into device's GPS sensor. To analyze the PX, dependent variables were derived from the standard psychology surveys PANAS (Positive And Negative Analysis Surveys) and IMI (Intrinsic Motivation Inventory). PANAS allowed us to investigate the variation of experience in terms of positivity and negativity. Through IMI, players' interest/enjoyment, competence, tension/pressure and effort were recorded. The experiment was designed to look for main effect of Noise Structure and Game Genre on Player Experience, and to look for interactions between Noise Structure and Game Genre. The scale of Noise Level is ordinal and included four experimental groups - Low, AverageLow, Medium and AverageMedium - and a control group where measurement was made without artificially added noise. Bonferroni post-hoc analysis was applied. We employed repeated measures MANOVA followed by pairwise comparisons to compare results between groups.

Relationship with the taxonomy: This experiment demonstrates the PX sensitivity of playing location-based AR games under two different input sensor noise models. Because location-based AR games use GPS as their primary sensor to detect location or Earth we injected noise of of both kinds (e.g. ZMGN and SNM) to both latitude and longitude parameters of the GPS readings. To perform the comparison, the games chosen for this experiment were the same as those used in the experiment described in manuscript 3 - SpecTrek (group: Outdoor Aiming), Temple Treasure Hunt (group: Outliers) and PasswARG (group: Outdoor Explorer) (described in 2.2). Although all three games are location-based AR games, due to their different game mechanics and play techniques, the spatio-temporal requirement varies.

The experimental outcome demonstrated significant sensitivity in PX with the variation of noise while playing Temple Treasure Hunt and the least variance was observed while playing PasswARG. According to the taxonomy, the games in Outdoor explorer group demand a medium level of location accuracy and precision to keep the game playable. Our experimental result reflects analogous behavior to the taxonomy as PX did not have significant differential impact with the variation of standard deviation of noise in GPS. With a high sensitivity to location accuracy and precision requirement, scenario could be different (e.g.Temple Treasure Hunt). Because this game demands a high spatial accuracy as well as precision, negative play experience was increased with the presence of noise. The taxonomy describes that outdoor aiming games such as SpecTrek also require high location accuracy but the game remains playable at moderate precision. Our experimental outcome reflects that, although, noise caused negative play experience, players' feelings of competence was increased.

Game Input Technique: This is a generalization experiment of manuscript 3. Hence, the same two commercial games and one research location-based AR games were used in this experiment. The game mechanic is as follows -

- **SpecTreck:** The players need to find digital ghosts anchored on real-world positions. After the game initiates, 3-5 ghosts around the player's location appears on the map. When looking through the camera towards the particular direction, the ghosts appear on screen. The size of the ghost increases as players walk closer to it. To catch the ghosts, when players reach within 100 meter of radius, the reticule located at the center of the screen turns green from red indicating that the ghosts are catchable. Then the players need to tap a button located at the bottom right of the screen making sure the reticule is placed on top the the digital ghost.
- **Temple Treasure Hunt:** Only one treasure in one particular level is loaded every time the game is initiated. The location of the treasure can be viewed through the map mode. Once the player reaches around approximately 5 meter of the physically anchored treasure, the camera view is loaded and the treasure appears onto the screen. Then the player needs to tap on the treasure to capture it. If the player is not within necessary proximity, the augmented view is not initiated.
- **PasswARG:** This is a strict location based games where players need to only look at the digital artifacts providing letter clues to unveil the password. The characters are loaded on screen when the game is initiated and necessary clue is provided at the bottom of the screen.

6.1 Introduction

Augmented Reality (AR) is a technology where digital artifacts are superimposed on a real world view to provide a more engaging, useful, or enjoyable merging of the digital and real. With the advent of high-end consumer technologies such as Microsoft's Hololens, or the Occulus Rift, and with compelling titles like Pokemon Go available for commodity handsets, AR technology and games are poised for mainstream adoption. Based on the success of early entrants into the space, entertainment and game companies will likely look to expand their offerings to include AR titles for both high and low end systems. However, the technology underlying AR requires several techniques that are not broadly understood in industry and have not been fully studied in academia.

At the center of the AR input stack is the requirement to solve the registration problem, a canonical problem in computer vision and robotics, where the coordinates of an object in digital space (as a rendering or model) must be mapped to real physical coordinates or vice-versa. For AR games in particular, the position and orientation of the phone's camera must be measured and translated into virtual coordinates so that digital artifacts can be appropriately rendered. In AR games, the physical camera or cameras replace the virtual cameras more familiar to game developers. If the locations of all cameras in both physical and virtual space are known, then digital objects can be rendered according to camera transforms. To determine the six degree of freedom (x, y, z, yaw, pitch, roll) pose of the camera, a suite of sensors is typically employed.

Built-in sensors available on mainstream commercial devices are subject to noise disruption leading to potentially erroneous mappings between the real and virtual environments. While experiences in other genres, for example, on-line first person shooters, has demonstrated some degree of player tolerance for inconsistencies in position mapping, such as jittering players due to lag, at some point the introduction of noise degrades player experience [164]. For AR games, accurate pose estimation is vital as Player Experience (PX) is the primary outcome of any video game. Understanding the degree to which noise impacts experience, how different types of noise impact experience, and how different mechanics are more or less susceptible to this sensor noise would be beneficial to game developers and designers.

Game designers have proven themselves skilled in hiding the limitations of input devices ranging from traditional controllers to more sophisticated motion capture systems like the Kinect. However, absent guidance on the degree and magnitude of sensor noise impacts on player experience, designers are forced to adopt a risky and expensive trial and error approach.

Although a handful of papers have been published on this issue, they were limited to simple zero mean Gaussian noise models [66] [63] [65]. While this noise model is appropriate for some sensors such as accelerometers, other sensors such as GPS, can have patterned noise (e.g. white noise or colored noise) due to atmospheric conditions, and may be disrupted by naturally occurring interference such as buildings, trees, or geographical features.

Because sensors such as GPS can have different patterned noise triggered by various factors [109], in this experiment, we intended to investigate the impact of PX under different patterned noise models containing different scales of noise while playing location-based AR games that use GPS as the location sensor. Our primary objective was to analyze PX while playing games interrupted different patterned GPS sensor noise model with same variance. With the developed noise models, controlled experiments were conducted and performance data was collected. With an anticipation of exploring divergent players' behavior, we applied repeated-measure MANOVA (Multivariate Analysis Of Variance) on the collected data.

In this paper, we have developed two noise models: a unimodal Zero Mean Gaussian Noise Model (ZMGNM) - a canonical model in sensor systems and a multimodal noise process generated from a Sequential Noise Model (SNM). By conducting controlled experiment, we compared the impact of different noise models on player experience for games featuring different inputs and narratives. By modifying the operating system, we can deploy any publicly available AR game as a potential experimental testbed, dramatically decreasing the development overhead. Furthermore, we are able to ensure that the games tested are of commercial quality, as they can be downloaded directly from the Android store. By conducting a controlled experiment with two commercial and one academic AR game – all of which employ GPS location as their primary game input – we demonstrated that different noise models can impact the location-based AR games with different input in different ways. Based on the final outcomes, guidance for the AR game development community and other researchers in this arena are provided.

6.2 Literature Review

Video games are a logical application of AR, as blending fantasy and reality has been a goal of game designers for many years. AR games have been the subject to academic research and commercial development. We provide a thorough background on the academic games and a brief overview of relevant commercial games here for completeness.

6.2.1 Research Games

Early work in AR games focused on understanding how technology could be leveraged for different play or educational experiences. ARQuake [190] was the first location based AR game that used GPS, digital compass, and fiducial vision-based tracking to convert the desktop version of Quake to a mobile AR game, played with a laptop, haptic gun, and an HMD (Head Mounted Display). AR characters were deployed using ARToolkit [70]. Similar to ARQuake, Human Pacman [58] is a location based AR game, focused on collaboration among the team members in a virtual 'Pac-World'. Epidemic Menace [117] is a cross media game with several different interfaces such as game board station, a mobile assistant and augmented reality. Players must find a virus that is spread by an evil scientist. TimeWarp is played outside [83] where the virtual characters passively provide information and do not demand any player interaction. Mad City Mystery [187] establishes the idea of learning through location-based AR games. While technical limitation were noted in many of these works, explicitly characterization of the impact of input degradation on player experience was not addressed.

A body of more recent work has focused on AR tagging of locations for educational or artistic purposes. Donald Richardson explored the potential of a location-based AR game as a language learning tool [168]. Koutromanos and Styliaras introduced a location-based AR game - 'The Buildings Speak About Our City' that was specially designed for primary school children [106]. Arkenson et. al. introduced a location-based game 'Tag and Seek' that acts as a traveller's guide in Titan City of Taiwan using Near Field Communication (NFC) tags [29]. 'Street Art Gangs' is a hybrid pervasive location-based game played with a mobile phone app, allowing gangs of competing players to tag geo-locations [24]. The design and evaluation of storytelling location-based game 'GEMS' is demonstrated by Procyk and Neustaedter [162]. The players receive prompts from game narrative from their former activities and a geolocated digital memory is created visitable by the other players. Typically these games focus on educational outcomes and take input performance as given.

Other researchers have investigated the role of AR in other educational experiences. Casual adventure game Energy Saving [52] scaffolds player awareness on reducing energy use. GARLIS [197] (Game-based Augmented Reality Library Instruction System) provides for AR interaction within in a real world library. The game play centers on a character who provides information regarding the Chinese library classification scheme. The Table Mystery [46] is a collaborative AR game for exploring chemistry, where each group in the game receives instructions from character with amnesia. GenVirtual [76] is an educational musical AR game designed for people with learning disabilities. Burke et. al. described three aspects of AR games (meaningful play, challenge and conservative handling of failure) for limb-stroke rehabilitation named Shelf Stack [53].

Researchers have investigated how novel or newly commoditized technologies can create new experiences. Technologies such as smart phones, table top display and virtual realty headset (e.g. Oculus Rift, Microsoft Hololens, Google Glass) have enhanced AR gaming research research variants. The potential of touch-less approach in AR games has been explored by Zhihan et. al. where Google Glass was employed [122]. Table-top AR games usually depend on fiducial markers for AR rendering. Lee et. al. [113] presented the augmented reality squash game using 'estimated geometric information of images' taken using a stationary camera. The game AR2Hockey (AR AiR Hockey) [146] is a collaborative real time AR game demanding both high fidelity and high response rate from the input sensors. Like ARSquash, AR Tennis [82] is a face to face collaborative AR game. Using 3D sound as an effective parameter, Chatzidimitris et. al. introduced a location-based game 'SoundPacman' that conveys game information with engaging gaming experiences [57].

6.2.2 Commercial Games

As is common in the games, industrial research and development has driven innovation. Niantic in particular has published location-based AR games of note. In Pokemon Go [17] real locations on Earth contain Pokemon. Once a Pokemon is found a simple orientation-only AR minigame is instantiated, allowing the player to catch the Pokemon. In Ingress [142] the geo-based competition is primarily between the two cliques rather than between individual players.

Most other commercial AR games are based on stationary aiming mechanics. Sky Siege [96] is an AR shooter game played with iPhone. The player's goal is to shoot virtual helicopters and earn points. Star Wars Arcade: Falcon Gunner [28] is a similar game with TIE Fighters instead of helicopters. DroidShooting [126] is a shooting game made for Android Platform, where the player shoots waves of virtual android robots. In AR Invaders [90] and Dimension Invaders [165] the player shoots virtual spaceships. All of these games employ sensors to determine the orientation of the screen for aiming. Skeeter Beater [157] is a casual game demanding lower aiming accuracy. The players need to kill the mosquitoes by locating them with the camera, then tapping. ARSoccer [92] and AR Basketball [89] are simple casual AR games inspired by popular sports.

6.2.3 GPS Performance

Accuracy and precision are the most commonly used terms to describe GPS measurement quality. Accuracy is expressed through Distance Root Mean Squared (DRMS), Circular Error Probability (CEP) and R95 [11], and corresponds to how closely the sensed signal matches the position in the real world. Moen et. al. described telemetry collar that uses GPS readings to locate animals and demonstrated that at least 50% of locations are expected to be within 40 meters in uncorrected mode GPS, and within 5 five meters in differential mode GPS under an ideal scenario. However, the frequency of reliability of location readings decreased under interruptions such as within a forest canopy. The authors calculated both the uncorrected and differential mode and compared the precision [134]. GPS signal structure was discussed by Spiker, who demonstrated that if the Root Mean Squared (RMS) position error is less than 10 meters, a better performance is achievable [184]. Langley discussed different kinds of GPS receiver noise including thermal noise, antenna noise, and system noise [109].

6.2.4 Player Experience

Most research on the impact of noise processes on player experience have focused packet jitter in networked games. Player experience has been shown to be impacted by this noise. Anastasia et al. investigated how network delay affects player experience in cooperative games when interaction with shared objects are required during gameplay. The authors demonstrated that delays over 100 ms significantly decrease player performance and jitter negatively affects user performance [39]. Henderson and Bhatti noted that in spite of lower QoS, networked games are popular [80]. The authors performed an experiment to examine players' tolerance towards the QoS and showed network delay affects player's decision to join a game server. Aline et. al. investigated the impact of latency and jitter upon players' frustration, enjoyment, performance and experience [143]. Their findings demonstrated that constant play is not impacted until 300ms of delay (no jitter) although with an addition of jitter to a delay of 200ms, players' experience was affected.

A more limited body of work has highlighted the impact of noise on AR games. Lochrie et al. explored the challenges restricting the wide scale adoption of augmented mixed reality games due to sensor error [119].

The authors identified low quality of augmentation as the main factor affecting location-based AR gameplay experience. Later, they proposed an iterative design approach to improve the play experience of such games. Eishita and Stanley have experimentally explored the impact of sensor noise in AR games from a number of perspectives [66] [63] [65].

6.3 Methodology

In this work, we wish to replicate the earlier experiments described in [63], but employing a more nuanced noise model. To test the impact of the more sophisticated noise model, we ran similar experiments to [63] and used the same modified Android system and games as a test platform. Each of these games employs a simple location based mechanic, where GPS and orientation sensors are used to determine the pose of the phone in space; however, only the GPS location was corrupted by artificial noise. Each of these experimental apparatuses are outlined in the following sections.

6.3.1 Noise Model

To compare the outcome of PX under different noise models, two models were developed - Zero Mean Gaussian Noise Model (ZMGNM) and Sequential Noise Model (SNM).The ZMGNM is similar to those reported in [67] [64] [66] [63]. ZMGNM is an appealing unimodal noise model, as multiple random noise processes tend to sum to a Gaussian distribution according to the Central Limit Theorem, at least to a first approximation, and because as a zero mean additive process, the original signal can be represented by the mean of the corrupted signal. Four different levels (None, Low, Medium and High) are defined in this model based on different standard deviation (described in table 6.1). The procedure to define the numeral value of the standard deviation of different levels is described in experimental detail.

However, some sensors, such as GPS, are not always well characterized by zero mean Gaussian distribution. In fact, the noise characteristics of GPS can vary depending on the proximity to buildings, natural formations (e.g. canyons or mountains) or even the weather. In these cases, the noise itself might still converge toward a Gaussian distribution, but with a different variance than in the case where a user is standing in the open. In geo-science the most common noise models for GPS are White Noise and Colored Noise, including Flicker Noise [124]. White noise is random signal with samples uncorrelated in time (zero mean), similar to our ZMGNM. Colored noise is defined as a random signal with samples that are correlated in time - that is the current noise level depends on the history of noise levels [124].

The simplest model for time dependence is a Markov chain model. In a Markov chain, the model is represented as a sequence of discrete states (in this particular case, each state is a zero mean Gaussian with a given variance), and the probability of moving between those states. When in a state, the model emits a value drawn from the distribution associated with that state. As aforementioned, our system has four independent states of ZMGNM - None, Low, Medium and High - distinguished by increasing variance, shown in figure 6.1. We introduced a multimodal Sequential Noise Model (SNM) which is a noise model that moves between ZMGNM of different variance. For ZMGNM, a single zero mean Gaussian distribution with the defined variance was employed with a unimodal structure. For the multimodal SNM noise levels, each individual state consisted of a single Gaussian with the same variance as the individual level of the ZMGNM – that is, the Low noise state in the Markov chain is a Gaussian with the same mean (zero) and variance as the single distribution used in the Low ZMGNM condition.

Altogether we defined five different conditions for the experiment as follows -

- None – no noise; as a control
- Low and Medium levels of ZMGN
- AverageLow and AverageMedium levels of SNM (the mean variance of the SNM condition equaled the mean variance of either the Low or Medium noise ZMGNM); described in figure 6.2.

In the None condition, no noise is added to the signal, acting as a control. In other conditions, noise values were drawn and added to both latitude and longitude, generating a two dimensional noise-perturbed reading centered on the value returned from the sensor. Because both the models consist of zero mean noise, the average GPS accuracy is not impacted, but the precision of sensed position is perturbed by increasing offsets in the low, medium, and high noise levels. As far as the game engine was concerned, the artificial noise led to a false indication that the player was moving and it attempted to render the view of the digital object with respect to the player's new apparent position. However, from the player's perspective, having not actually moved in real space, the re-rendering appears as motion of the digital asset. To keep our observational data comparable, we deployed the same standard deviations used in [63], shown in Table 6.1. The standard deviation chosen (through informal testing) for three different noise levels (low, medium, and high) have average values comparable to the variance observed in empirical GPS values in [149]. The standard deviation of each noise condition was calibrated through pilot testing, such that the game was always playable even at the highest noise levels. Several pilot tests were conducted to identify the highest amount of noise variance that could be added to the location signal before the game became unplayable and this noise level became the variance for the High noise level condition. The Medium noise and Low noise conditions were defined as half and one quarter of the High noise standard deviation respectively.

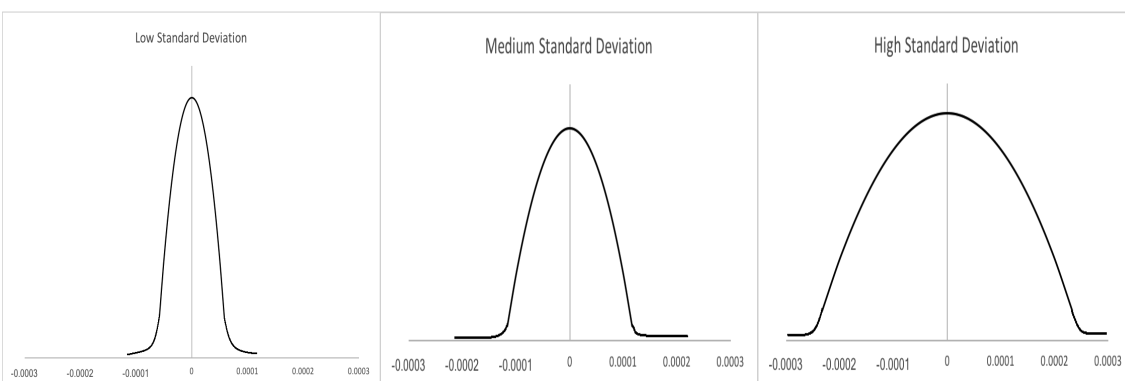
Because GPS positioning accuracy is achievable to up to 10 meters on commodity devices [184], we wanted to keep the highest noise close to that boundary as our goal was to keep the game playable. The standard deviations in medium and low levels were reduced to half. If compared with practical scenario, the high noise resembles with the noise that may appear receiving signal while passing through an area with tall buildings. The medium level noise may appear under an area with large trees and finally the low level noise could be an environmental interruption such as bad weather. However, an open field experimental area was selected to minimize the potential for natural GPS interference.

Table 6.1: Standard Deviations (σ) for Noise Levels

Level	**SD(σ) in Degree**	**SD(σ) in Meter**
None	0	0
Low	2.5 x 10^{-5}	2.77
Medium	5 x 10^{-5}	5.53
High	10 x 10^{-4}	11.07

Table 6.2: Transition Probability of Noise Levels in SNM

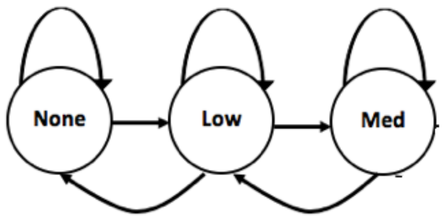
From	**To**		
	Low	Medium	High
Low	0.5	0.5	0
Medium	0.33	0.33	0.33
High	0	0.5	0.5



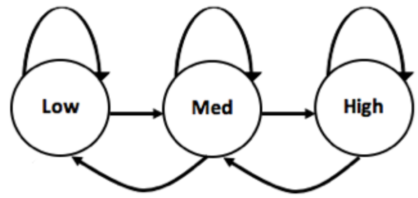
(a) Low **(b)** Medium **(c)** High

Figure 6.1: Noise distribution of Low, Medium, and High Standard Deviation

At every iteration the SNM model randomly draws a transition (including self transition) between the different possible states. That is, the model can transition from a low noise to no noise, low noise or medium noise, but not directly from low noise to high noise, as shown in Figure 6.2.



(a) AverageLow



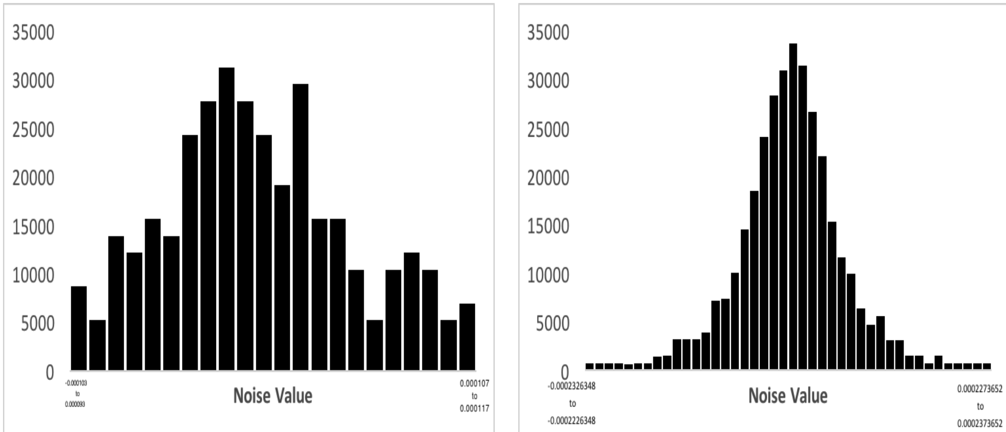
(b) AverageMedium

Figure 6.2: Sequence of AverageLow and AverageMed levels of SNM

For consistency of comparison between the two noise models, we set transitions probabilities, such that averaged over a sufficient number of samples, the mean variance of the SNM condition approximated the mean variance of either the Low or Medium noise variance ZMGNM. Players would have experienced the same average precision in AverageLow as Low and AverageMedium as Medium, allowing some degree of consistency during comparisons. Because the SNM can enter states where it is more likely to draw larger noise-based offsets (e.g. from the High Noise distribution), correspondingly more draws must be made from the Low noise model to compensate. This behaviour leads the SNM to have lower noise offsets in general, punctuated by periods of larger disruptions as opposed to a similarly-valued ZMGNM which is characterized by a sequence of more consistent moderate noise levels. Figure 6.1 shows the standard deviation format used in the noise levels. Figure 6.3 and 6.4 demonstrates the histogram and time series (respectively) of both noise models. Transition probabilities for the tested model are shown in Table 6.2.

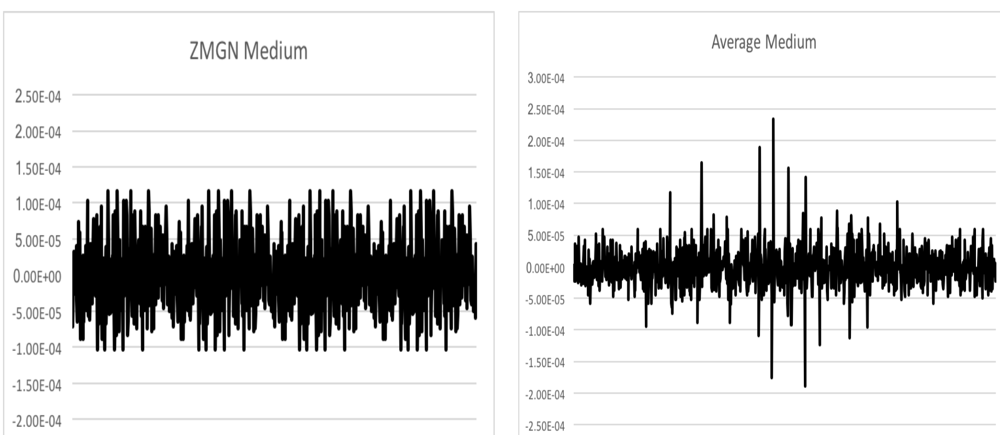
6.3.2 Game Description

Because this experiment is based on the methodology in [63], we chose the same games as an evaluation testbed. Three games were chosen for this experiment. While many AR games exist on the Google App store, only a few use GPS as input (orientation is much more common) and fewer still have sufficient stability and user interaction to warrant testing. After eliminating unsuitable games, we chose two commercial AR games with similar mechanics, but different design, a ghost hunting game and a treasure hunting game. We included an academic edugame based on an Easter egg hunt mechanic as the third game, giving us three games centered on finding a digitally tagged location, but with different interaction mechanics and narrative. The selected games are briefly described in the following subsections. Screen shots of each game are shown in Fig. 6.5.



(a) ZMGNM **(b)** SNM

Figure 6.3: Histogram of ZMGNM with medium standard deviation and SNM of average medium noise distribution



(a) ZMGNM **(b)** SNM

Figure 6.4: Time series of ZMGNM with medium standard deviation and SNM of average medium noise distribution

6.3.2.1 SpecTrek (ST)

SpecTrek is a casual AR game where players hunt for digital ghosts in a given area. At the beginning, a circular play area is defined by selecting a radius. We employed the lowest radius (467 meters). A number of ghosts (from 3-5, default 3) are randomly placed within the play area and can be located through the map as points of interest (POI). A map interface is visible when the phone is held parallel to the ground. To find the ghosts through camera, the player must hold the phone perpendicular to the ground, as if taking a picture, in the direction indicated on the map. If pointed in the right direction, the digital ghost is displayed. The size of the ghost depends on the distance of the player from the ghost. To catch the ghosts, the players must walk towards the ghost holding the phone in hand. When the player is within 175 meters of the ghost's location, the ghost can be caught by aiming the reticule at the ghost and tapping the net located on bottom right corner of the screen.

6.3.2.2 Temple Treasure Hunt (TT)

Temple Treasure Hunt is a scavenger hunt game where players hunt for virtual treasure located at points in the physical world. Similar to SpecTrek, players need to walk towards a POI displayed on a map, visible while the device is held parallel to the ground. Unlike SpecTrek, the digital avatar is not loaded until the player reaches the position of the treasure. Once the label of player's location and treasure matches (demanding higher precision), the the digital character is loaded and visible through the AR interface, when held perpendicular to the ground. The last task of the player is to tap on the treasure, completing the level.

6.3.2.3 PasswARG (PW)

PasswARG [67] is an AR game that employs the Layar reality browser [85] and can be played on iPhones and Android smartphones and tablets. The PassWARG game is based on an Easter egg hunt mechanic, where players navigate a given area to find clues held by virtual characters [64]. Players were given a sentence with a blank word in it. The answer was hidden as a form of scrambled letters. Players search for geo-located digital characters who have the scrambled letters in the form of speech bubbles. Players must physically approach a character for the clue it holds to be visible through the magic window AR. Solving the puzzle by unscrambling the letters reveals a password. A correctly-deciphered password completes the level.

Table 6.3: Game Descriptions

Game	**Play Area**	**Time**	**Target**
Temple Treasure Hunt	500 m	15 minutes	Find treasure guardians
Speck Trek	407 m	15 minutes	Capture ghosts
PasswARG	450 m	Customized	Find the passwords

PasswARG SpecTrek Temple Treasure Hunt

Figure 6.5: Game Screenshots

6.4 Experimental Setup

6.4.1 Software Configuration

To implement the noise variation in system, we employed the Android 4.1 AOSP (Android Open Source Project) provided by Google. Because Android is open source, changes can be made to the sensor data serving components of the system. Because of the architecture of Android, this can readily be accomplished by changing a single set of method calls within the appropriate sensor classes. Most Android smartphones or tablets are equipped with built in sensors to measure motion or location. The Android API divides sensors into three major categories: Motion, Environmental and Position. The sensor frameworks are available with classes and interfaces to allow apps to interact with sensor data. However, sensor availability varies depending on API version as well as hardware configuration [26]. This system was initially described in [63].

Our experiments were conducted using GPS sensors. Although most of the motion sensors were defined in the `SensorManager` class, location sensors are located in the `android.location` package and become operational with supported hardware. `LocationManager` is the key component of the location framework. An instance of `LocationManager` needs to be requested from the system with `getSystemService(Context.LOCATION_SERVICE)` call to handle a new instance of `LocationManager`. Noise is added by adding values randomly drawn from as described above within the `getLat()` and `getLng()` method in this class. Apps that employed the sensor then received the noise-corrupted data. Parameters for the Gaussian distribution could be adjusted through a separate app interface, which modified the parameters retrieving values from an array checked by our noise injection module at startup. This process is illustrated in Fig.6.6.

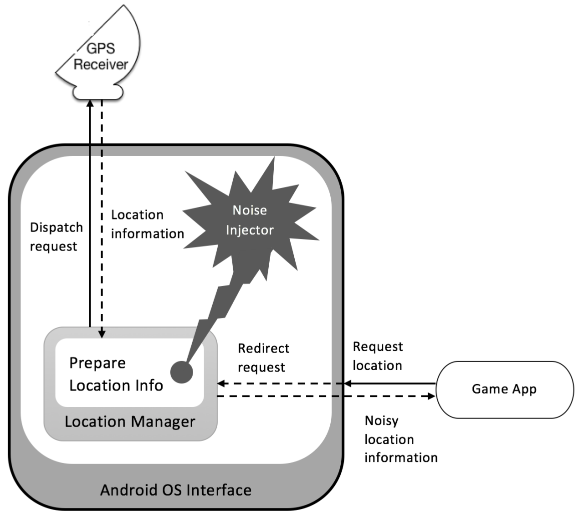


Figure 6.6: Android OS Manipulation Process

6.4.2 Participant Detail and Procedure

Participants were required to report to the same area individually and play the games under all four noise levels and the no noise control. The order of games were constant but the order of noise levels within the games was randomized based on a Latin square design. Two rounds of 15 participants (for a total of 30) aged 22-36 took part in the experiment. Prior to engaging in the experiment, players were briefed on the purpose of the experiment and signed informed consent forms, in keeping with the approval from our Ethics Review Board. To allow participants to familiarize themselves with the game, we provided a 2-3 minute learning period for players to play the game and ask questions, prior to beginning the experiment. Each play session was limited to 2-3 minutes. For the SNM levels (AverageLow and Average-Med), the transition from the previous state occurred randomly in every 5, 10, and 15 seconds and therefore, 2-3 minutes of gameplay provided 4-20 state transitions.

After each experimental condition, participants completed the PANAS (Positive and Negative Affect Schedule) [60] and IMI (Intrinsic Motivation Inventory) [172] surveys, standard instruments for evaluating user experience in games. Both IMI and PANAS have been used previously to evaluate PX in game research [43][42][41][171][44][47]. With practice sessions, play sessions, and survey completion, each game condition took approximately one and a half hours per participant. A demographic survey was administered on the last day of the experiment.

6.4.3 Design and Research Question

We wished to investigate the interaction of the two factors (game and noise levels) with PX. Our objective was to analyze whether the PX varies based on the noise levels or noise type for different kinds of location-based AR games. A repeated-measure MANOVA was used to compare the main effects of Game and Noise

Levels and the interaction effect between the Game type and Noise Level on players' positive and negative experiences and intrinsic motivation.The two independent variables were Game and Noise Levels. The factor Game has categorical data with three different kinds of location-based AR games (SpecTrek, Temple Treasure Hunt and PasswARG) and Noise Level had five different ordinal levels (None, Low, AverageLow, Medium, and AverageMed) as conditions.

The dependent variables included Positive and Negative Experiences, Interest-Enjoyment, Competence, Effort and Tension-Pressure. The data type of Noise Level was ordinal and included four experimental groups - Low, AverageLow, Medium and AverageMedium - and a control group where measurement was made without artificially added noise. All effects were were considered to be statistically significant. Bonferroni correction was applied to adjust the value of the confidence interval. Later, pairwise comparisons were performed to compare results between groups.

6.5 Results

Qualitatively, players completed all the games in all noise conditions except for Temple Treasure Hunt where they had difficulty locating the treasure guardian. SpecTrek players occasionally expressed difficulties when the ghosts moved quickly. Playing PasswARG was qualitatively unimpeded by noise. Although Low and AverageLow level noise belong to different noise models, both contains same standard deviation, as do the Medium and AverageMed levels. Table 6.4 shows the standard deviations for all noise levels calculated from the aggregated data logged during the experiment. This provides the insight of recording adequate amount of data during the experiment to receive the same standard deviation as defined in the experimental design.

Table 6.4: Standard Deviations (σ) for Noise Levels of Different Noise Types

Noise Level	**Noise Type**	**SD(σ) in Degree**	**SD(σ) in Meter**
Low	ZMGNM	2.5 x 10^{-5}	2.77
AverageLow	SNM	2.5 x 10^{-5}	2.77
Medium	ZMGNM	5 x 10^{-5}	5.53
AverageMed	SNM	5 x 10^{-5}	5.53

The result of our experiment revealed a significant multivariate main effect for Game ($F(2, 28) = 50.351$, $p<0.001$) and Noise Levels ($F(4, 26) = 12.305$, $p<0.001$) on players' positive play experience. A significant multivariate main effect for Game ($F(2, 28) = 71.115$, $p<0.001$) and Noise Levels ($F(4, 26) = 6.211$, $p=0.001$) on players' negative play experience as well. For all factors of IMI, significant effects were observed for both Game and Noise Levels.

6.5.1 Analysis of PANAS

In Temple Treasure Hunt, players' positive play experience gradually decreased with noise with the best experience in No Noise ($F(4,26)=17.823$, $p<0.001$). However, negative experience remained unchanged with None and both AverageLow, AverageMedium conditions; but increased with existence of Low and Medium noise. In pairwise comparison, effects were significant between Medium-AverageMedium ($p<0.001$), Medium-AverageLow ($p<0.001$), Low-Medium ($p=0.02$) and None-Medium ($p<0.001$). PANAS did not display any significant differences for the game SpecTrek under variable noise. PasswARG demonstrated a consistent play experience for almost all the noise conditions for PANAS, with no significant differences measured. For both positive and negative experience, the mean experience of AverageLow and AverageMed was close to the control group. Figure 6.7 demonstrates the the result of PANAS for all three games.

6.5.2 Analysis of IMI

Interesting and significant effects were observed from the IMI parameters for SpecTrek and Temple Treasure Hunt. Box plots showing the distributions of responses for competence and interest/enjoyment are shown in Fig. 6.9. Here, the whiskers and boxes represent the quartiles, the inner line represents the mode, and the mean is indicated by the small circle. Outliers are plotted as individual points (crosses) on the top and bottom of the upper and lower whiskers. The y-axis in all graphs corresponds to the unnormalized score for the experience parameters according to the survey instrument guidelines.

6.5.2.1 Analysis of IMI - SpecTrek

From IMI, while playing SpecTrek, only competence varied significantly between different noise models reflected in pairwise comparison. Players felt competent playing the game under the None, Average Low and Average Medium noise, and felt significantly less competent under Low and Medium noise. Pairwise comparison demonstrated significance in competence between None-Low ($p=0.002$) and none-medium ($p=0.008$). Fig. 6.9 demonstrate the competence and pairwise comparison of players' competence levels of SpecTrek. For interest-enjoyment the variation of PX under different noise models were non significant. Even the pairwise comparisons did not show any significance Fig. 6.9c demonstrates the interest-enjoyment along with pairwise comparison of players' interest-enjoyment levels of SpecTrek. Effort of playing SpecTrek showed significance with None-AvMedium pair ($p = 0.026$) and AvMedium-Medium pair ($p = 0.024$). For pressure the pairwise comparison showed significance in None-Low ($p = 0.023$), None-AvMedium ($p = 0.036$), Low-Medium ($p = 0.001$). Fig. 6.8b and 6.8d demonstrate the Effort and Pressure of playing SpecTrek respectively.

Overall, SpecTrek demonstrated that, players competence degrades under ZMGNM where under SNM with variance as the ZMGNM, competence remains close to the control. Slightly higher of effort is required to play SpecTrek under ZMGNM compared to SNM. Similar trend is displayed in pressure. Interest-enjoyment remains very similar (lower than the control) in both noise models.

6.5.2.2 Analysis of IMI - Temple Treasure Hunt

Players had a lower feeling of competence while playing the levels under ZMGNM compared to SNM and No Noise conditions ($F(4,26) = 34.482$, $p<0.001$) while playing Temple Treasure Hunt. Pairwise comparison showed that perceived competence was similar to the No Noise and the conditions of SNM having $p<0.001$ for Medium-AverageLow, None-AverageLow, Medium-AverageMedium, None-AverageMedium, Medium-Low, None-Low, and None-Medium. Similar results were observed for effort. Compared to ZMGNM levels, SNM levels required subjectively more effort to play. Significance was observed in pairwise comparison of levels between Medium-AverageLow ($p<0.001$), Medium-AverageMedium ($p<0.001$), Medium-Low ($p<0.001$), None-Medium ($p=0.003$). Unlike competence and effort, interest-enjoyment had no significant difference between ZMGNM and SNM. However, an overall decrease of interest was observed with increase of noise ($F(4,26) = 13.065$, $p<0.001$). The pairwise comparison showed significance between None-AverageLow($p<0.001$), None-Low ($p<0.001$), Med-AverageLow ($p=0.04$), None-AverageMedium ($p<0.001$) and None-Medium ($p<0.001$). Likewise, pressure tends to increase gradually with noise ($F(4,26)=11.129$, $p<0.001$). Pairwise comparison showed significance in None-AvMedium ($p=001$), Low-AvLow($p=0.041$), Low-AvMedium($p<0.001$), Low-Medium($p=0.013$). AvMedium level varied significantly with all other levels except for AvLow which is its own kind of noise model (SNM). Medium level of noise significantly differed from all other levels of noise.

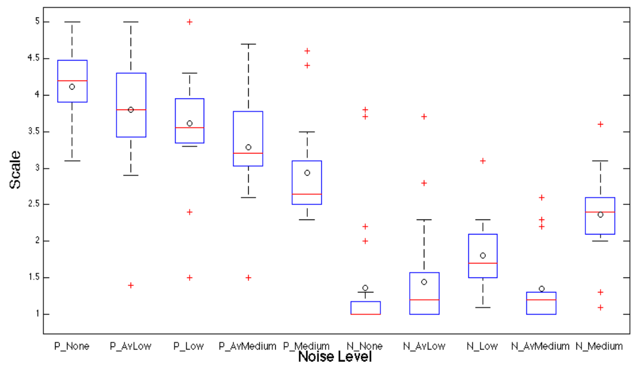
The pairwise comparison demonstrates that, the competence remained very similar with control under the noise in SNM and significantly went down in ZMGN. Higher level of effort was required to play Temple Treasure Hunt under SNM compared to ZMGN. Interest enjoyment was gradually going down regardless of noise model. Players felt highest pressure in the highest level of ZMGNM. The other levels (regardless of SNM and ZMGNM) were very close to control. Fig. 6.8 demonstrates the IMI for Temple Treasure Hunt.

6.5.2.3 Analysis of IMI - PasswARG

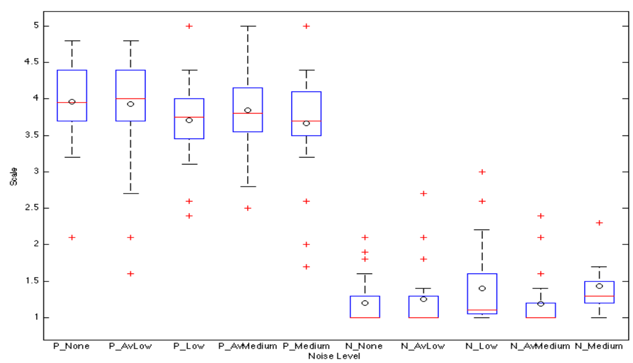
PasswARG demonstrated a consistent play experience for almost all the noise conditions as well as different noise models (e.g. ZMGNM and SNM), demonstrating, as noted in [65], that game mechanics, narrative and input modality differentially impact player enjoyment under noisy input conditions. No statistically meaningful significant differences were found for the PasswARG game for. Figure 6.8 6.9 and 6.10 demonstrates the IMI of all three games.

6.6 Discussion and Future Work

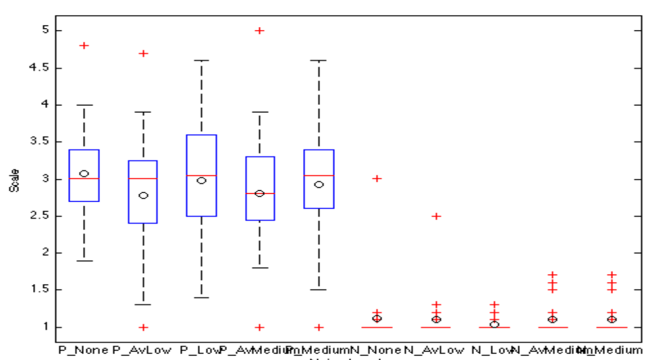
In our experiment we hoped to determine the differential impacts of noise model on player experience crossed with game narrative and input. Game genre and input modality had an impact as expected from [63], with PassWARG player experience being essentially immune to the noise manipulations. However, Temple Treasure Hunt, and to a lesser extent SpecTrek were impacted by manipulating noise. Consistent with previous work [63], players were more susceptible to higher levels noise in Temple Treasure Hunt because of



(a) Temple Treasure Hunt

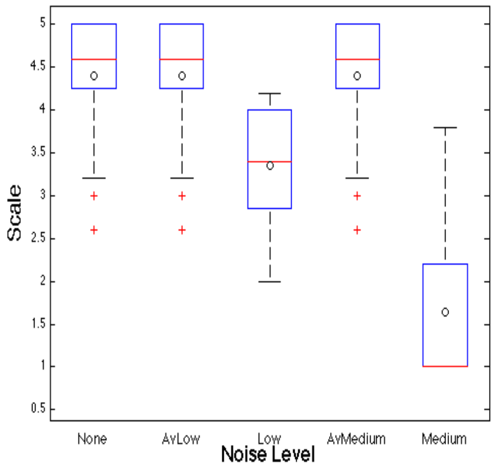


(b) SpecTrek

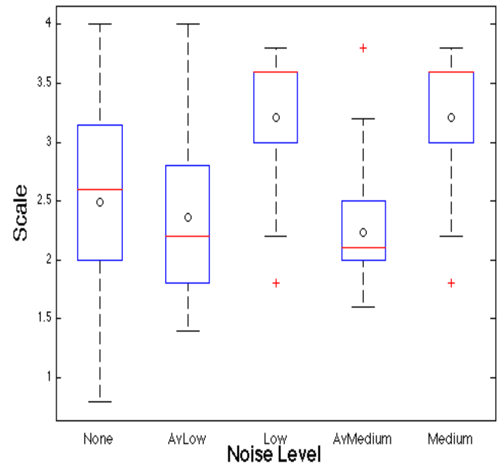


(c) PasswARG

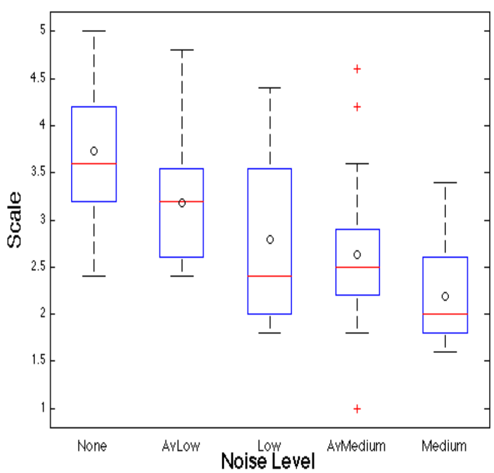
Figure 6.7: PANAS of Temple Treasure Hunt, SpecTrek and PasswARG (N=None, L=Low, M=Medium, AL=Average Low, AM=Average Medium)



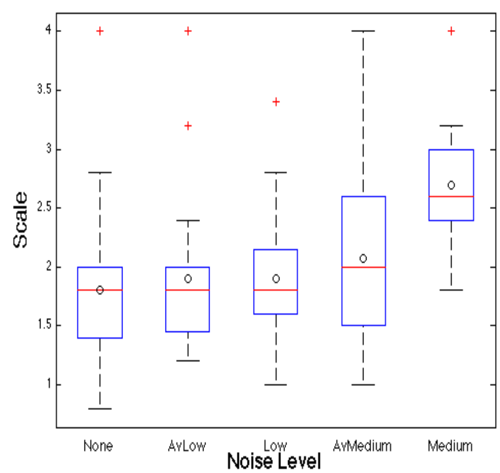
(a) Competence



(b) Effort

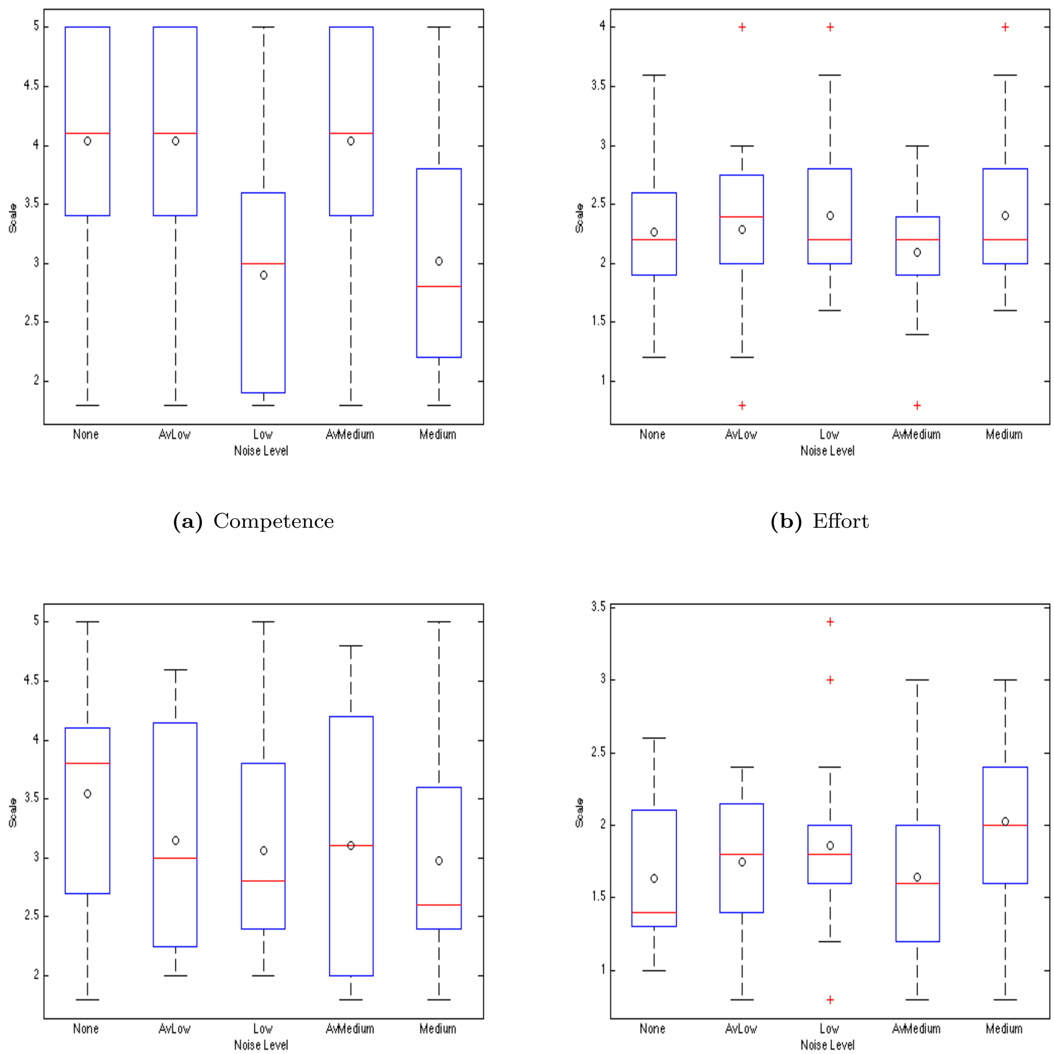


(c) Interest-Enjoyment



(d) Pressure

Figure 6.8: IMI of Temple Treasure Hunt



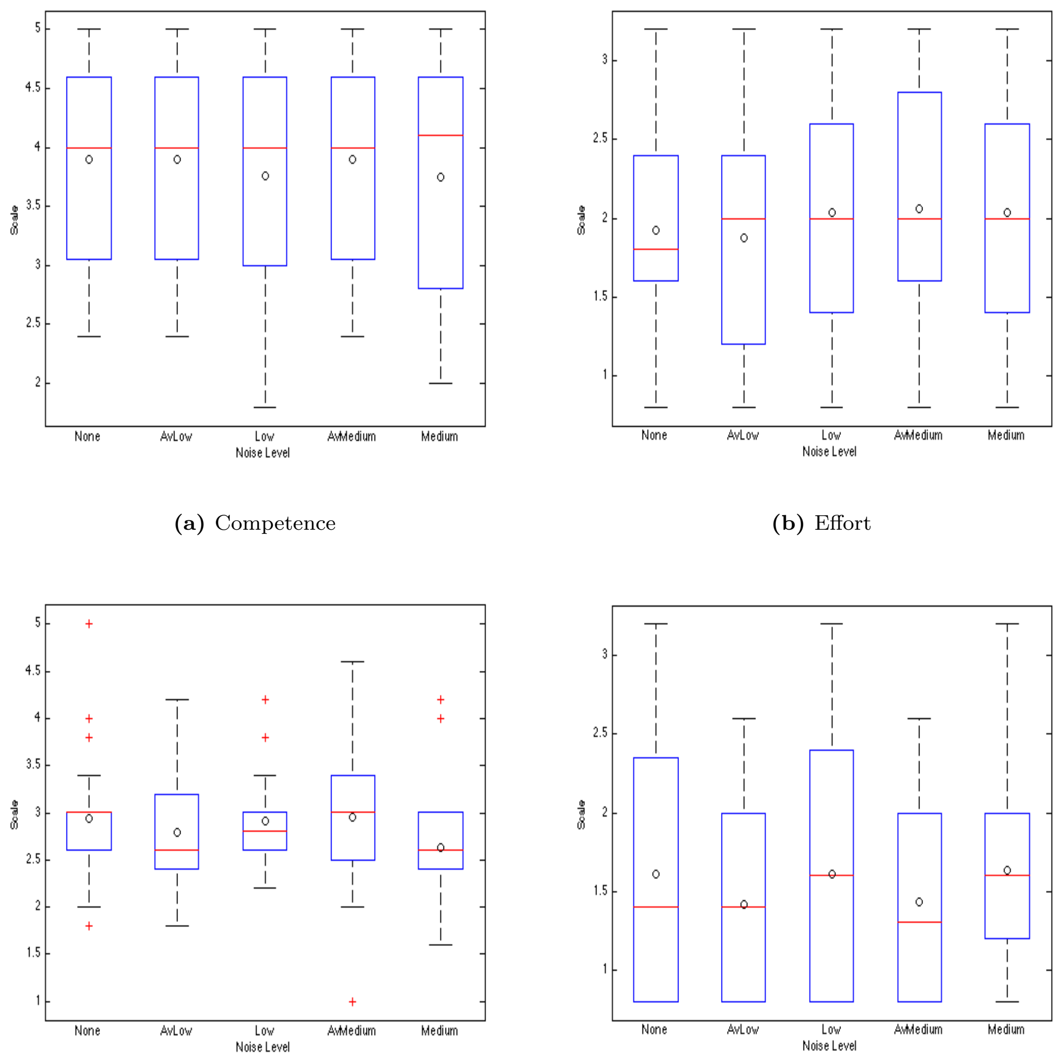
(a) Competence

(b) Effort

(c) Interest-Enjoyment

(d) Pressure

Figure 6.9: IMI of SpecTrek



(a) Competence

(b) Effort

(c) Interest-Enjoyment

(d) Pressure

Figure 6.10: IMI of SpecTrek

the sensitivity of the input, and a reasonable expectation that an inaminate object should not move. The validation of earlier results is heartening in and of itself, and provides confidence that the extended analysis reported here is building on a solid foundation. In particular, we noted an additional effect due to the the sequential noise model. Even though participants were exposed to the same average noise variance between the Low and AvergeLow conditions, participants reported significantly fewer drawbacks to player experience in the AverageLow condition than the Low condition. This trend held for the AverageMedium and Medium conditions as well.

In the SNM, participants were occasionally subjected to lower precision of location information than the equvalent ZMGNM levels. However, to maintain the same average variance, they also had significant periods at higher relative precision. It appears that players were more easily able to reject short periods of low precision, and benefit from the prolonged periods of lower noise (demonstrated in result). This may be explained by the Peak-End theory proposed in [78]. In Peak-End theory, player experience is dominated by player state at the peak of play, and the end of play, rather than being averaged over the entire play experience. If players were pausing during periods of higher noise variability, and acted during periods of lower noise variability, then the key player experience windows (the Peak and End) would have occurred during periods of lower noise, and the player experience would have been more consistent with having played in a low noise environment.

This hypothesis provides some hope to GPS-based game designers, as player experience should reflect the play which occurs during low noise periods, if the game design permits players to select when to interact. In all of the games examined here, there were no timing mechanics attached to the interactions – the treasure did not disappear on a timer and the ghost did not shoot back, allowing the player to pick the best time to interact. If the player were forced into peak or end interactions during high noise variability episodes, we would not expect the lower noise regime's experience to dominate. A significant design finding from this work is that players can benefit from systems with variable noise behaviors, but only if they have sufficient timing freedom to determine under what noise regimes peak and end experiences occur.

This experiments described here have made a significant contribution towards the AR game development community. Nevertheless, some limitations exist. The participants recruited were biased towards university community and male. Only GPS sensors were evaluated, and only simple selection mechanics within the games. Additional and more complex game mechanics should be considered in future work. Finally, we primarily used commercial games. While this does provide a minimum level of polish and code stability, it also limits the opportunity for telemetering the games. These effects should be investigated in custom games including more fulsome telemetry to probe the extent to which Peak-End hypothesis is reflected in gameplay. If we are correct, most play actions should be recorded as happening during periods of lower noise in the SNM conditions.

6.7 Conclusion

In this paper, we have presented a novel approach for investigating the differential impact of sequential noise in comparison with ZMGNM upon user experience in different location-based AR games. By modifying the sensor services in the operating system to provide structured noise disruptions following both Gaussian and sequential noise patterns, we conducted a controlled experiment with three different kinds of AR games which employed GPS as their primary input. After performing a user study, we found that depending on game design, narrative, and interaction technique, the players' experience varies deferentially for Zero Mean Gaussian and Sequential Noise Models. The findings also demonstrated, that player experience was less sensitive to variable noise than the equivalent Gaussian noise. In the future we intend to investigate new games, sensors and demographics to understand the generalizability of these findings.

Acknowledgement

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Chapter 7

Discussion and Conclusion

Augmented Reality (AR) is a technology where digital avatars are superimposed on the real world, as seen through a camera. This technology has enhanced the opportunity to experience the fantasy of digital worlds, embedded in the real world. Moreover, with the evolution of smartphone technology, AR is now widely accessible. Video games are an early adopter of this technology.

Video games are generally considered a leisure activity. Player experience (PX) is a key criteria to consider when evaluating games because the quality of the game is related to the emotional response of the player. Spatio-temporal sensing plays major role in AR games because the virtual and real world views must be aligned. The QoS from the sensing system can impact the Quality of Experience (QoE) or PX of the players during gameplay by impacting this alignment. While significant research has been done analyzing player experience, fewer contributions have been made in Augmented Reality games.

In AR games, spatio-temporal position and orientation of the camera are important game interface inputs, and by extension mean that Quality of Service (QoS) of the sensors equipped with the device can impact the PX. However, one could expect sensor errors to have differential impacts on different games and game mechanics. Therefore, I examined the spatial and temporal dependencies and sensitivities through literature review and found evidence for significant heterogeneity in sensor QoS requirements across both academic and commercial AR games.

Because aiming is one of the primary interaction techniques of AR games, investigating the sensitivity of sensor QoS and its impact upon players was required. I analyzed play experience while playing indoor AR aiming games with distinct aiming techniques under different spatio-temporal conditions. Location-based AR games are example of AR games which have become more mainstream. I analyzed the PX under different level of QoS by subjecting outdoor AR games to both different levels and and structure of noise. Because aiming is a primary interaction technique in AR gameplay, I examined the impact of both game genre and input modality on player experience.

This thesis is composed of four manuscripts each with their own contribution.

Defining Spatio-Temporal Resolution Criteria and a Taxonomy of AR Games

The spatial and temporal sensitivities of different genres of AR games are distinct. I examined WHAT are the criteria that actually defines HOW these games will behave under different spatio-temporal resolution through literature review. I classified based on how Space, Timing and Orientation are sensitive to sensor QoS. My taxonomy highlighted significant heterogeneity in game QoS requirements implying that findings for one genre cannot apply to another.

Manuscript 1

Title: Analyzing the play experience while playing indoor AR aiming games with distinct aiming technique in different spatio-temporal environment

In this manuscript I examined the orientation sensor noise on PX in three commercial games adopting different aiming techniques - tapping, shooting and tapping with reticule.

I recruited 24 participants to play the games in a modified Android OS. After each play session, participants completed standard surveys to record their play experience. The goal of this experiment was to distinguish the degree to which aiming technique is sensitive towards spatio-temporal sensor resolution. The results demonstrated players' sensitivity level for sensor QoS of the sensors was different under different different aiming techniques. The tapping technique was most sensitive to noise compared to the others. This paper established the validity of the central hypothesis of this dissertation that noise matters, and that it matters differently based on game genre and design.

Manuscript 2:

Title: Quantifying the Differential Impact of Sensor Noise in Augmented Reality Gaming Input

In this manuscript, a user study was performed with 48 individuals playing both head mounted and magic window variants of the same game with different input techniques, under different orientation sensor noise conditions. The four different control techniques were - fixed/flexible reticule on smartphone and fixed/flexible reticule on head-mounted display. Evaluating user experience using both logs and standard experiential surveys, I found differential effects of the introduction of noise on different systems. The final outcome demonstrated that under the same level of spatio-temporal resolution, players are most sensitive to noise when using a magic window display. The results demonstrated that QoS of the sensors impacts the PX significantly. I also found that players do better with HMDs compared to the handheld device under poor sensor QoS. Therefore, it is sensible to test the game mechanics and balance on the less compelling platform first. Providing targeting assistance can help controlling players' rapid and short movements while tracking the monsters. As players performed poorly with handheld smartphones and unanchored reticules, using FPS (First Person Shooter) mechanics should be preferred. This study demonstrated that even within genres, interface design decisions can lead to significant differences in PX in the presence of input noise.

Manuscript 3

Title: Analyzing the play experience of outdoor AR games of different gameplay in different spatio-temporal environment

In this manuscript, a novel technique was proposed for evaluating the sensitivity of augmented reality games and game mechanics to input noise by modifying the sensor input stream of an open source operating system in a controlled manner, providing the technical capacity to investigate the central hypothesis of this thesis. A noise model was implemented to inject four different levels of noise on the location sensor with ZMGN. An experiment with 24 participants exploring players' experience with different levels of sensor noise for three AR games was performed. I found that players were more sensitive in the treasure hunt mechanic than the trivia and targeting mechanics. Unexpectedly, while playing the targeting game, positive experience increased with noise. For the trivia game, the play experience was consistent for all levels of noise. This paper established that game narrative and design could ameliorate or exacerbate sensor QoS issues, supporting the central hypothesis of the thesis and demonstrating that design can be used to ameliorate poor QoS.

Manuscript 4

Title: Player Experience in Augmented Reality Outdoor Games of Different Noise Models

Instead of only applying zero-mean Gaussian distribution as the sensor noise model, a three-state noise model was deployed along with the zero-mean Gaussian noise to examine the differential impact on PX. A controlled experiment with 30 participants with different levels and different types of sensor noise for three location-based AR games was performed. I observed that, overall, players were more sensitive in the ZMGN noise models compared to the SNM noise models. However, the level of sensitivity also varies depending on the game input modality and mechanics, as expected from earlier chapters. This paper established that the differential impact of noise on PX does not only depend on noise level and game genres, rather, a difference in noise structure can impact PX differently. This finding supports the central hypothesis of the thesis by demonstrating that AR game designers can mitigate the noise effects on PX by leveraging Peak-End theory.

7.1 Significance of this dissertation

Because AR games render digital objects over a real world representation, the real and the virtual world must be synchronized, making AR games different from regular video games where an entire virtual world is created for the gameplay. An accurate mapping between the virtual and the real world is essential, providing designers are faced with new challenges. Precise and explicit guidelines can aid the game development community in building more completing experiences.

I analyzed the PX of AR games, under varying Quality of Service (QoS) from the spatio-temporal sensors of the smartphones used to request real and virtual elements of games. While it is commonly considered that the best QoS is capable of providing best PX, AR games of different categories have differential sensitivity to sensor QoS. My dissertation focuses on examining the variation of Players' Experience (PX) with the Quality of Service (QoS) from sensors across genres and input techniques of AR games. As a first step I examined the spatio-temporal behavior of existing AR games to determine the extent to which genres of games were likely to have heterogeneous dependency.

My hypothesis, derived from the literature review, was that different levels of QoS would have differential impact on PX depending on the nature of the input and game mechanics. To continue and explore this hypothesis, a cluster of AR games was examined in controlled experiments. The literature review indicated that a large portion of AR games included aiming as their primary interaction technique, leading me to examine aiming in two papers (chapter 3 and 4). Through the experiments I confirmed that differential impacts of QoS exist for aiming in AR games, a contribution in itself but also was able to explore the nature if those inputs and make design recommendations. Another important genre of AR games is location-based games as demonstrated by the recent Pokemon Go. Unlike aiming, GPS sensor noise is subject to more complex models. Over two experiments I demonstrated that both the magnitude and structure of noise interact with genre and narrative to shape PX. These findings further contribute the central hypothesis of the thesis and produce amelioration recommendations and directions.

Aiming AR games can employ various input techniques. The findings of the first two experiments (chapter 3 and 4) demonstrated sensor noise impacts AR gameplay differently for different aiming techniques. Different genres of AR games played in the same platform such as magic window posses differential impact on PX. In the second experiment, I demonstrated that playing the same AR game with different input modality can have differential impact upon PX as well in presence of varying sensor QoS. While these first two experiments contributed towards the central research hypothesis of this dissertation in terms of input modality, two more experiments were performed to examine the impact of different game genres and narrative upon PX for location-based AR games. The findings of the third experiment (chapter 5) demonstrated that noise matters; players experience while playing different genres of location-based AR games are impacted differently based on input, genre and narrative. While the first two experiments mostly focused on orientation based aiming games, the third experiment concentrated on location-based games. Nonetheless, overall, from these 3 experiments, a common finding was 'Noise matters' but the magnitude really depends mostly on game genre, input technique, game modality even under the presence of same kind of noise category. An instinctive query that arises from here is does the PX vary if different models of noise impacts the gameplay? To investigate, an extension of the 3rd experiment was performed as the fourth experiment (chapter 6) to analyze the sensor QoS sensitivity under different design of sensor noise. The findings of this experiment demonstrated that players experience varies depending on the noise models as well.

While analyzing the impact of sensor QoS on PX, differential impact of players' enjoyment was observed in terms of competence. Depending on the game genres, the competence varied in a different manner under different level of sensor QoS. This finding was particularly interesting because existing research demonstrated that people play computer games to engender a feeling of competence [163]. Gutwin et. al. established 'Peak-End' theory stating that player experience is dominated by player state at the peak of play, and the end of play, rather than being averaged over the entire play experience [78]. The outcome of the fourth experiment reflected the impact of Peak-End behavior because players were able to reject short periods of higher noise and and utilize the longer periods of lower noise for active play, engendering an experience close to a low noise than high noise condition.

Initially, one of the hypothesis of this dissertation was noise can differentially impact player experience for different AR game mechanics. My experiments 1,3,4 (described in Chapter 3, 5 and 6 respectively) address this hypothesis by displaying the fact how players? were sensitive in different AR games such as magic window indoor games and Location-based AR games. PX varied based on the input technique, aiming technique and game mechanics for these categories of AR games. Next hypothesis was noise can differentially impact player experience for different AR game input techniques. Experiment 2 (described in Chapter 4) demonstrated how PX varied in two different aiming techniques played in MW and HMD. The differences in these differential impacts can be leveraged to develop AR games which are more robust to sensor noise and based on these differences, guidelines are provided to develop AR games that are robust under the existence of noise.

The overall findings of these experiments contributes towards the establishment of the central research hypothesis of the dissertation by confining and quantifying the fact that input sensor QoS impacts PX differentially based on game mechanics, input modality and narratives. To mitigate this, AR game developers could benefit from concrete guidelines. The findings of our experiment lead us to overall three recommendations -

- **Develop for worst case scenario:** Game developers should concentrate on confronting the worst case scenario while developing AR games. For example, all possible input types should be considered for multi-platform based AR games and mechanics selected to mitigate sensor noise in the highest sensitivity.
- **Reduce timing impact:** Allowing players some freedom in selecting when they will interact will allow them to wait out noisy periods.
- **Provide comprehensive game narrative:** The game narrative should be extensive enough so that even if the noise interrupts the gameplay, players assume that as a part (e.g. harder level) of the game

7.2 Future Work

The dissertation demonstrates an influential overview of players sensitivity towards sensor QoS of different game mechanics in Augmented Reality games. Through four controlled experiments followed by statistical analysis, it was determined that sensor noise has differential impact upon PX based on input modality, game mechanics and genre. However, similar to any other research, my dissertation has some limitations to overcome as of future work.

The AR games available both academically and commercially mainly uses the various sensors equipped with the handheld device. While camera is the primary sensor to use of AR enviorinment, the other commonly incorporated sensors include GPS, orientation, zyrometer, compass, accelerometer and wifi. The experiments conducted in this dissertation solely investigated the primary sensor used by the AR game (orientation or GPS). However, most of the location-base AR games use both GPS and orientation in their game mechanics. Because our experiments were limited to inject the sensor noise to individual sensor, an analytical investigation will be to inject sensor noise to multiple sensors of the same AR game and analyze PX under this circumstance.

Based on the ubiquity and popularity of orientation and location based AR games, this thesis focused on those genres. As mentioned earlier in chapter 2, a moderate amount of AR games of different genres are available commercially. For example, looking at the game cluster provided in chapter 2, a significant kind of AR game is the table-top AR games that primarily use the fiducial marker for AR rendering. Several other kinds of games other than table top games (e.g. Temple Treasure Hunt indoor version) use these black and while markers as well. Because very subtle amount of orientation is required for these kinds of gameplay, a significant future work will include examining the differential impacts of sensor noise on different genre of AR games incorporating these sensors.

Game researchers have investigated how novel or newly commoditized technologies can create new experiences in gameplay. Recently, technologies such as smart phones, table top display and virtual realty headset (e.g. Oculus Rift, Microsoft Hololens, Google Glass) have enhanced AR gaming research research variants. The potential of touch-less approach in AR games has been explored by Zhihan et. al. where Google Glass was employed [122]. It will be an acute area of research to explore the differential impact of PX while playing AR games adopting different game narratives and mechanics using these headsets. Because these headsets are profound to be more immersive than the handheld devices, the PX might vary with a presence of sensor noise for different genres of AR games.

The games that are being used in this dissertation are single player games. Because a compelling amount of multiple-player games are available in the game world currently, investigating differential impact of sensor noise on PX among the players while playing AR games will be an interesting area to research in future.

While conducting the user experiments, only moderate number of participants were recruited and biased towards a university population. The future work includes an intention of recruiting participants from different kinds of background. To analyze the intrinsic motivation and experience, mostly different dimensions of ANOVA (e.g. Friedman, Pairwise, Repeated-measure) was applied. Applying different kinds of statistical analysis and comparison among them is considered to be a part of the future work.

7.3 General Comments

The first experiment conducted for this dissertation is the one elaborated in chapter 5 (Analyzing the play experience of outdoor AR games of different gameplay in different spatio-temporal environment). The sequence of rest of the experiments are - Manuscript 1 (Analyzing the play experience while playing indoor AR aiming games with distinct aiming technique in different spatio-temporal environment), manuscript 3 (Quantifying the Differential Impact of Sensor Noise in Augmented Reality Gaming Input) and finally manuscript 4(Player Experience in Augmented Reality Outdoor Games of Different Noise Models).

In three of the four experiments conducted (manuscript 1,2,4), F-statistics repeated Measure ANOVA was applied for statistical analysis. In manuscript 3, a non-parametric analysis named Friedman test was applied. As aforementioned, the experiment described in manuscript 3 was the first experiment conducted. Hence, our experimental maturation was inadequate to justify the test results for optimal result. However, Friedman test was appropriate enough to display the statistical significance of our required research investigation. Only the significant statistical outcomes were written in the manuscripts. The result of the statistical analysis were presented (e.g. values of F, χ^2, p) in a format of up to 3 decimal places. In case of exact value the 'equal to' sign has been used. In case of extremely significant probability value, 'less than' is used.

7.4 Summary

The fundamental goal of my dissertation was to address the impact of sensor QoS on AR games. As the initial step, I analyzed 94 different existing AR games and developed a classification of AR games depending on their spatio-temporal sensor sensitivity. I performed four experiments to determine the differential impact of QoS on AR games PX under diferent game mechanics and input modalities. In the first experiment I analyzed the PX under different level of sensor QoS while playing different techniques of aiming AR games as aiming is one of the primary AR interaction techniques. From the four user experiments significant differential impacts of sensor QoS upon PX were observed while playing different genre of AR games. The overall findings of these experiments contributes towards the establishment of the central research hypothesis of the dissertation which was 'codifying the differential impact of sensor noise in AR games and input techniques using controlled experiments and standard PX evaluation techniques' by enacting the fact that input sensor QoS impacts PX differentially based on game genre, input modality and narratives. The overall finding of this dissertation lead me providing concrete guidelines of AR game mechanics to mitigate the sensor errors for different kinds of AR aiming games.

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