Improving Digital Object Handoff Using the Space Above the Table

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ABSTRACT

Object handoff – that is, passing an object or tool to another person – is an extremely common activity in collaborative tabletop work. On digital tables, object handoff is typically accomplished by sliding the object on the table surface – but surface-only interactions can be slow and error-prone, particularly when there are multiple people carrying out multiple handoffs. An alternative approach is to use the space above the table for object handoff; this provides more room to move, but requires above-surface tracking. I developed two above-the-surface handoff techniques that use simple and inexpensive tracking: a force-field technique that uses a depth camera to determine hand proximity, and an electromagnetic-field technique called ElectroTouch that provides positive indication when people touch hands over the table. These new techniques were compared to three kinds of existing surface-only handoff (sliding, flicking, and surface-only Force-Fields). The study showed that the above-surface techniques significantly improved both speed and accuracy, and that ElectroTouch was the best technique overall. Also, as object interactions are moved above-the-surface of the table the representation of off-table objects becomes crucial. To address the issue of off-table digital object representation several object designs were created an evaluated. The result of the present research provides designers with practical new techniques for substantially increasing performance and interaction richness on digital tables.

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LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
AboveFF	Above-the-surface Force-Field
SurfaceFF	Surface-only Force-Field
TLX	NASA Task Load Index
HCI	Human Computer Interaction
IK	Inverse Kinematics
IR	Infrared
EM	Electromagnetic
ET	ElectroTouch
FFT	Fast Fourier Transform
XMOB	Extremity Movement Observation

CHAPTER 1
INTRODUCTION

As with many technologies, touch table technology is improving rapidly. Concurrently, the costs of such devices are declining to the point where many institutions can install large multi-touch tables for a variety of activities. Such tables allow group projects to be carried out in the same digital environment with face-to-face (or *collocated*) collaboration. Good touch table design allows people to walk up and use the device with the natural interactions that people have learned with real tables. Similar to the use of real-world tables, people can interact with one another and often exchange objects in order to gain ownership of an item.

As people collaborate around a real-world tabletop, there are a number of interactions that take place. One very common interaction is the passing or transfer of one object from one person to another. This object transfer is called 'handoff'. Generally, social conventions dictate that people use handoff in particular situations, such as when an object appears to be 'owned' by another individual [64]. However, handoff is also necessary in circumstances where the object is out of reach but close to another individual. The handoff action can be initiated by the giver ("I think you need this") or the receiver ("May I have that?"), and can be performed with little to no verbal coordination (e.g., exchanging cards during a card game, or passing tools during a work session). How the handoff action is initiated, and the intended purpose of the handoff, influences the diverse and precise hand postures required to complete the exchange, which, despite the complexity, requires little effort from the giver or receiver [74]. Handoff is also common in digital tabletops, but has traditionally been limited to surface-based interactions where users transfer objects by sliding them across the table surface. Such limitations can create problems for collocated collaboration.

1.1 Problem

The problem to be addressed in this thesis is: object handoff at digital tables is slow and error-prone when using surface-based techniques.

Exchanging digital objects around table devices traditionally involves surface-based interaction, which decreases performance in collaborative group settings. Surface-based handoffs are handoffs that force people to maintain contact with the surface of the table for the entire process. Handoff performance is poor when enforcing surface-based interactions for two main reasons. First, surface-based handoffs are slow. Handoff speed is reduced because of the high amount of friction experienced when maintaining contact with the surface throughout the handoff action. Additionally, friction is increased as users slide their finger away from themselves [10]; this effect is often noticed by the skipping or 'judder' effect of fingers as they move across the table.

Second, surface-based handoffs suffer from a high error rate caused by interference, occlusions and collisions. As individuals attempt to hand off objects with surface-based techniques, their reach will be impaired by the hands, arms, and objects, of the other collaborators. If the number of collaborators around the table is greater than two (i.e., one pair), the handoff action can result in object or vision occlusions, arm or hand collisions, and possibly *handoff errors*. Such errors occur when an unintended recipient receives the object; this is particularly important in collocated collaboration since, as the number of collaborators increases, so does the error rate.

1.2 Motivation

Large digital tables provide a unique opportunity to encourage group work in a collaborative setting similar to the real world, but with the benefits and flexibility of digital environments. If common collaborative interactions such as handoffs, however, cause a significant reduction in performance the value of digital tables as settings for collaboration is greatly reduced. While individuals may tolerate poor handoff techniques in situations with one other collaborator, the performance drawbacks increase as the number of collaborators increase. Poor handoffs result in slower transfers and an increase in the number of errors made during the transfer. This leads to a frustrated and unhappy group, unhappy because of the increased interference involving handoff techniques.

1.3 Solution

The solution presented in this thesis is to use the space above the table to improve the performance of digital object handoff.

With real-world tables, people naturally and easily overcome many of the limitations of surface-based handoff by simply raising the location of the handoff. For example, a card player may reach over the table to hand a specific card to another player. This approach can also work at digital tables if we can create a way to include interactions above our digital tabletops. Interaction in the three-dimensional space around tables has recently been explored using technologies like affordable depth-sensing and camera devices; the Microsoft Kinect is one example. Designating the area directly above the surface of the table, from the surface to approximately shoulder height, with the edges of the table acting as a boundary (see Figure 1.1), allows for a new dimension of interaction around digital tabletop surfaces that can be captured by placing a camera directly above the table.

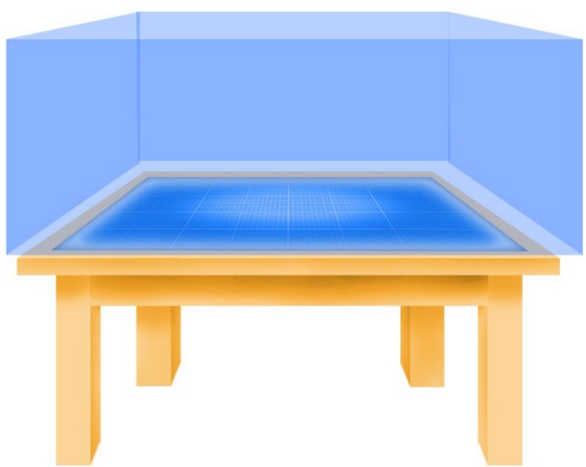

Figure 1.1: Designating the area directly above the table for handoff interactions.

Digital object handoff traditionally occurs on the surface of the table (called surface-only or surface-based handoff) and is simply the synchronous exchange of one digital object between two individuals. The entire process of a digital object handoff begins with one user possessing the object, usually by touching it, and moving the object to a transfer or intercept area. The other user then receives the object by taking possession of it at approximately the same time as the other individual releases it. This technique allows the receiver to move, deposit, or manipulate the object (see Figure 1.2).

Figure 1.2: An example of a digital object handoff that occurs on the surface. On the left, the giver takes the object and moves it to the transfer zone (middle), where the synchronous exchange takes place and the receiver takes possession (right).

Surface-only handoffs, as indicated earlier, are slow and subject to interference. By moving the handoff action to above the surface of the table (called above-surface handoff), the amount of friction experienced by the user is reduced. Additionally, the amount of space available to carry out handoffs is greatly increased and allows for flexible coordination negotiations to occur as they do in the real world.

This solution does raise some concerns about how users manipulate an object that is no longer on the surface of the table. Objects above the surface could be represented using futuristic holographic technology or by using bulky virtual-reality helmets that let users see objects in three-dimensional space. However, it would be more practical to represent above-the-surface objects directly on the surface of the table. Such representations would require that the position and ownership of the object can be clearly indicated.

1.4 Steps in the Solution

In order to improve the performance of digital object handoff by using the space above the surface of the table, several steps were completed during the research process.

- First, *handoff* must be defined in terms of the kinetic motion that occurs between two individuals. Handoff can be defined by examining the elements of object exchange in the real world. This task was accomplished by conducting a formative study in three parts. In the first part of the study, a game was created that required the exchange of different types of real-world objects, which allowed for the examination of the hand postures and gestures of real-world handoffs. The second part of the study examined how people would transfer digital objects if they were not confined to the surface of the table, which determines how individuals would attempt to remove objects from the table and exchange those virtual objects with others. The final part of the study examined how people exchanged digital objects if they were required to do so quickly and repeatedly without any visual representation. This determined whether people would be faster at handoffs above the surface than handoffs restricted to the surface alone. This step resulted in recognizing that handoffs above the surface could be defined in one of two ways: either, handoff is the set of actions and gestures that occur above the surface of the table, or handoff is reduced to a single trigger action, such as a touch.

- Second, it is important to examine the capabilities of digital tables, and how to use the space above the table. This step focused on discovering the above-surface capabilities of digital tables, which requires addressing two issues. First, there must be a way to track the movement of hands and objects above the table. Technology for this type of tracking has existed for some time, but traditionally is expensive and cumbersome. It requires special objects to be used to 'hold' the digital objects or requires users to wear special gloves. Fortunately, with cost-effective, off-the-shelf devices that incorporate depth sensors, such as the Microsoft Kinect, it is possible to effectively monitor behaviour in three-dimensional space. This approach can be used as a cost-effective method for tracking hands and objects above the surface of the table. Second, the system needs to determine when a handoff will occur. In the real world, a handoff occurs with a careful negotiation of grasping and releasing provided largely by tactile feedback. In the digital world, digital objects offer no such feedback. As a result, the handoff action needs to be accomplished in a different manner such as using gestures to indicate when a transfer should occur, using boundaries around a person's hand, or using touch as an indicator to transfer the object. These techniques can be accomplished using gesture recognition, video and depth-sensing cameras, and capacitive coupling methods to determine when contact occurs. This step resulted in a better understanding of the limitations of digital tables and what technologies could be used to add above-surface interaction.

- Third, above-surface handoff techniques that are representative of the handoff definition from step one must be developed. In this step, two new above-the-surface techniques were developed that represent the two separate handoff definitions determined in step one. The first technique, Above-the-surface Force-Field, classifies handoff as a set of actions and gestures above the table. It extends Force-Field transfer [42] to three-dimensional use, by using a Kinect depth camera to track hand location and proximity. The second technique classifies *handoff* as a single trigger action. For this technique, ElectroTouch was created, which senses physical touches through changes to electromagnetic fields – allowing users to perform handoffs by touching hands over the table. This step resulted in the development of two innovative techniques for conducting handoff above the surface of a digital table.
- Fourth, an experimental harness that will evaluate the techniques in terms of performance, measuring speed and errors, needs to be created. Step four focusses on creating an experimental system for evaluating such techniques in terms of performance. Performance in this case is defined as the speed with which a handoff can be completed and the number of errors that occur when attempting to complete a handoff. For this step, the worst-case scenario for collocated collaboration was created. In this scenario the handoff occurred between the furthest reachable points of the table and across the reach of other individuals also attempting to complete a handoff. This step resulted in the development of an experimental harness that creates an even playing field for evaluating every handoff technique.
- Fifth, the new above-surface techniques must be evaluated against traditional surface-based techniques in order to determine if they offered a performance improvement. The fifth step evaluates the two new techniques with three existing surface-based techniques using the experiment created in step four. Here, a user study was conducted to compare the performance of surface-only handoff techniques (Slide, surface-only Force-Field, and Flick) to above-the-surface Force-Field and ElectroTouch. Performance was evaluated using time and

accuracy: the time needed to carry out handoff actions, and the number of times a handoff went to the wrong person. This step resulted in revealing which techniques had the best and worst performance.

- And finally, the effects of digital object representation, once the object leaves the surface of the table, needs to be examined. This final step addresses the problem of not having a visual representation of objects once they have been 'removed' from the surface of the table. Using the space above the table for handoffs requires individuals to pick up intangible objects from the surface. Without tactile feedback, users must rely on memory or visual cues to determine who possesses the object, and whether the object has been exchanged. This step evaluates several representations in order to determine how objects should be depicted once they are above the surface. This step resulted in the recommendation that above-surface object representations should be designed according to the primary task of the program.

1.5 Evaluation

The evaluation process in regards to improving digital object handoff has two parts. One part focuses on comparing above-surface techniques to surface-only techniques. The other part focusses on determining the best above-surface technique. Since it was determined that the definition of handoff could be classified as a tracking-based technique or a trigger-based technique, the evaluation methodology also had to include an evaluation of the best above-surface technique. Both parts are performance-based evaluations, and focus on the speed and number of errors that occur with each technique.

The evaluation process examined five different techniques: three surface-based techniques that represent traditional handoff (Slide, Flick, and Surface-only Force-Field), and two above-surface techniques (Above-surface Force-Field, and ElectroTouch). Evaluating the speed of each technique involved recording the time taken for each complete handoff. The complete handoff required the possession of an object by one participant (called the object pickup), the exchange of the object with another individual (called the transfer), and placing the object in its final resting place by another participant (called the object deposit). To evaluate the errors for each technique, the number of accidental handoffs that occurred for each object were examined. That is, a handoff error occurs when an object is picked up more than once or transferred more than once. Lastly, the evaluation process also examined the preferences and workload for each of the techniques by the participants.

This study provides the following main results:

- The above-surface techniques resulted in the fastest completion times and the lowest error rates;
- ElectroTouch was significantly faster and significantly more accurate than any other technique;
- Depth-based sensing is prone to error when there are four people at the table, but ElectroTouch is robust to increased group size;
- Object flicking was the best of the surface techniques;
- Participants rated both ElectroTouch and object flicking best for effort and preference;
- Visualizations of digital object representation for objects no longer on the surface of the table are provided and shown to be task dependent.

1.6 Contributions

The primary contribution of this research is the development of novel above-the-surface handoff techniques, and the empirical evaluation of their effectiveness, both in terms of time and errors.

There are also several secondary contributions of this work:

- First, empirical evidence about the performance characteristics of three traditional surface-based transfer techniques are provided.
- Second, this research demonstrates a new tracking technology – ElectroTouch – that can provide physical contact sensing easily and inexpensively[1].

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[1]ElectroTouch was invented by Zenja Ivkovic and Dr. Andriy Pavlovych. While ElectroTouch details are provided, the contribution in the present research is the demonstration and evaluation of this technology.

- Third, limitations of depth-camera-based sensing are introduced.
- Fourth, the value of object flicking for surface-only handoff when several people are working at the table is documented.
- Fifth, recommendations for the representation of objects above the surface of the digital table are provided and reveal that visualizations are task dependent.

1.7 Thesis Outline

The remainder of this thesis is organized in the following manner:

- Chapter 2 introduces background material by first examining digital tables and the handoff action. This chapter also examines the traditional surface-based techniques that were used in the evaluation, as well as additional proposed above-surface techniques. In order to examine handoff as a tracking technique, a detailed look at gestures reveals the hurdles of pursuing such a method. As a prelude to classifying handoff as a trigger-based technique, and as a prelude to the work accomplished with ElectroTouch, an examination of capacitive coupling technology reveals the benefits of using touch as a trigger mechanism. This is followed by an examination of the social stigma of touch between strangers. Finally, a brief exploration of interference and representing digital objects in three-dimensional space presents the advantages of interference resolution and challenges with object representation.
- Chapter 3 describes the formative study conducted in order to analyze handoff as it occurs in the real world. The three parts of the formative study are presented in detail followed by a comparison of above-surface interactions to surface-only interactions.
- Chapter 4 describes the design and implementation of each of the five techniques used in the main study: Slide, Flick, Surface-only Force-Field, Above-the-surface Force-Field, and ElectroTouch. This section includes the sub-system used to track hands above the table as well as a detailed look at the construction and implementation of ElectroTouch.

- Chapter 5 reports on the study design, setup, evaluation, and results. The results of the evaluation include analysis of handoff times, handoff errors, workload assessment, and user preferences.
- Chapter 6 discusses the results of the evaluations in Chapter 5. This chapter considers why above-the-surface techniques were better, why ElectroTouch performed the best of all techniques, why flick was the best performing surface-only technique, and which technique requires the most effort. The comparative analysis is followed by an explanation of the types of errors that occurred, and the generalizability of this study to the real world. Lastly, the limitations of the study are presented.
- Chapter 7 explores a brief study of digital object representation when using above-surface handoffs. This section reports the design, implementation, evaluation, results and conclusions of the study.
- Chapter 8 concludes this thesis and outlines several areas for future work.

CHAPTER 2
RELATED WORK

This research is based on two key areas of previous work. First, a brief look at collaboration and handoff around digital tables examines previous implementations of digital tables and the definition of handoff as it relates to digital tables, both on and above the surface. Second, table interactions without physical objects are considered. These include surface-based and above-surface gestures, issues with gesture recognition, reducing handoff to a tracking and proximity technique, reducing handoff to a trigger-based technique, sensing technologies and touch and interference avoidance.

2.1 Collaboration and Handoff at Digital Tables

A number of recent studies have explored ways in which digital tables can support collocated collaboration [4][22][59]. As technology continues to advance digital tables are becoming larger, more affordable, and offer higher resolution displays. These factors were previously a hindrance for using digital displays in collocated collaboration [58]. Larger tables allow groups with greater than two members to gather around a single table in order to collaborate, which improves efficiency over smaller tables that only support two individuals [64]. Digital tables allow users to access and share resources, literally within arm's reach of one another, and promote the natural and intuitive interaction found in the real world [56]. At the same time they increase the awareness of each other's actions during interaction activities such as pointing, reaching and direct touch input [30]. These tables also allow for a wide variety of interactions that can occur between people, including gestures [25] and communications [59].

In recent years there has been increased interest in using the space above the surface of digital tables to accommodate the variety of above-surface interactions. The majority of this work has focused on creating holographic objects above the surface using projectors and semitransparent mirrors [8][36]; however, these strategies are unsuitable for collocated collaboration due to their inability to display objects simultaneously for multiple perspectives. Other research has focused on remote embodiments, that is, representing hand and arm gesture information above displays in distributed groupware systems [26]; however, these representations are not particularly important for collocated systems. Yet some above-surface interactions are particularly useful for collocated collaborations and are relatively unexplored. One such interaction is handoff, which is the focus of this research.

2.1.1 Handoff

In order to evaluate digital object handoff solutions, handoff must be defined by examining handoff in the real world. Subramanian and his colleagues write that a "handoff can be characterized as a synchronous target acquisition task where two people need to negotiate a complex hand-over of a shared object" [72]. An asynchronous exchange could also be considered a handoff event (e.g., exchanging a letter by mail). However this type of handoff is not performance based and for the purposes of the present research an asynchronous exchange falls outside the research domain. The handoff begins with the acquisition of a target which is classified as *pickup* in this research. The individual who acquires the object becomes the *giver*. Object pickup is typically accomplished by grasping, touching, or otherwise seizing an object. Usually, an object is seized using a *power grip* or a *precision grip*. The power grip refers to gripping an object in a clamp fashion between flexed fingers and the palm with the thumb applying counter pressure. The precision grip refers to pinching the object between the flexor aspects of the fingers and the thumb [57] (see Figure 2.1). Napier notes that both the power grip and precision grip may be used for small and intermediate objects but usually only the precision grip is used for large and very small objects [57]. While individuals typically grasp an object to take ownership, resting a finger or hand on the object can also indicate possession. This action allows the object to be moved using either of the two main methods for hand movement in order to get the object to the *transfer zone.* This zone is a location mutually accessible by both parties in which to carry out the object *transfer*. The transfer is the act of exchanging ownership of an object between the giver and receiver and it involves two atomic actions, *give-to* and *take-from*. That is, the giver gives the object to the receiver, while the receiver takes the object from the giver.

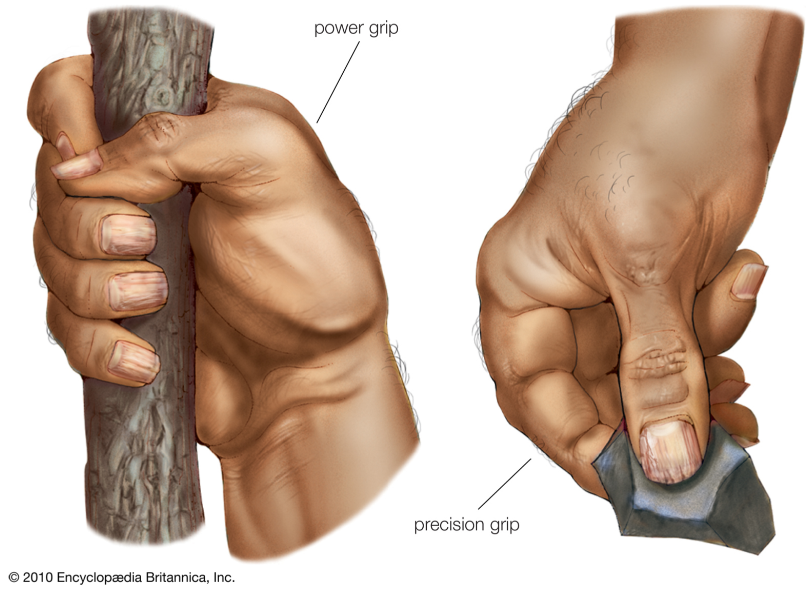


Figure 2.1: Illustration of the power grip and precision grip from the Encyclopedia Britannica, Inc. [33]

Napier classifies the two main hand movements as *prehensile movement* and *non-prehensile movement* [57]. Prehensile movement requires that the object be seized and held partly or fully within the hand whereas non-prehensile movement includes movements with no grasping or seizing. In non-prehensile movement objects are manipulated by pushing and lifting motions. The objective of the giver is to move the object using prehensile or non-prehensile movement, depending on the method of possession, to the transfer zone. During the process of object possession and movement by the giver, the individual waiting to take ownership of the object from the giver, hereafter classified as the *receiver*, has not been idle. While interacting with the giver, the receiver has been noticing the non-verbal-communication cues which can be used to predict, before the handoff process has begun, when a handoff will occur [70]. The giver and the receiver then begin to coordinate their approach to the transfer zone. The coordination of visual cues and object movement of the transfer falls into one of three temporal patterns: the passer arrives at the interception area first and waits for the receiver; the receiver arrives at the interception area first and is given the object; or the receiver and giver arrive simultaneously at the interception area [69]. In this third pattern, the giver and receiver engage in a collaborative negotiation as they conduct the transfer of the object.

The act of transferring an object between giver and receiver is quite complex. There are numerous intricacies that influence how the object is exchanged. Individuals are easily able to adapt to different objects and timing during the handoff process. They make these adjustments by altering the aperture of their grip and modifying the contact time based on visual and tangible cues and object movement [67]. Svensson, Heath and Luff describe in great detail the transfer of one object to another in the prehensile passing of surgical instruments from a scrub nurse to a surgeon in the area above the surgeon's table [74]. These authors note the dynamic effects of transferring objects through a complex series of actions based on skills and the resources available. The act of the transfer relies on the receiver correctly grasping the object in such a way as not to prevent the giver from removing their hand. In the surgeon example, correctly grasping the object is treated as a secondary event, distracting from the primary task (the surgery) only for an instant to make slight adjustments to the hand posture in order to grasp the object properly. The giver waits to be sure that the receiver has fully grasped the object, making slight adjustments to aid in the receiver's grasp if needed. The giver shifts the weight of the object over to the receiver quickly but methodically, by adjusting the force grip [52], to avoid the object slipping out of grip and falling to the floor. During this transfer time, the giver and receiver share the possession of the object. Once the receiver has completely accepted the entire weight of the object, the giver can release the object and move away from the transfer zone. The receiver now has complete possession of the object.

The above type of transfer, however, only accounts for prehensile passing. Transfer may also take place through non-prehensile passing [48]. Examples include pushing an object towards another individual or tilting an open-palm to allow an object to slide off from the giver's hand into a receiver's hand [21]. In surface-based non-prehensile passing, one individual pushes the object towards another individual along a surface. Such an event occurs frequently in games using playing cards or when exchanging digital objects on touch tables using traditional handoff techniques. Ringel and her coauthors document the surface-based non-prehensile transfer process during the description of their release technique [63]. Once an object has been moved to the transfer zone, the receiver also touches the object, thus indicating that the transfer can begin. The giver then removes their hand from the object and, by this action, transfers possession to the receiver (see Figure 2.2).

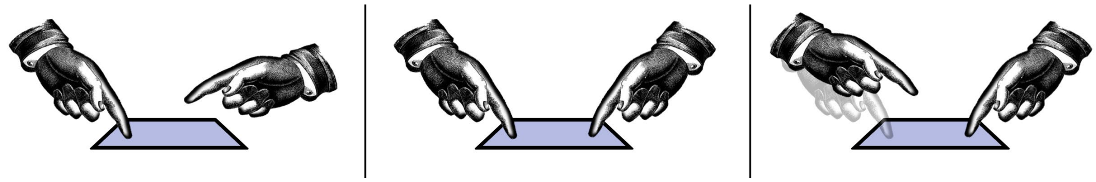


Figure 2.2: The non-prehensile transfer process adapted from Ringel et al. [63]

While the surface-based non-prehensile process of object transfer simplifies the intricacies of the prehensile transfer [48], it introduces another variable into the transfer action. As defined earlier, handoff is the synchronous exchange of an object; yet in the non-prehensile process of object transfer, it is possible for the event to become asynchronous. This variation occurs when the giver releases ownership of an object before the receiver has touched the object (see Figure 2.3) due to coordination difficulties introduced by the perceptual nature of the task [10]. The premature release of an object by the giver generally has no adverse consequences (i.e., there is no danger in the object falling to the ground since it is already resting on a surface). People are therefore less cautious about having to complete the object transfer synchronously. For this reason the definition of handoff must include asynchronous transfers. However, adding asynchronous transfers to the definition of handoff must be contingent on only allowing a short delay between the giver releasing the object and the receiver taking the object. This restriction will prevent classifying every pickup action as a part of a handoff transfer even if the object was released hours, days or weeks earlier. For the purposes of the present research, an asynchronous transfer with only a short delay between the release of the object by the giver and the taking ownership of the object by the receiver will be called *near-synchronous*.

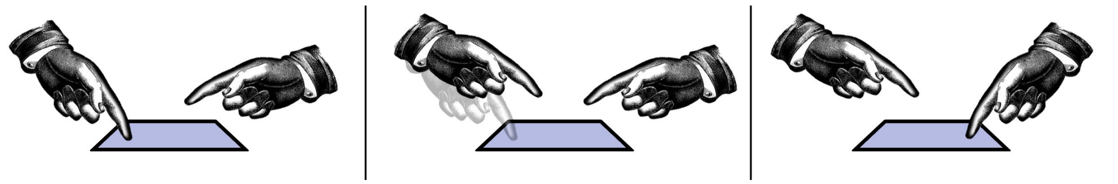


Figure 2.3: The non-prehensile non-synchronous transfer introduces asynchronicity to object handoff.

Once the transfer of the object is complete, the receiver now can use the object or place the object in another location depending on the objective of the exercise. For the purposes of the present research, the definition of handoff will include one final step by the receiver after the transfer has occurred. To complete the handoff procedure, the receiver must place the object in a desired location and release it, a process classified as *deposit* in the present research. While the real-world handoff process might not end with a deposit (e.g., engaging in another handoff, dropping the object, or throwing the object away), including deposit in the handoff process plays a vital role in evaluation as will be seen in Chapter 5.

Handoff is a complex task requiring precision, timing and coordination and is influenced by social context [6], emotional relationship [31], purpose [51], and even the fragility of the object [29]. However, people are able to conduct many handoffs effortlessly as if they were a trivial task [20]. Bringing this effortless real-world technique to digital tables is fundamental in producing a well-performing collocated collaborative environment. The next section examines handoff as currently employed as a surface technique with digital tables.

2.1.2 Surface-based Handoffs

Large touch tables are now becoming an affordable means of collaboration. They allow multiple people to gather around a single table and interact with one another in addition to interacting with the device. Studies reveal that handoffs will occur frequently in these collaboration settings and make up approximately half of all object transfers [72]. In order for the handoff interaction to take place on touch tables they need to be effortless or collaborators will hesitate to use such interactions [72]. Collaborations around digital tables involve sharing resources and require individuals to be aware of the actions of others in order to complete the handoff quickly and effectively. Basil and his co-authors note that if the receiver is aware of the entire transfer process, starting from the verbal or non-verbal cues that led to the giver picking up the object, it is possible for the receiver to infer the intention of the giver. This awareness allows the receiver to predict the position of the handoff and aids in the smoothness of the transfer [4].

The present research defines *surface-based handoffs* as handoff actions taking place solely on the surface of a digital table using non-prehensile passing. This type of handoff requires the giver to take ownership of an object with a finger or input device (e.g., mouse or stylus pen), to move the object along the surface to the transfer zone, and to engage in a non-prehensile object transfer process like the one described earlier. The horizontal touch table, as with real-world tables, provides a large, reachable area that allows for handoffs to occur without the need to adjust the positioning of the bodies [39]. Although handoffs occur frequently regardless of the input device used (mouse, finger, etc.) [56], research indicates that collaboration is improved with touch interaction since participants are more aware of the activities of others and can negotiate and resolve conflicts easily with little interruption in their work [37].

2.1.3 Surface-based Handoff Techniques

A number of surface-based handoff techniques have been employed over the years in an attempt to improve the performance of interactions with digital tables. The techniques in the present research focus on those that can be used to perform near-synchronous close-proximity handoff interactions. These techniques are slide, flick, and surface-only force-field. A few other techniques are mentioned that help to clarify why defining handoff to be a near-synchronous close-proximity event is important.

Slide

One of the first and fundamental techniques to be developed for touch tables was the drag and drop technique [84] which has been designated as *slide* in the present research. This technique was a carry-over from the click and drag feature of desktop computers. It simply moves the object with the movement of the finger or input device at the same rate as the user's input. This action is identical to sliding a playing card across the table with a finger. However, developers have sought new methods to improve the efficiency of the slide technique. One recent and popular implementation is flick.

Flick

Flick is a technique that attempts to mimic the real world action of propelling an object across the surface of the table with a quick motion. In early use of wall displays this technique was often called throwing the object. It involved a short stroke in the opposite direction from that intended for the object to travel followed by a longer stroke in the intended direction (the difference between the shorter stroke and the longer stroke determined the velocity of the object) [24]. This throwing version, however, was not entirely intuitive. It required training [24] and gradually developers evolved this technique into more natural forms [2]. In the real world flick depends on a variety of variables including: the weight of the object, the force applied to the object (including the direction of the force), and the friction that occurs. All of the real-world variables can be simulated on digital devices. In some cases, digital devices are capable of improving such techniques by adding guidance systems to the flick mechanism to determine a final resting place for small targets [60]. Flick is now a common feature on all touch devices (e.g., smartphones, tablets, etc.). It is typically included in scrolling applications [2] and is a beneficial implementation on touch tables [60].

Despite its popularity flick has not been studied as a handoff technique. Flick allows users to send objects flying across digital surfaces, covering large distances that would be impossible to reach using the slide method [60], and the action of exchanging objects primarily takes place asynchronously. However, flick can be considered a handoff technique given the definition provided in the present research. That is, it is possible for flick to be treated as a near-synchronous event in which the receiver must catch the thrown object.

Surface-only Force-Field

Surface-only Force-Field (SurfaceFF), also called 2D force-field, was introduced by Jun and his colleagues [42]. This technique improves on the slide technique by causing the digital object to drift towards the receiver's approaching hand, making it easier for the user to grab the approaching object (see Figure 2.4). Jun determined that this technique sped up the time required to perform object transfers and would be an excellent implementation for collaborative settings on digital tables.

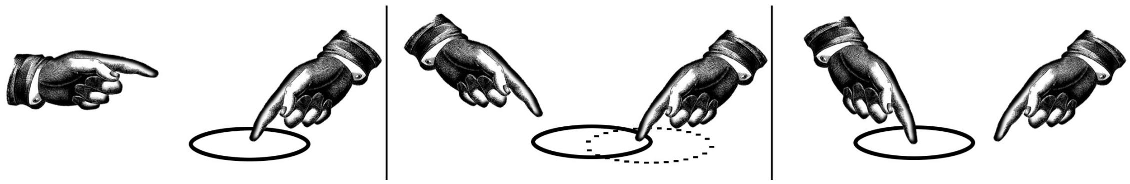


Figure 2.4: In the SurfaceFF technique, the digital object drifts towards the approaching hand.

While SurfaceFF works well with two people, it has issues when moved to larger tables with more than two users. This problem is due to how the object begins to drift towards other individuals when there are many individuals around the table. In the evaluation section, it is demonstrated that the performance of SurfaceFF begins to suffer with multiple users.

Asynchronous Handoff Techniques

A number of other techniques have also been developed on large digital tables to aid in the transfer of objects. The Bumptop table gives physical properties to digital objects. It allows them to be manipulated and to collide with other objects on the table in a process similar to flick but with additional object physics [1]. Some implementations create circular zones or wormholes at the corners of the table [88]. When individuals deposit an object into one of these wormholes, it will instantly be transported to another wormhole at a different location. One implementation focused on the personal zones or territories that people naturally create in collaborative settings [68]. This territory technique creates an artificial constraint on certain areas on the table. Individuals are only able to retrieve objects from their own, personal territory and the public shared territory. In order to pass an object from one individual to another, the object must be moved from the personal territory of the giver to the public territory where another individual can retrieve the object. Each of these techniques treats handoff as an asynchronous transfer event. These types of techniques have their place in digital table interaction and can be useful for transferring objects remotely. However, they fall outside the scope of the present research and are only presented here for breadth.

2.1.4 Above-surface Handoffs

Moving the handoff to occur above the table is not a new concept. Jun and colleagues proposed a new technique called Above-the-surface Force-Field (AboveFF) in the present research. It uses styluses to exchange objects over the surface of a digital table [42]. In Jun et al.'s implementation, a force-field was generated around each stylus when it was above the surface of the table. Whenever one stylus was within range of another stylus (crossing the force-field boundary), the object transfer would occur. In their study Jun et al. allowed participants to use both the surface-based handoff and above-surface handoff. They found that participants used the above-surface handoff much more frequently (82% of the time [42]).

Other forms of above-surface handoffs typically involve attaching digital objects to real-world objects. MediaBlocks are a popular example of using real-world objects to represent digital objects [81]. They use electronically tagged wooden blocks that serve as physical icons (*phicons*) that are able to store and transport online media. The phicons can then be passed around from individual to individual in prehensile transfers. Streitz et al. describe using a system called *passage* [71]. This system binds virtual information structures (e.g., documents, photos, etc.) to an arbitrary physical object. They accomplish this action by identifying the object by its weight or by attaching an RFID tag to the object. Individuals can then bind a digital object to a readily-available physical object such as keys, pens, rings, or watches. While the use of tangible objects or styluses to transport digital media does provide a natural, real-world implementation of above-surface handoff, such objects are not convenient to use and require additional effort to prepare and transport [72]. However, other methods are available as an alternative to using physical objects. These alternatives will be explored in the next section.

2.2 Table Interaction Technologies without Physical Objects

In order to avoid using physical objects such as styluses, phicons, or arbitrary objects (as in the passage system) it is possible to infer the meaning of digital object manipulation. This action is accomplished by observing the hand postures and motions, or *gestures*, that occur around tables without individuals needing to physically manipulate a real-world object. Researchers track the arm and hand gestures individuals make as they manipulate imaginary objects identical to mime acting where performers simulate the existence of objects during a play. The methodology for the implementation of these technologies relies on how the term gesture is defined and how technology can be used to observe gestures in interactions above the table.

The term gesture is an extremely overloaded term. Efron was the first to classify gestures into five categories: physiographics, kinetographics, ideographics, deictics, and batons [18]. These categories have been refined and reclassified over the years by various authors. McNeil's categorization (beats, deictics, iconics, and metaphorics) [53] has become a popular taxonomy due to the clarity with which the relationships between gestures and functions are associated [9]. Further work includes the analysis of gestures in face-to-face design teams [7]. It has been used in collaboration around drawing surfaces [76] which was refined to the categorization of mechanics of collaborations in shared workspaces [59]. Typically, gestures are atomic postures that are strung together to form complete actions. Genest observed seven atoms in distributed collaborative settings: preparations, strokes, points, contours, retractions, rests and hesitations [25]. These atoms are combined to form gestures that occur both on and above digital tabletop displays (among other settings).

McNeil and Efron's categorization of gestures were largely communication-based and do not translate well to interactive surface-based gestures [87]. For this reason, the use of the word gesture in the present research will be used to focus not on aiding communication but on conducting events to perform actions on intangible objects on tabletop surfaces [59]. In this context, *gesture* is defined as a composition of gesture primitives, hand postures and dynamics [41], or as combinations of continuous movements [89] in three phases – start, dynamic, and end [5]. This definition allows us to include two types of gestures: those that occur directly on the surface of the table as if the user was interacting directly with the intangible object (such as tap, flick, flat hand, and catch as in Wu's tabletop gestures [88]); or those gestures that occur above the surface (such as the pinch, stretching, and moving that occur in Hilliges' interactions for object manipulation off of the surface [35]). Baudel and Beaudouin-Lafon's start and end phases are static hand postures (wrist orientation and finger positions) while the dynamic phase is the motion that occurs between the start and end phases [5]. Gestures based on this design require that all start positions differ from end positions and that gestures be classified according to the combination of their start and dynamic phases.

In the mechanics of collaboration, Pinelle and his colleagues define two main categories of activity: communication and coordination [59]. The communication activity focuses on verbal and visual cues whereas gestures are used as a communication method. Coordination focuses on sharing objects, tools, and time. The object handoff falls into this category although two other mechanics are naturally involved in order for the handoff to take place. These mechanics include: obtaining the resource, referred to as the pickup for simplicity; and deposit, or placing the object. As there are no tangible objects in the digital world, the gestures used in the present research can only mimic the coordination mechanics.

2.2.1 Surface Gestures

Surface gestures are the primitives, postures, and dynamic actions that take place strictly on the surface of the table. Typically, these are the one or two finger gestures forming interactions, such as pinch, flick, double tap [88], or the pick-and-drop gestures where an individual touches the surface to pick up an object and touches another surface to drop the object [61]. Since touch tables are able to provide the positions of the fingers on the surface, there is no need for external devices such as cameras or tracking devices. Surface gestures have been studied and developed quite extensively and have led to many innovations that have enhanced surface interactions. Wu and Blakrishnan developed context-sensitive actions based on gestures that allowed for easy interactions such as rotation and scaling, flicking and catching, and blocking information from viewers [88]. Wigdor and his associates developed surface interactions that take place both on the top and bottom of the touch table [85] and Wobbrock, Morris and Wilson allowed users to define their own gestures [87].

In another study, Wu and colleagues expanded on the surface gesture recognition work of Baudel and Beaudouin-Lafon. They proposed three new elements: registration, relaxation, and reuse [89] (compared to the start, dynamic, and end elements of Baudel and Beaudouin-Lafon's work [5]). The *registration* element is the starting phase of every gesture set, and is created out of a unique posture and can be continuous or discrete. This element differs from Baudel and Beaudouin-Lafon's start position that used a mutual position for all gestures. The *relaxation* element allows for the hand posture to change during the action, as gestures do in the real world. Previously, hand postures were required to remain the same throughout the dynamic phase. Lastly, *reuse* allows individuals to reuse gesture primitives, so that the same hand postures can be used to define different gesture sets. This feature decreases the cognitive load of the user that is required with a larger number of gesture primitives to remember.

While surface gestures have been used and developed extensively, they are not immune to a number of significant difficulties. Surface-only gestures tend to invoke learned behaviour from standard input devices such as the mouse. Wobbrok, Morris, and Wilson noticed that surface-only gestures tended to mimic mouse behaviour that could be alleviated if the users were not restricted to the surface [87]. They also noticed that individuals frequently use off-screen interactions and therefore natural gestures should not be constrained to the surface. Most significantly, participants in their study frequently used the space above the surface to resolve issues such as navigating around existing objects or in order to move objects from one surface to another [87]. Last of all, surface-only gestures generally require moving fingers across the surface which causes friction that slows the user and can cause discomfort. Cockburn, Ahlström and Gutwin note that finger movements, particularly in the north-west direction, are prone to error and are slower due to the increase in friction [10]. This friction induces a tendency for the finger to bend and requires increasing the force to move the finger.

2.2.2 Above-surface Gestures

Wobbrok, Morris, and Wilson showed that surface-only gestures are limiting [87]. Instead, Marquardt and colleagues suggest creating the 'continuous interaction space' where gestures begin on the surface of a digital table and extend the gesture into the space above the table, thus allowing for interactions to take place both on and above the surface [49]. The continuous interaction space can be implemented by allowing digital objects to be carried using depth cameras and projectors [86]. However, there are two fundamental drawbacks for above-the-table gestures when attempting to manipulate digital objects in the continuous interaction space. These are the tangible and visual feedback of a two-dimensional digital display. First, digital objects have no tangible properties. The user is provided with limited tangible feedback from the surface of the table but the lack of tangible feedback once the object has left the table can be an issue of concern [49]. Second, it is difficult to represent digital objects once they have left the surface of the digital display. A variety of techniques have been used to represent how objects should look once removed from the surface. Hilliges and colleagues attempted to extend realism by adding support for manipulating the objects in three-dimensional space. Hilliges et al. used arm shadows, object shadows and transparency in order to provide visual feedback to the user when the object is 'lifted' from the surface [35]. Hilliges later extended his work to include a representation of the object in three-dimensional space with the use of projectors and reflective glass [36]. Alternatively, Wilson and Benko decided to represent all objects as a ball once they were removed from the surface [86]. Despite the lack of tangible and visual feedback, researchers are still optimistic about using the space above the digital surface for interactions. As Grabowski, Rutherford and Mason summarize, "Humans can function quite well under conditions of impoverished, yet useful and appropriate visual feedback" [29]. Additionally, Marquardt's work does reveal that it is possible to implement gestures above the surface.

The continuous interactive space studies by Marquardt and colleagues focussed primarily on using proximity to initiate above-surface object interaction [49]. Yet if a full range of hand gestures could be detected above the surface of a digital table, it would then be possible for the full manipulation of digital objects using a variation of hand postures and movements. However, detecting complete gestures above the surface is more complicated than simply detecting movement since the interpretation of hand posture is also required. Hand detection is typically accomplished with camera tracking technology using gloves [19], markers [41] and/or colour [44]. Recently, depth-sensing devices have been used to perform hand tracking [47][36] where a depth-sensing camera separates the hand from the background using a depth constraint. One of these depth-sensing technologies, the Microsoft Kinect, has become quite popular recently [75].

The Kinect became popular because of its cost and flexibility. The Kinect works using an infrared (IR) laser emitter, an IR camera and an RGB camera. The laser source emits a beam (split into dots through diffraction). This pattern is captured by the infrared camera and correlated against a reference pattern (captured at a plane of known distance from the sensor and stored in memory). When a dot is cast on an object closer or further from the reference plane, the dot will be shifted in the direction of the baseline between the laser projector and the perspective center of the infrared camera. These shifts for all the dots are measured to create a disparity image; for each pixel, the distance to the sensor can be retrieved from the disparity image [43].

Using the Kinect camera both for its depth sensing and RGB-video features allow developers to create gestures from a combination of the hand location, posture, movement, orientation, and speed [47]. Tran and Trivedi were able to infer upper-body posture based on extremity tracking [79]. They accomplished this action by implementing an extremity movement observation (XMOB) system which tracks the extremity location and predicts motion as a temporal inverse-kinematics problem. Rather than using a single frame to predict the posture from the endpoint, posture inference from extremity tracking is done in real time. The motivation for using endpoints to determine posture stems from research in psychophysiology where it was observed that humans have the ability to recognize gesture activity by only observing points of lights representing the fingertip locations of a hand [40]. Additionally, a common hypothesis is that humans tend to optimize their movements in order to minimize the displacement of joints [79]. Even though Tran and Trivedi addressed the issue of recognizing upper body posture from endpoints, their methodology can also be applied to hand posture recognition. Joslin and colleagues were able to determine the hand and finger endpoints using only two-dimensional coordinates [41]. Using an inverse projection, they were able to convert the two-dimensional data into three dimensions that were refined with the use of inverse kinematics to determine the finger joint angles (since each joint angle has a unique solution that can be determined using joint constraints and fingertip location [46]).

The work accomplished by Tran and Joslin demonstrates the ability of depth and RGB camera combinations, such as the Kinect, to infer posture positions over time. Stringing individual postures over time allows developers to detect gestures (postures and motion), creating above-the-surface gestures. Additionally, improving the data retrieved from the Kinect can be accomplished by integrating the RGB and depth camera images by using image processing techniques such as colour balancing and dilation/erosion, and incorporating the depth image using a probabilistic model [77].

2.2.3 Issues with Gesture Recognition

While gesture recognition can be captured with cameras, allowing surface gestures to be moved away from the surface, it does so with some difficulty. People adapt and modify hand postures to interact with other people and objects depending on the shape, size and intended purpose [74], and do so easily without much thought for what they are doing [70]. The ability for people to adapt, manipulate and change their postures makes it difficult to have a set of predefined postures or to use predicting techniques. For instance, while Sallnas and Zhai believed handoff to be modeled by Fitts' law [65], their results did not take into account the flexibility of a free moving arm and, without haptic feedback, the handoff interaction cannot be modeled by Fitts' law [29].

Also, the line-of-sight cameras suffer from the *occlusion* of fingers, limbs or objects. Occlusions occur when one object is hidden by another object and, in the case of hand gestures, this interference occurs frequently. Lathuiliere and Herve identify three common occlusions that occur during the approach and grasping phase of an object pickup [45]. First, in the approaching phase the hand can rotate around the middle finger axis occluding the furthest finger tips (Figure 2.5 a & b) and self-occlusion may occur when the wrist is folding, rotating the hand (Figure 2.5 c). Second, in the grasping phase any finger closer to the camera may occlude another finger (Figure 2.5 d & e). If there is contact with the surface of the table, then these points can be detected and, along with the occluded blob, can determine the approximate area and position of the hand [82]. However, hands or objects above the surface of the table will continue to be a problem.

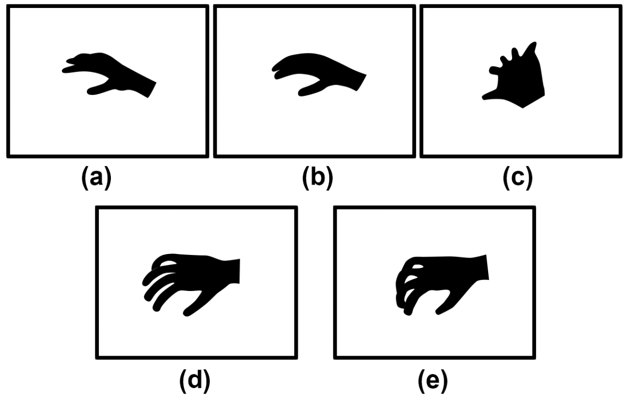


Figure 2.5: Possible line-of sight occlusions that can occur, adapted from Lathuiliere and Herve [45].

Third, the frame rate of the camera device will have an impact on the precision of the data collected. Movement that occurs too quickly will be lost from frame to frame. The depth data may also be obscured when objects or hands are touching one another. This problem limits the usefulness of devices like the Kinect [54].

2.2.4 Proximity as an Alternative to Gesture Recognition

While determining the exact posture of fingers may be difficult for low-resolution depth cameras such as the Kinect, it is quite feasible to detect the general area of the hand and fingers. Genest and colleagues developed a toolkit for capturing and displaying arm embodiments using the Kinect [27]. This toolkit, called KinectArms, uses the Kinect's depth camera to extract arm images from the RGB camera and determine the height of the arm. The toolkit provides two features, a capture module that segments hand information from the remaining background (i.e., the table) and a display module to reproduce the arm information at a different location [27]. If above-surface handoff is generalized to a tracking technique where object transfer is triggered by proximity (similar to Jun et al.'s work with the styluses used in their version of AboveFF), then the KinectArms toolkit could be adapted to allow for handoffs to occur when two hands are within close proximity of one another.

2.2.5 Touch as an Alternative to Gesture Recognition

A second alternative to gestures for above-surface handoff is to reduce the handoff process to a trigger action. If handoff could be defined entirely as a trigger action, such as a touch, then issues for above-surface tracking and posture detection disappear. Although any number of trigger techniques could be used, using a person-to-person touch as a trigger technique is very convenient. This approach does not require the individual to use any additional hardware when interacting around the table. Person-to-person touch detection can be achieved by taking advantage of the natural conductive powers of the human body.

In the late twentieth century a significant amount of research was conducted on using *people as antennas*. To use a person as an antenna refers to the ability of the human body to receive Electromagnetic (EM) signals or noise from a device or environment [13]. The human body is capable of acting as an antenna over a broad frequency range (from 40 Hz to 400MHz) [12]. Depending on how the antenna is created (based on the loop orientation) can affect how people influence the signal generated [14]. Cohn and colleagues used changes in a signal that occur as the body moves into different poses, leveraging the whole body as an antenna and demonstrating the ability to recognize whole-body gestures. They did this by using the body as an antenna to receive EM signals present in the environment (AC power in the walls for instance, in 50 to 60 Hz range) [13].

However, antennas can also generate EM signals and can be very useful for creating communication channels. An object that has capacitance can create a capacitive coupling between two conductors. For instance, a capacitive coupling object can create a conduit for a signal to travel from one antenna to another conductor. Since the human body has this capacitance property, people are able to act effectively as conductors and can provide capacitive coupling between an antenna and a conductor or between a transmitter and a receiver. At low frequencies, EM waves have a significant penetration depth of the human body (e.g., at 10MHz the penetration depth is about 200mm for muscle and over 1m for fat) [32]. At these frequencies, people could only provide capacitive coupling via physical contact such as holding an antenna and another conductor. Similarly, if a person holds two antennas, each generating a unique frequency, both of those frequencies would be transmitted to the other antenna.

2.2.6 Sensing Technologies

The use of capacitive coupling in Human Computer Interaction (HCI) is not a novel approach. A number of sensing technologies have been developed that use capacitive coupling. DiamondTouch, for instance, is a technology developed that lets developers know which individual is touching a particular location on a touch table [16]. DiamondTouch transmits a different electrical signal to each insulated antenna embedded on the tabletop. As Dietz and Leigh say, “When a user touches the table, signals are capacitively coupled from directly beneath the touch point, through the user, and into a receiver unit associated with that user. The receiver can then determine which parts of the table surface the user is touching” [16].

A different system, Smartskin, uses a grid-shaped mesh with transmitting electrodes in the vertical and receiving electrodes in the horizontal. The transmitters produce an electric signal in the area of several hundred KHz and the receiver receives a signal proportional to the frequency and voltage of the transmitter’s signal. When a capacitive signal approaches a grounded signal (e.g., a person touching the floor and whose hand approaches the surface) the wave signal is drained and the signal amplitude is weakened. Using this arrangement it is possible to determine whether someone is approaching closer to the table (within 5 to 10 cm) and finger positions on the table [62].

Touché uses a small sensing board (36x36x5.5mm) that both creates and receives electrical signals using a small battery and a microprocessor. An AD5932 wave generator synthesizes sinusoidal frequencies from 1 KHz to 3.5 KHz. The user interacts with an object that is attached to the sensor board (via a wire or electrode). Different types of touches (one finger, two, gripping, etc.) modify the signal waves that are generated in different ways. The sensing board measures the returned signal at each frequency, allowing the creation of a *capacitive profile* that can be used to determine different types of touches [66].

Also, mobile devices commonly use capacitive touchscreen technology that use an array of conducting electrodes behind a transparent insulating glass. Electrodes are driven by an AC signal which sends the signal through the touching finger (through the body), and back to the case of the touchpad. Vu et al. used a battery powered ring with a small amount of flash memory which sends a unique bit sequence to the mobile device in order to differentiate one user from another [83].

2.2.7 Touch Avoidance with Sensing Technologies

Typically, most people in North American culture subscribe to some form of touch avoidance. Touch avoidance, where people naturally try to avoid physical contact with others, is influenced by age, sex, religion and marital status [3]. This reality may indicate that technologies that rely on touch would be impractical for the general populace. While uninvited touch from a stranger, including accidental touch in a grocery store [50], can be considered offensive, intrusive or threatening [78], justified touching, or touching within acceptable boundaries, such as touching for attention and assistance, is acceptable [73]. Socially acceptable touching depends on how and where an individual is touched [3]. Moreover, a touch can invoke a range of emotions, either good or bad, depending on the interpreted meaning of the touch. Touching between strangers can have positive effects, casual touch by a librarian can change patron's attitudes [23], by a waitress to increase tips in restaurant [15], or by an employee to increase the favourability of a grocery store [38]. As Thayer writes, "Even a fleeting touch could influence attitudes and feelings between total strangers" [78]. For these reasons, task-based touching is an acceptable form of contact in North American culture and provides a venue for sensing technologies for use with the public.

2.2.8 Interference with Table Interactions

Interference is "unintended negative influence on another user's actions. It covers all instances where coordination fails, requiring participants to interrupt their activity and to re-negotiate who does what and when" (p. 169) [37]. Interference in above-the-surface interactions can be caused by occlusions and collisions of physical and digital objects. Moving handoff actions to the center of the table and above the surface increases the amount of interference experienced over other transfer techniques such as the Wormhole. Any increase in interference is generally considered to increase the hindrance of the users actions [80]. Typically, people try to minimize interference since, as Doucette and colleagues write, "People working at a table with their real arms and hands almost never touch or cross one another's arms…that is, people are careful to negotiate access to shared areas of the table, and rarely reach for the same object" [17]. This interference avoidance causes individuals to create personal workspaces or territories [80].However, interference will always occur and, some would argue, it is better to equip users with the resources to negotiate interference rather than prevent it [37]. In some poetry-based and music-browsing applications, Morris and colleagues witnessed the breaching of social norms on a collocated shared digital workspace where people would 'steal' words from one another. They found "people violating this social protocol by reaching into other users' areas of the table rather than asking them to pass something …We have observed that social protocols do not always suffice in relatively simple situations" [55]. Also, direct touch input, as opposed to device input such as mice, has a positive influence on interaction including un-requested assistance and non-verbal handoffs. However, it causes a slight increase in the rate of interference and user effort requiring lightweight re-negotiation between users when conflicts occur during handoffs [37]. While introducing handoffs above the surface of the table will produce interference, above-surface handoff also produces a convenient and intuitive method for negotiating that interference.

CHAPTER 3
OBSERVATIONS OF HANDOFF AT REAL-WORLD TABLES

In the real world, people use the space above the surface of a table for interactions such as handoff quite frequently. On the digital tables, people are forced to use the artificial constraint of surface-only interactions which requires more effort and is subject to occlusions and collisions. This chapter investigates how to bring above-the-surface handoff to surface-only environments, such as digital tables, by examining how people exchange objects in the real world and in unconstrained digital table settings.

3.1 Three Observational Studies

For this thesis, three studies were designed to determine:

- How handoff is performed in the real world
- How people would interact with digital objects if those objects could be removed from the surface
- How the speed of above-surface handoff compares to surface-based handoff

3.1.1 SHIFTRS, the Real-World Game

The first study examined how handoff is performed in the real world. To accomplish this study a game was created, called SHIFTRS, that involved different types of objects and required users to complete handoffs frequently. The game format was used in order to prevent participants from focusing on how they were exchanging the objects. Participants instead focused on the goal and strategies of the game, which resulted in natural handoffs more like what would occur in the real world. Since handoffs can be initiated by the giver ("Please take this") or the receiver ("May I have that?"), SHIFTRS forced participants to request objects from and give objects to the other player. Different types of objects were used in order to promote different hand postures and to examine the handoff of objects that require sensitive handling. Examples included a dangerous object (the knife) and a fragile object (an empty egg) in addition to the typically checkers-like game pieces.

Following is an outline of how the game SHIFTRS was played.

Game Objective: to make a path from the starting position to the center of the board using black and white pieces (see Figure 3.1).

Game Contents: 18 white pieces; 19 black pieces; 18 red pieces; 1 three player checker board; 2 knives; 2 eggs (hollowed out)

Game Assembly: each player gets 9 white pieces, 9 black pieces, 9 red pieces, 1 knife, and 1 egg

Game Setup: the spare black piece is placed in the center of the board, as the objective to be reached and each player puts one of their black pieces at the starting location

Game Rules:

1. Red, white and black pieces.
    a. Each red, white or black piece played in the game must be placed next to another piece.
    b. Black pieces must go on black tiles, and white pieces must go on white tiles, unless a wild object has been played (explained later).
    c. Red tiles and red pieces obstruct the path. A red piece can go on a white or black tile, thus obstructing the path for the opponent (see Figure 3.2).
    d. A single player cannot play two red pieces in a row.
    e. Each player attempts to build a path, made up of white and black pieces, from the starting point to the center point.
    f. The first player to make a complete path from the origin to the center wins.
2. Eggs
    a. An egg can be given to the opposing player in order to grant the player a free move. This action allows the player to play on a red tile providing it is adjacent to one of their own white or black pieces.
    b. The opposing player can then use the egg in any subsequent turn.
3. Knives
    a. A knife can be given to the opposing player in order to remove any red piece that is blocking a path.
    b. The opposing player can then use that knife in any subsequent turn.

Game Play:

Players flip a coin to determine who begins.

Players take turns to continue their own path or obstruct the opponent's path.

On each turn the player may do one of the following actions:

- Place a black piece on a black tile adjacent to another white piece
- Ask for a white piece from the opposite player, and can place that white piece on a white tile adjacent to another black piece.

- Give a red piece to the opposite player who must then place that piece either on a black or white tile, adjacent to any other piece that is closest to the center of the board, thus obstructing the shortest path to the destination
- Give a knife to the opposite player thus granting the giver the ability to remove a red piece
- Give an egg to the other player thus granting the giver the ability to play any piece on a red tile

Winner: The first person to complete a path from the origin to the destination.

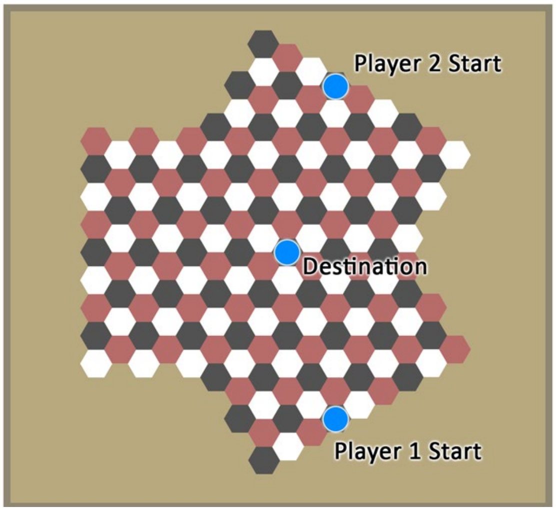


Figure 3.1: The game board for the SHIFTRS game with starting and destination locations

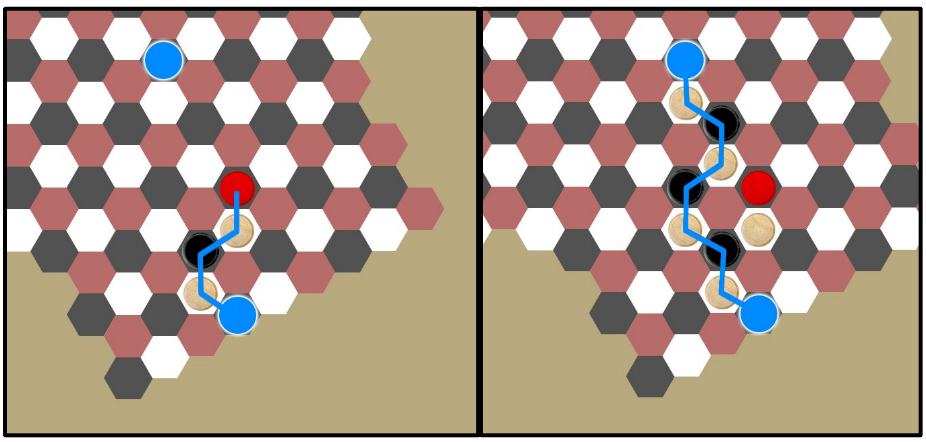


Figure 3.2: An example of the game in progress. On the left, player 1 is blocked by a red piece and must now choose a different path to reach the middle. One possible solution is given on the right, and can be achieved after at least 5 turns.

3.1.2 Unconstrained Object Transfer in the Wizard of Oz system

The second study examined how people would transfer digital objects if they were not confined to the surface of the table. To accomplish this study, a Wizard of Oz system was created for a large digital table environment. A Wizard of Oz system is a system that appears to be fully functional to the participants but is actually controlled by an experimenter working in the background. The system displayed a variety of digital objects on the surface of a 60" touch table display: a large box, a knife, an egg, a penny, and a plate (see Figure 3.3). Each of these objects was chosen since their real-world counterparts reflect different shapes, sizes, fragility and hazards.

Two participants stood on either of the long sides of the table, within easy reach of all the objects, and were asked to exchange those objects in the space above the table in any manner that felt natural to them. The task required that one participant 'pickup' the object and handoff the object to the other participant who would then place the object back on the surface. After all objects were exchanged one time, the participants would change jobs. The second participant would 'pickup' the object and handoff the object to the first participant who would then place the object back on the surface. The experimenter would observe the behavior of the participants and manually trigger the events of a digital object leaving the table and returning to the table to give the illusion of a fully working system.

Figure 3.3: The objects displayed on the Wizard of Oz system. A red line divides the table into two halves. One participant would stand on the side with all the objects and the other on the opposite side. The participants then needed to 'pick-up' the object, hand it off, and 'deposit' the object back on the surface. The objects, from left to right, are: a knife, a penny, an egg, a plate, and a large box.

3.1.3 Examining Speed in Sliders vs. Pickup

The final observational study, entitled Sliders vs. Pickup, examined how people exchanged digital objects if they were required to do so quickly and repeatedly without any visual representation (since digital objects currently have no representation in three-dimensional space), and whether handoffs above the surface could be performed as quickly as handoffs on the surface. Participants completed this task in pairs and stood on opposite sides along the lengths of the table. Eight areas were designated on the table as object origin and destination zones, four on each side of the table (see Figure 3.4). Participants were first instructed to handoff an imaginary object using only the surface of the table. In this surface-based situation, participants had to slide the imaginary object from the origin zones to the destination zones via a handoff. Participants passed four imaginary objects from each origin point to each of the destination zones for a total of 16 passes per participant. The experiment was repeated with the handoff occurring above the surface of the table. In this version, participants completed a physical touch to indicate that the object was transferred to the other individual.

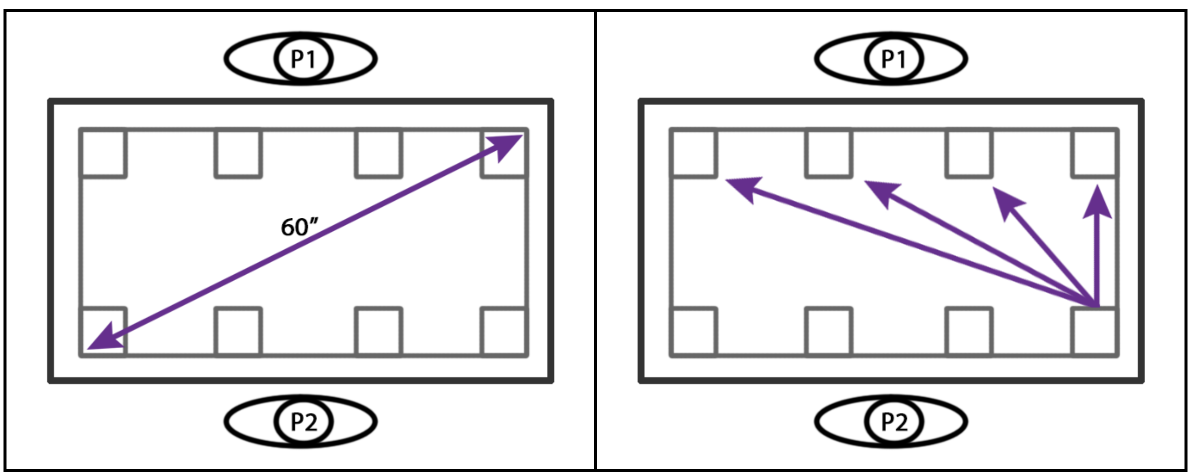


Figure 3.4: The Sliders vs. Pickup system - a 60" region was outlined on the table with eight squares designating origin and destination zones (left). Each participant had to pass an imaginary object from each origin to every destination (right).

3.2 Evaluation

Each observational study used a large table, measuring approximately 60” in diagonal, with the surface resting at approximately 32” above the floor (see Figure 3.5). Two video cameras were used to record the interactions that occurred. One camera was mounted at table level and filmed the interactions occurring from a landscape perspective while the second camera was mounted above the table facing down. The video was later analysed to determine: a) what hand gestures used for pickup, transfer and deposit; b) if physical contact occurred during handoff; and c) if there were any interaction patterns (e.g., givers reaching consistently farther).

Each study had participants working in pairs, standing at opposite sides of the table. Participants were recruited on three separate occasions from available graduate and undergraduate students in the Computer Science department at the University of Saskatchewan. The age, handedness, and height information was recorded for each participant in case this influenced the height or reach of the handoff. On each occasion of sets of participants, a different observational study was conducted. Some participants were involved in more than one of the observational studies. The details of each study are outlined below.

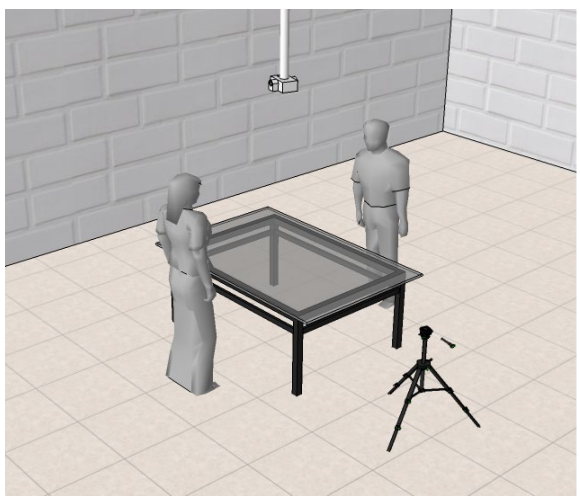


Figure 3.5: Participants for each of the observational studies stood at opposite sides of the table with two cameras capturing information. One camera positioned above the table facing down, and the other camera mounted beside the table.

3.2.1 SHIFTRS

For the observational study SHIFTRS, 11 participants were recruited, with one participant playing the game twice, the second time with a different opponent. Participants varied in ages from 22 to 35, with a mean age of 26.6, and a mean height of 173.8 cm. All of the participants were right-handed, 9 were male, and 2 were female.

Eight of these participants were graduate students. In order to participate in the SHIFTRS game, participants were brought into the experiment area in pairs. They were instructed on how to play the game SHIFTRS (as outlined above) and they were not informed of the purpose of the study. Participants stood on opposite sides of the table where the prepared game board and materials rested (see Figure 3.6). A height board was placed in the background to track the height of the hand and arm movements above the table. The game took between 5 and 15 minutes to complete.

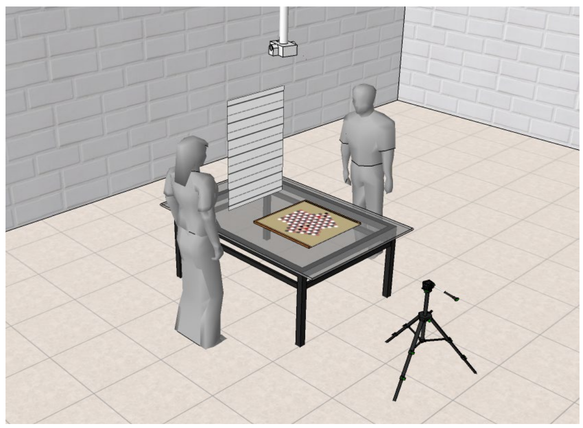


Figure 3.6: In the SHIFTRS study, a height board was used in the background to judge the height of reaches and handoffs. The game board rested on the table described above.

3.2.2 Wizard of Oz

For the observational study using the Wizard of Oz system, 8 participants were recruited (5 were in the previous observational study). Participants varied in ages from 22 to 35 with a mean age of 28, and a mean height of 171.7 cm. All of the participants were right-handed, 6 were male, and 2 were female. All of these individuals were graduate students. In order to participate in the Wizard of Oz system, volunteers were brought into the experiment area in pairs and stood on opposite sides of the table (see Figure 3.7). They were instructed to pickup, transfer, and deposit the objects being displayed in any manner that was comfortable to them, providing the transfer took place above the surface of the table. As the participants made a motion to pickup, transfer, and deposit an object, the experimenter would trigger the system to make the object disappear and reappear. The experiment ended when both participants had a chance to act as the giver for all the objects. The experiment took less than 3 minutes to complete.

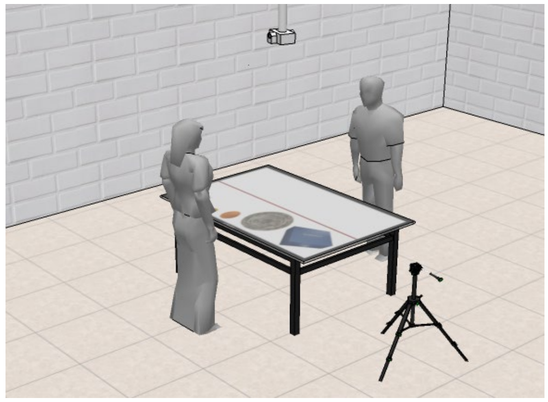


Figure 3.7: Participants using the Wizard of Oz system were positioned on either side of the table. The table displayed the objects while the experimenter triggered the events.

3.2.3 Sliders vs. Pickup

For the observational study Sliders vs. Pickup, 6 participants were recruited (5 of whom were in at least one of the previous observational studies). Participants varied in ages from 22 to 35, with a mean age of 25, and a mean height of 169.1 cm. All of the participants were right-handed, 4 were male, and 2 were female. Three of the volunteers were graduate students while the remaining 3 were undergrad students. In order to participate in the Sliders vs. Pickup, participants were brought into the experiment area in pairs and stood on opposite sides of the table (see Figure 3.8). Participants were instructed to handoff an imaginary object as detailed above. The experiment took less than 2 minutes to complete.

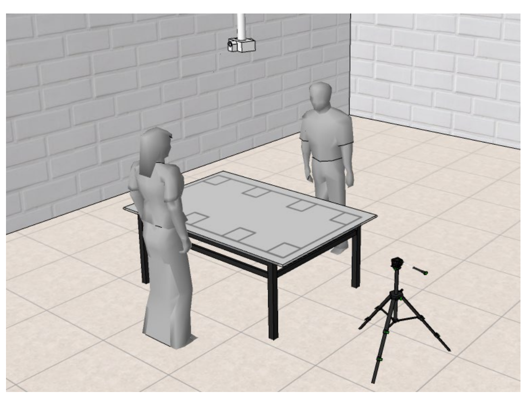


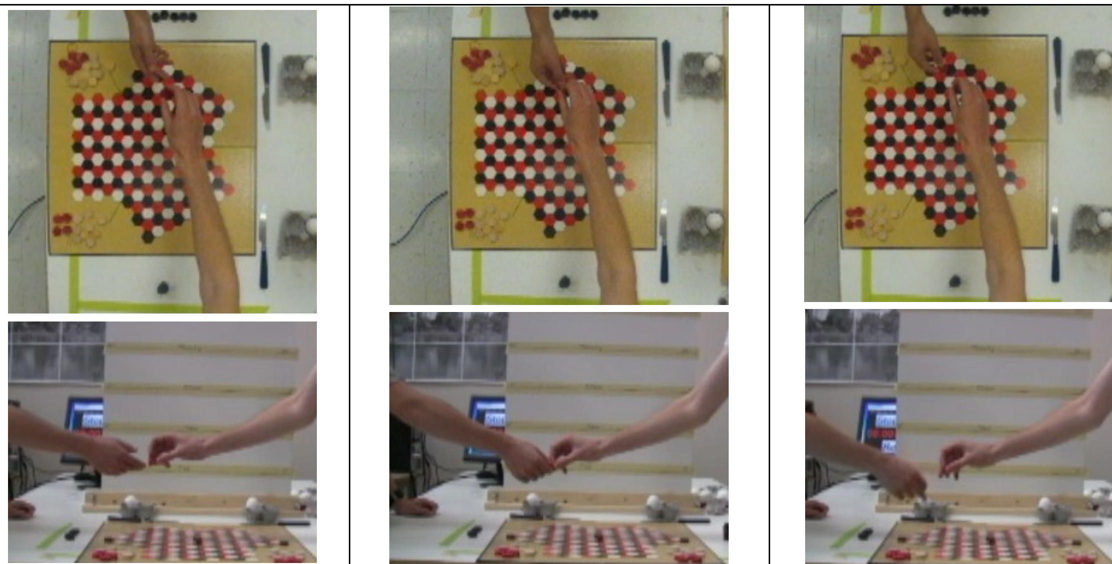
Figure 3.8: In the Sliders vs. Pickup study, participants exchanged an imaginary object, first on the surface then above the surface.

3.3 Results from Observational Studies

These studies led to research observations in several areas: a) how handoff is performed naturally (SHIFTRS); b) how flexible an above-surface implementation would need to be (SHIFTRS and Wizard of Oz system); c) how people interact with digital objects once they are removed from the surface of a table (Wizard of Oz system); and d) whether handoff above the table is faster than surface-based handoffs (Sliders vs. Pickup).

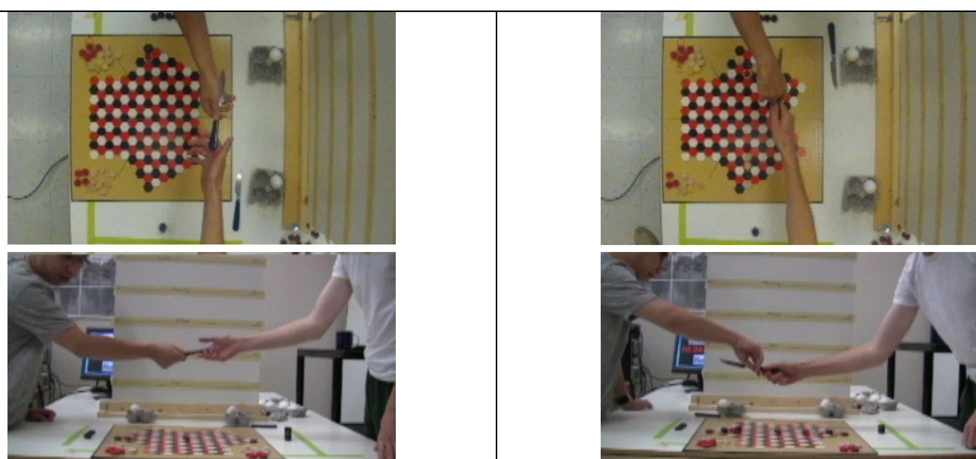
3.3.1 Dissecting the Handoff

The first two studies, SHIFTRS and the Wizard of Oz system, reveal a number of details about the hand positions, postures, and movements required to complete a handoff above the surface of a real-world table. From the first study, two observations can be made. First, people are able to give and receive a wide variety of objects that require different hand positions without a large increase to their cognitive processing load. This was evidenced by the fact that participants continued to plan strategies and examine the game board while conducting the handoff. Second, people use a wide variety of hand gestures to give and receive objects even when the objects are identical (see Figure 3.9 to Figure 3.13 below). These observations reveal that a digital object handoff system should be flexible (able to handle a variety of gestures), and natural, in order to prevent an unacceptable increase in physical effort or mental demand.



A. The giver (right) reaches the handoff point first in order to give the object.	B. The players touch as they complete the handoff. This could be accidental or an inherent tactile cue.	C. The receiver (left) proceeds to place the object on the game board, but the giver maintains the current posture a while longer.

Figure 3.9: The transfer of a small object in SHFTRS. In this series of frames, the giver reaches the handoff position first, and waits for the receiver. The release gesture by the giver is so subtle that only a detailed look at the picture can reveal any change in posture.



A. The giver (left) gives the knife with the handle pointed to the receiver.	B. The giver (right) alternatively gives the blade first, and the receiver (left) twists his hand to grab the knife.

Figure 3.10: The transfer of a knife in SHIFTRS. The giver (left) flips the knife around, while the receiver reaches under the knife to complete the handoff. Here they use the object's length to aid in the handoff, thus requiring less distance to move.

	
A. The receiver (right) asks for a game piece and waits while the giver (left) gets into position.	B. The receiver then moves into position to take the game piece from the giver.

Figure 3.11: An alternative version of the small object transfer. Here, an open-palm receiving gesture is used to exchange objects.

Figure 3.12: A third version of the small object transfer. The giver (right) deposits the game piece into the hand of the receiver. The giver reaches much farther than the receiver and a touch occurs.

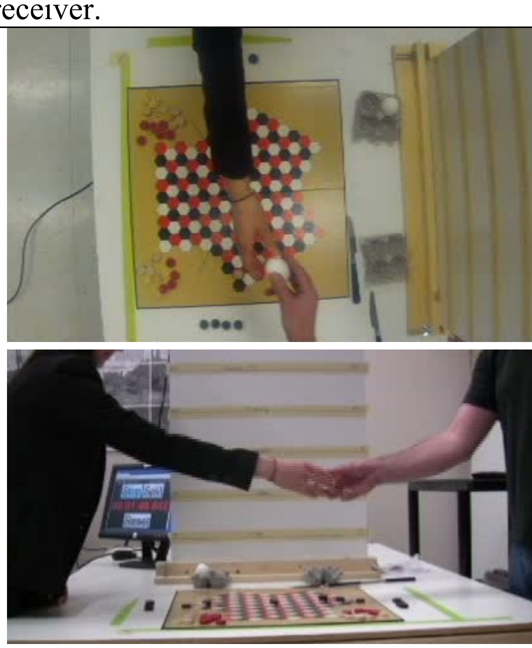
	
A. Giver (right) hands the egg over, the thumb and fingers being clearly visible from the top-down camera. Giver's thumb may be touching the index finger of receiver.	B. The giver (left) has no thumb visible from the top-down camera. Here a touch occurs.
	
C. A the same giver (left) uses a different posture for a new participant (right). The two touch and the hand postures look similar to shaking hands.	D. The giver (left), although shorter than the receiver, continues to reach across the majority of the table when giving the egg. From the top-down camera more fingers are visible than in (C) but the thumb is partly occluded.

Figure 3.13: Different hand postures are used when transferring an egg in the game SHIFTRS.

The second study revealed participants using a variety of hand positions when exchanging digital objects as they maintained their mental models of these objects once the objects were removed from the surface (see Figure 3.14). Also, individuals would often make physical contact when exchanging the intangible objects and the actions for picking up and putting down digital objects frequently involved touching the surface of the table (i.e., tap-to-pick-up and tap-to-put-down) as seen in Figure 3.15.

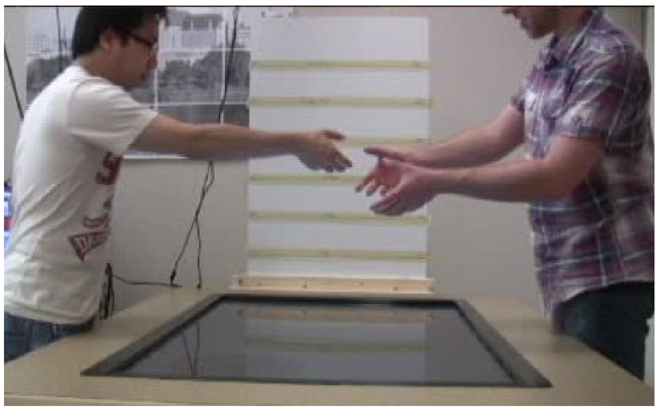
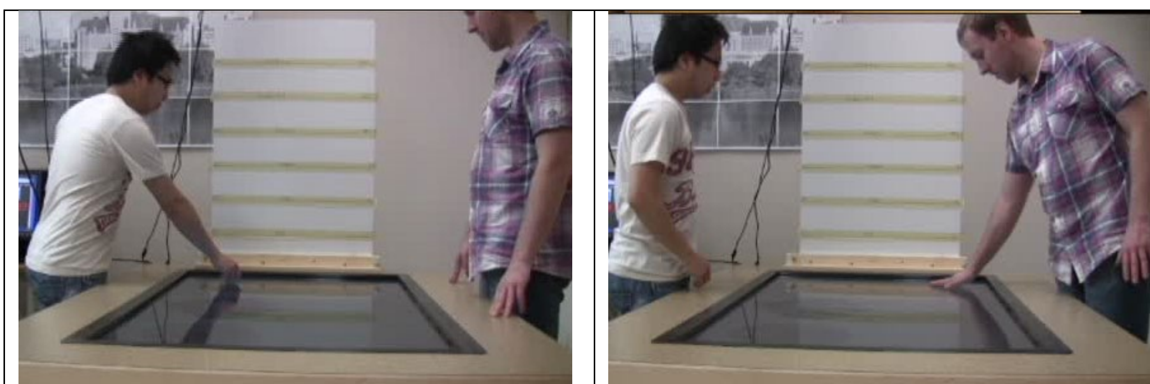


Figure 3.14: Participants maintain the shape of the 'box' as they exchange it in the Wizard of Oz System.



A. Participant on the left touches the surface of the table in order to 'pick up' the object.	B. Participant on the right touches the surface of the table in order to 'deposit' the object.

Figure 3.15: Participants touch the surface of the table to pick-up and place-down the digital objects in the Wizard of Oz system.

3.3.2 Surface-only Versus Above-the-surface

The second and third studies (i.e., the Wizard of Oz system and Sliders vs. Pickup) were used to determine if above-the-surface handoffs would perform better than surface-based handoffs.

The Wizard of Oz system

The second study led to a number of important observations.

1. Participants tended to maintain the prior mental images they had of objects even when not seeing the object.

This awareness caused participants to try to maintain the shapes of objects, such as the plate or large box, during the handoff process. From this observation it appears that people are able to work effectively with a minimal amount of visual feedback. In the Wizard of Oz system, objects simply disappeared when they were removed from the table, yet participants were able to keep a clear mental model of the object in mind during the interaction. This observation indicates that representing a digital object in the space above the table may be less important than might be expected.

As an interesting side note, a second set of objects were created for the Wizard of Oz system that showed several unseemly images, such as a rat and a needle (see Figure 3.16). However, participants had a strong aversion to touching such objects, even though they were only digital representations of the objects and not the real-world objects themselves (see Figure 3.17).

Figure 3.16: A second set of objects used in the Wizard of Oz system. Objects from left to right are: a piece of paper, a pile of salt, a needle, a rat, and a photo.

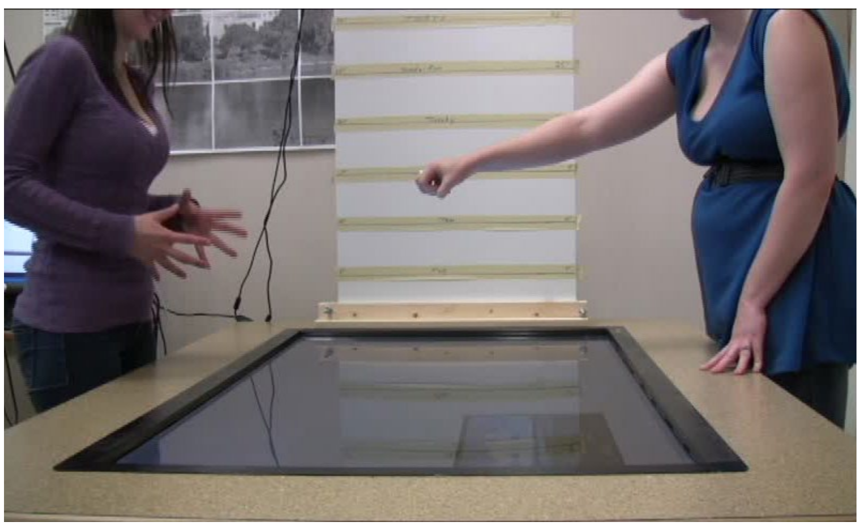


Figure 3.17: In the alternative version of the Wizard of Oz system, the participant on the right attempts to give the 'rat' to the receiver on the left, who reacts as though the digital object is real, even though there is no representation of the animal currently on the display.

2. The behavioral patterns of people interacting with the digital objects were quite intriguing and indicated interpretive mental processing that was going on concurrently with the physical acts of passing the digital objects.

Participants would attempt to pickup, pass, and place the digital knife safely (see Figure 3.18) even though there was no danger in passing around a virtual object. Also, participants used two hands for the large box when it had no weight or dimensions in the space above the table (see Figure 3.19).In some cases, participants determined that they could pickup and transfer objects simply with the touch of a single finger (see Figure 3.20).

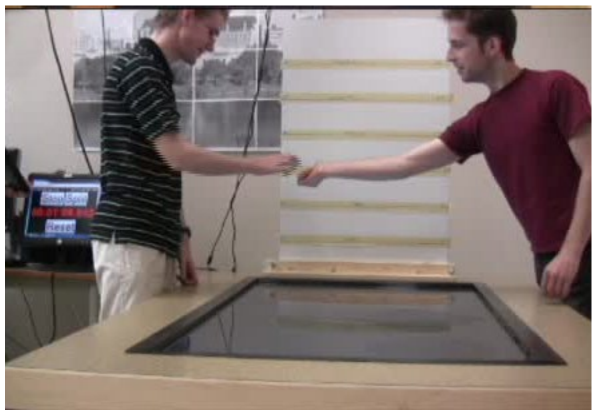


Figure 3.18: Two participants exchange a deadly 'knife' above the table in the Wizard of Oz system. Even though the digital object cannot possibly hurt them, they pass the object via the handle for perceived safety reasons.

Figure 3.19: Participants transfer a 'heavy' box in the Wizard of Oz sytem. Not only do they maintain the shape of the object but the perceived weight as well. There is a subtle decline in the receiving motion as the receiver (left) compensates for the 'weight' of the box.

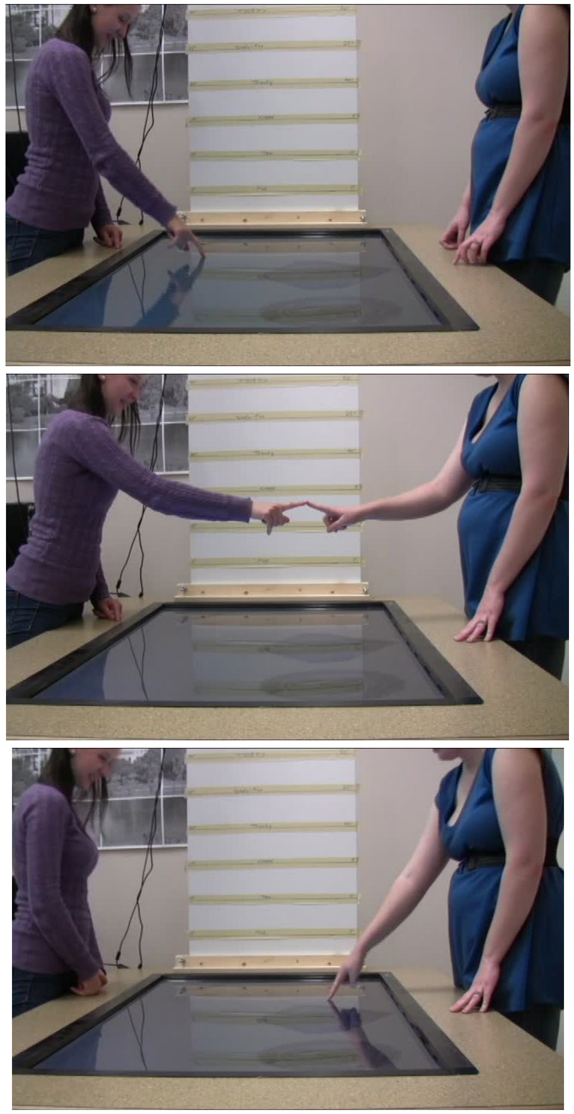


Figure 3.20: Two participants realize that they can simply touch the object to pick it up (top), touch to transfer the object (middle), and touch to set down the object (bottom) in the Wizard of Oz system.

3. It was apparent during the study that the novel idea of removing a digital object from the surface of the table would not prevent participants from completing the task.

Participants were quite comfortable coming up with ways to remove the object from the surface of the table. Some individuals would attempt to pickup objects as they would in the real world (Figure 3.21) attempting to maintain the shape of the object. Others would come up with simpler methods such as a simple touch (Figure 3.20).

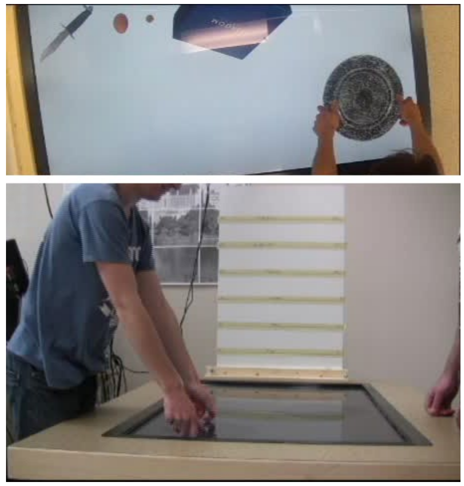


Figure 3.21: The participant picks up the plate as he would if the plate were real. However, the participant still makes contact with the surface of the table.

These observations indicate that it would be possible, with little difficulty, to require a particular method for picking-up or depositing the object, such as a tap-to-pick-up or tap-to-put-down. Participants also periodically made use of the dimensions that would exist if the digital object were real (see Figure 3.22). As individuals exchanged the virtual object in the space above the table, their movements included the approximate distance the object would have required, allowing the handoff to take place with some distance between the hands of the two individuals. This observation implies that techniques such as Above-the-surface Force-Field may have some merit.

Figure 3.22: Two participants exchange a large box, keeping the shape of the box as they interact above the surface.

The Sliders vs. Pickup system

The third study resulted in several additional observations.

1. People were initially unsure of how to perform a handoff above the surface but, with a few attempts they became 'experts' quite quickly.

This ability was witnessed in the Sliders vs. Pickup system, where participants struggled with attempting the handoff process at first yet were able to increase their speed quite dramatically after only a few attempts.

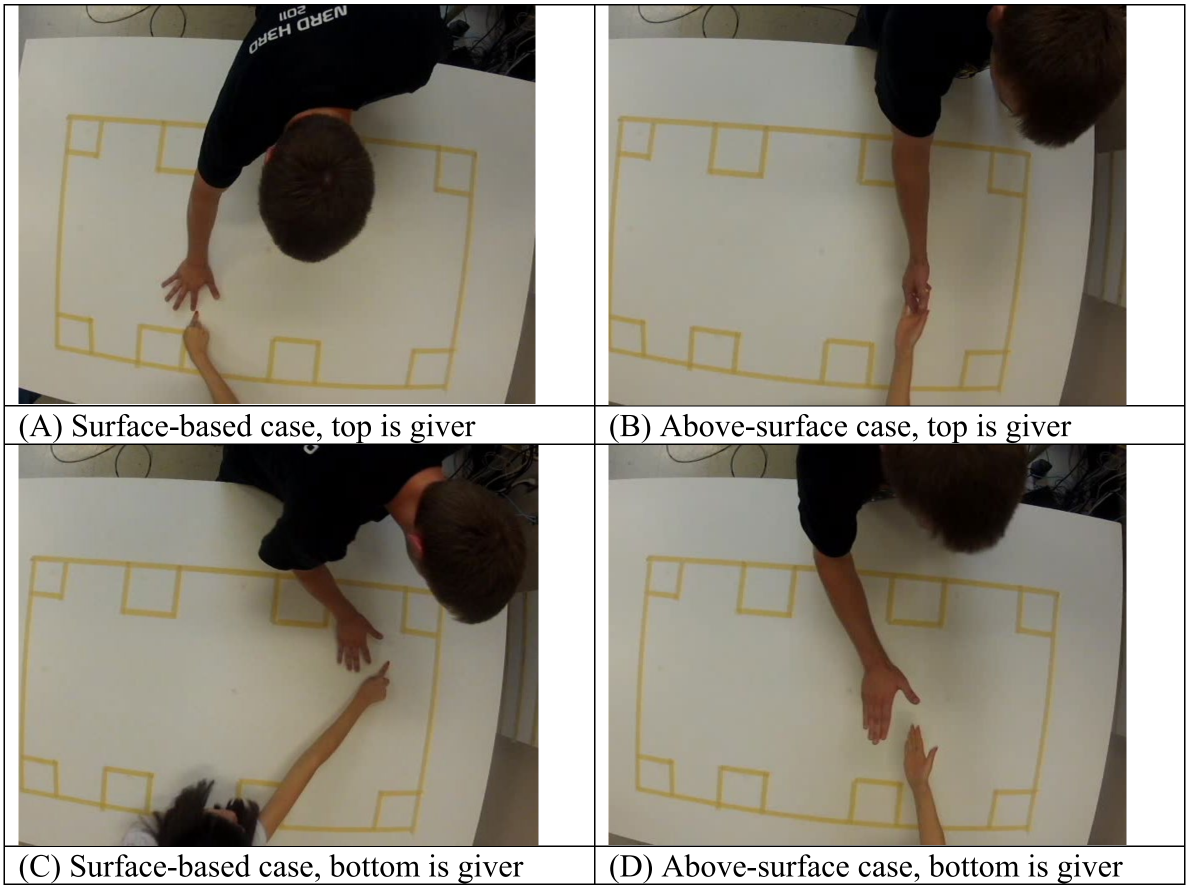
2. Handoffs above the table were noticeably faster than handoffs on the surface.

Even though individuals periodically started the above-the-surface task with some uncertainty, the handoffs above the surface became substantially faster than the surface-based handoffs. The increase in speed occurred regardless of the extra time participants took at the beginning to adjust to above-surface handoffs. The average time for surface-based handoffs was 38.84 seconds while the average time for above-surface handoffs was 31.58 seconds. The slowest group saw an approximately 11 second increase in speed over the surface-based handoffs while the fastest group saw an approximately 3 second increase in speed.

3. Interception (i.e., reaching a mutual handoff position) appeared to be more difficult for the surface-based handoff than the above-surface handoff.

The interception difficulties may have been caused by the lack of object representation on the table and influenced by the lack of tactile feedback that was experienced in the above-surface scenario. Since the surface-based handoffs have no tactile feedback at all, there was no additional sensory information for the receiver to be aware that the transfer had taken place. Likewise, if the giver removed their hand from the surface of the table before the receiver reached the transfer location, the receiver then showed hesitation in the pickup.

4. Based on the video observations, the giver generally reached farther than the receiver in the surface-based task. However, in the above-surface task, people with the longer reach reached further when giving and receiving, creating noticeably less effort in reaching by both parties (see Figure 3.23).



(A) Surface-based case, top is giver
(B) Above-surface case, top is giver
(C) Surface-based case, bottom is giver
(D) Above-surface case, bottom is giver

Figure 3.23: In the surface-based task, the giver generally reaches the farthest. However, in the above-surface task, the individual with the longest reach generally reached farther.

3.3.3 Conclusions

The observations gained from the three studies led to the following conclusions. First, any system implementing above-the-surface handoff would be required to be quite flexible to allow for a wide variety of handoff postures and dynamics as seen in the SHIFTRS and Wizard of Oz systems. Second, physical contact between people may be useful when exchanging digital objects in the space above the table, as observed in all three studies. Third, people are comfortable with the idea of removing an object from a digital surface, and touching the surface of the table would be an appropriate trigger for picking up and putting down the digital object as viewed in the Wizard of Oz system. Fourth, above-the-surface handoffs should be significantly faster than surface-based handoffs if implemented well as determined through the Sliders vs. Pickup study.

CHAPTER 4
DESIGN AND IMPLEMENTATION OF THE FIVE TECHNIQUES

This thesis examines five techniques for conducting digital object handoff both on and above the surface of a table. Three are surface-only techniques and are representative of common methods. These include: *slide*, the foundational and traditional technique; *flick*, a popular technique used in many tablet and smart phone devices; and *Surface-only Force-Field* (SurfaceFF), shown in the work of Jun and colleagues to be a faster technique than slide [42]. The remaining two techniques are new innovations for allowing handoffs to occur above the surface and include: *Above-surface Force-Field* (AboveFF), proposed in Jun's work [42] and treats handoff as a tracking-based technique, and *ElectroTouch* (ET), a new technique that reduces handoff to a trigger-based technique. The order of description in this chapter includes first the overall system design and implementation for the Kinect system (used by two of the techniques), then the design and implementation of each of the five techniques.

4.1 General System Design

All techniques were built for a 60" touch table that used a Sony NX720 LED LCD TV (native resolution of 1920x1028) for display, and a G3 PQ Labs frame to provide multi-touch input (see Figure 4.1). The system's display featured a single solid circle object and an outlined circle target area for one pair conditions, and two solid circle objects and two outlined circle target areas for two pair conditions. The solid circles had a radius of 6.5 cm and acted as the moveable objects to be exchanged between participants. In the two pair condition, the circles and outlines were colour coded (as seen in Figure 4.2) to ensure participants knew the correct destination. For each technique, participants needed to use their finger(s): to possess or take ownership of the object; to transfer the object according to the parameters of the appropriate technique (and thereby transferring ownership); and to deposit the object. For the surface-based techniques, transfers needed to take place within one second of the object being released or the object would be reset to its starting location. This duration (1s) was determined through pilot studies and allowed for a slightly asynchronous handoff which occurs from human perception errors, such as releasing the object too early. In order to encourage participants to perform the task quickly, an element of gamification was added to the task. Every time the object was moved from its origin to its appropriate destination the team (i.e., the giver and receiver) received a point. The score was displayed at the end of each round.

Figure 4.1: A PQ Labs frame is added overtop a Sony 60" TV with gorilla glass to create a large, mutli-touch display.

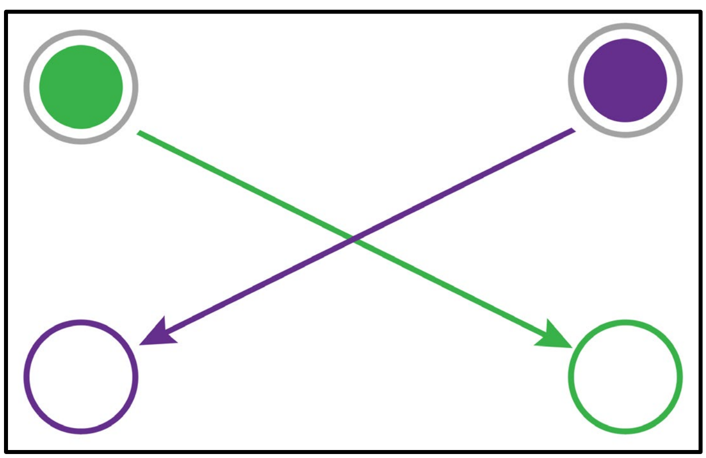


Figure 4.2: The Image displayed for the participants without the arrows.

4.2 Kinect Implementation

The Microsoft Kinect was used for hand tracking and for the force-field techniques. The system uses the Kinect to find the three-dimensional vectors of the farthest point from the users' arms, which are the fingertips, and converts these points to real-world coordinates. Using the KinectArms toolkit [28], objects appearing above the table are collected in a list. The list is modified, removing any objects that are too high above the table to be an arm, thereby removing heads that might be leaning over the surface. Next, the base for each arm is collected from the KinectArms toolkit as intersections between the table boundary and the arm (see Figure 4.3), except for the cases where the arm is occluded by another object, such as a person's head. In this case, the highest point on the arm is used as the base, a safe choice since people do not usually reach up to interact with other people. To assign each hand/arm to the proper user, a static anchor point in real-world coordinates is pre-assigned for each station, representing where an arm is likely to cross the table boundary on average for that station. For each arm, the distance between its base and each anchor point is calculated, and the anchor point with the minimum distance is noted. The arm is then assigned as belonging to the station corresponding to this anchor point.

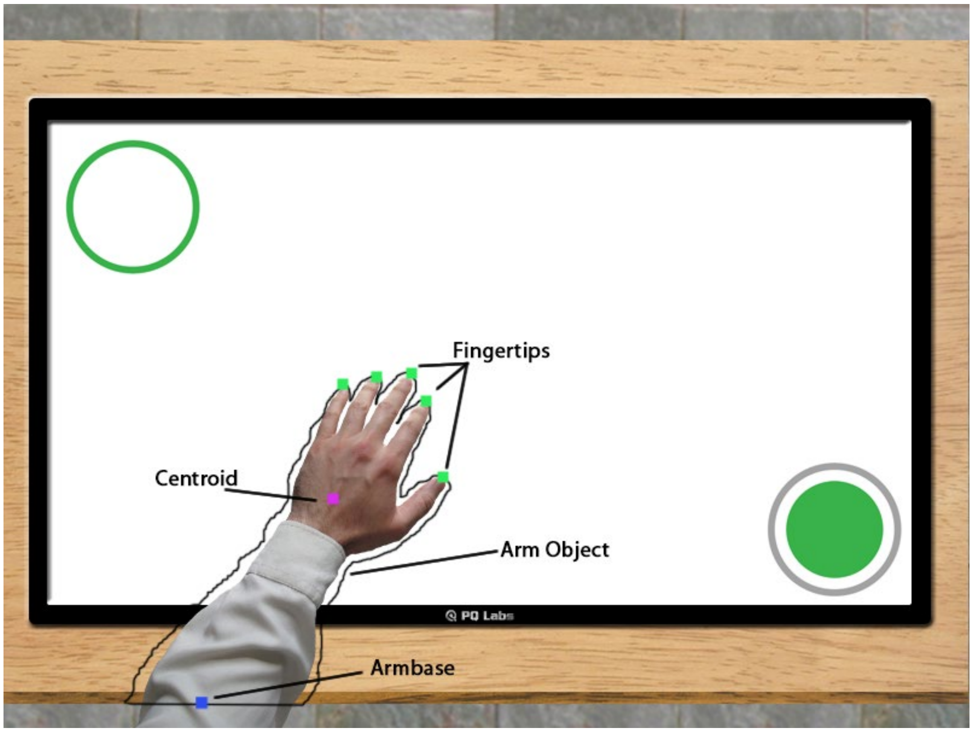


Figure 4.3: The *Arm Object* is found by the KinectArms toolkit, which is outlined in black, the center of the hand (centroid), fingertips and armbase are also detected and marked here for illustrative purposes.

According to the KinectArms toolkit, if any arms are crossing each other, the lower one is partially occluded and splits into two separate hand/arm objects (see Figure 4.4). To resolve this split the KinectArms toolkit was modified by casting lines between the centroids of each pair of objects, from the one crossing the table boundary, to the other object that does not (see Figure 4.5). For each of these lines, if the line intersects any other object aside from the two in question, it means that the two objects are part of the same arm (see Figure 4.6). If another line crosses the same occluding (i.e., another hand without a base on the table) object, then the pair with the shortest distance is used as the one to merge (see Figure 4.7).

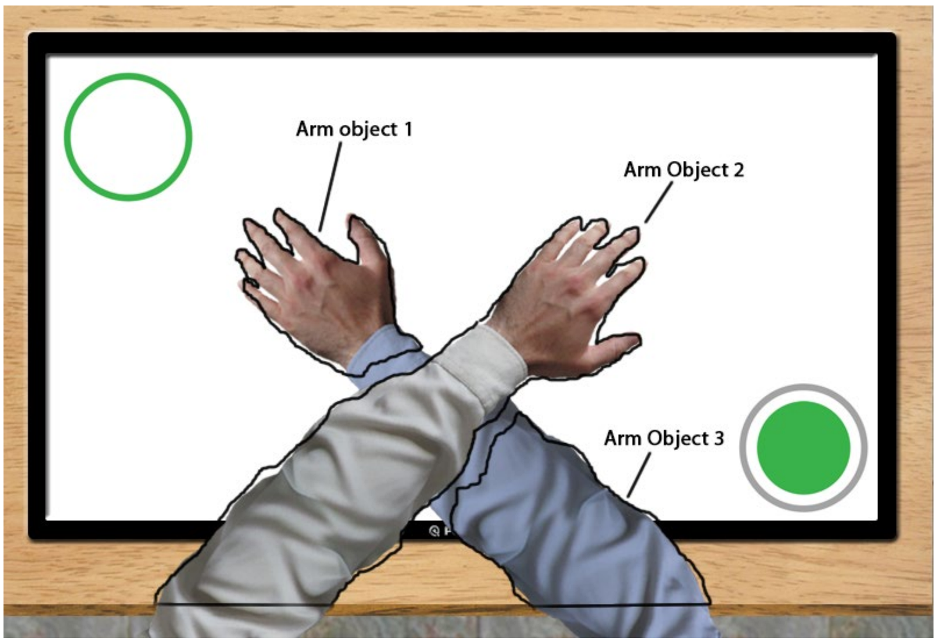


Figure 4.4: Multiple arm objects are created due to occlusion

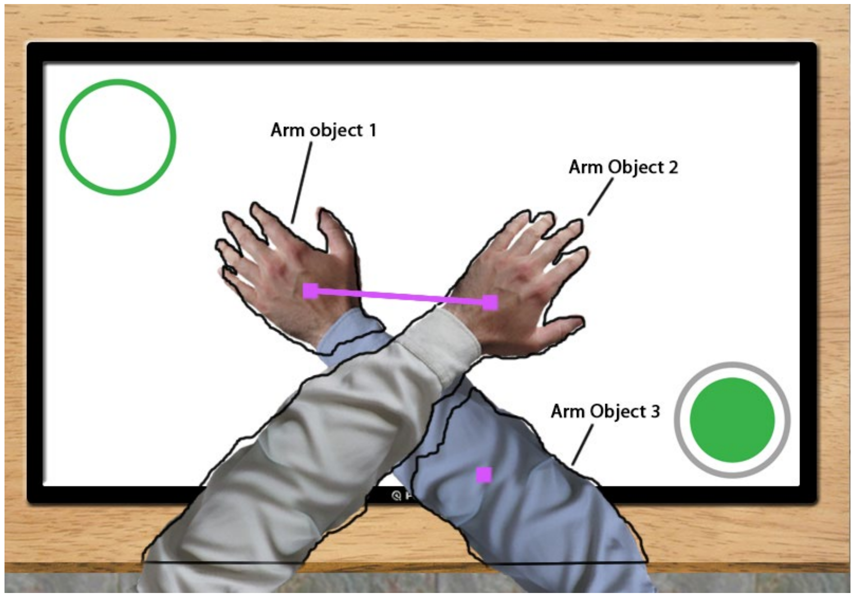


Figure 4.5: Casting a ray in this circumstance does not pair arm objects. Rays are cast from each arm object that has an arm base. In this instance the two arm objects are not matched up to a single arm object since the ray cast does not intersect with any other object.

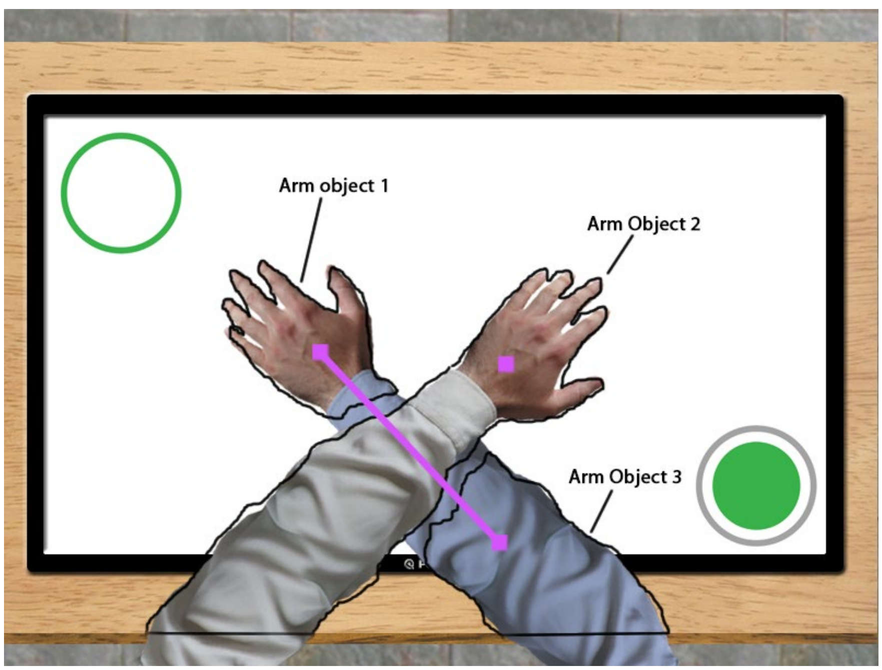


Figure 4.6: Casting a ray in this circumstance does pair multiple arm objects. Rays are cast from each arm object that has an arm base. In this instance the two arm objects are matched up to a single arm object since the ray cast does intersect another arm object.

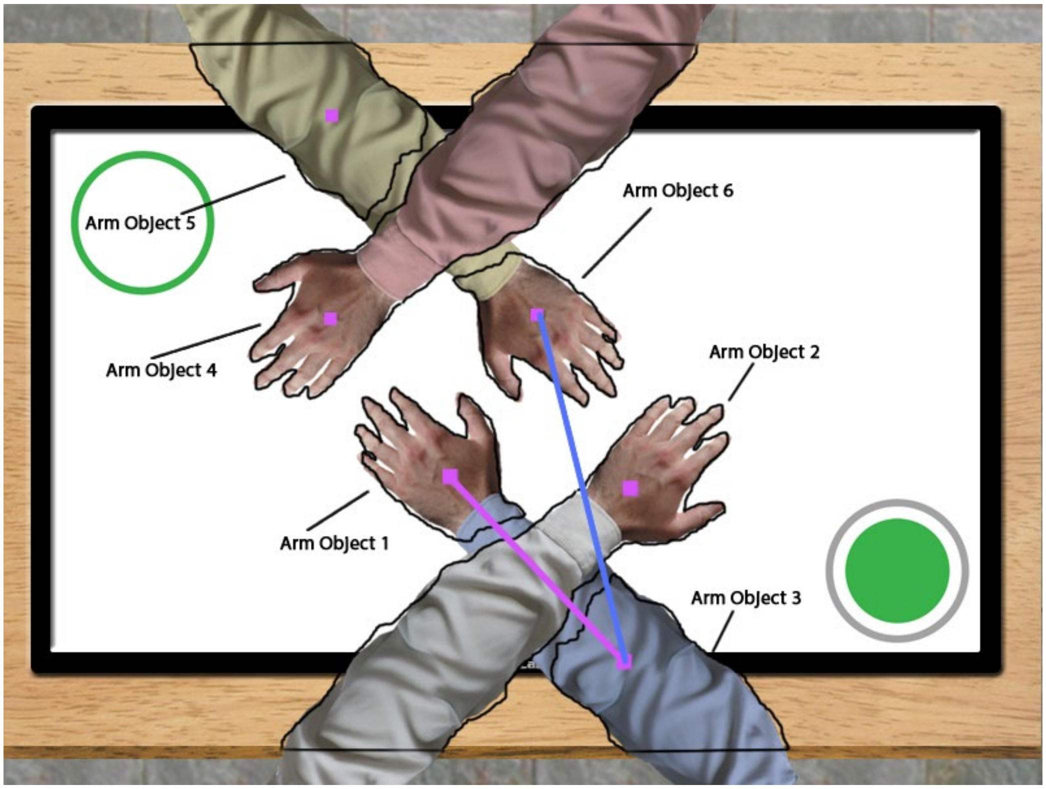


Figure 4.7: A ray is cast from Arm Object 3 and finds another arm object (Arm Object 1) on the opposite side of an occluding arm (Arm Object 2). A second ray also finds another arm object (Arm Object 6) that meets the same requirements, however, the distance to this object is greater than the one found earlier, so the program concludes that Arm Object 1 belongs to Arm Object 3.

Hand tips, representing fingertips, are assigned by iterating through the hand/arm boundary points given by KinectArms toolkit then finding the point with the farthest distance from the arm base. Using all of the visible hand tips, a matrix of three-dimensional vectors is calculated. This is called the hand proximity matrix. This matrix maps the location of each hand tip in its relation to the others. The hand tip locations and spatial relationship vectors are translated from Kinect-space coordinates (two-dimensional coordinates in the 640x480 depth camera view, plus the depth map value in millimeters) to real-world three-dimensional coordinates given in millimeters (see Figure 4.8).

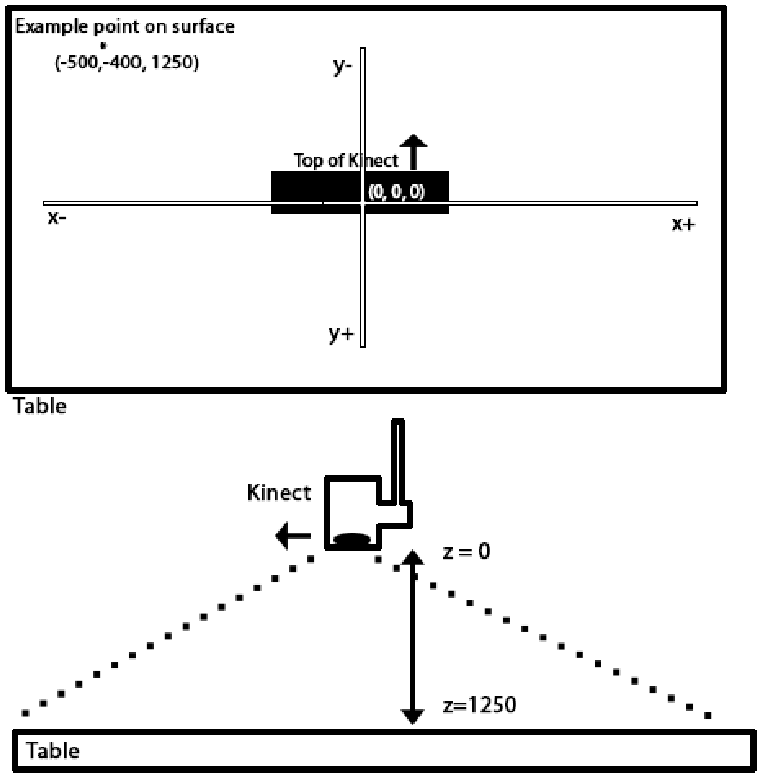


Figure 4.8: The real-world coordinates of the Kinect. At the base of the Kinect: (0,0,0), at the point on the table directly below the Kinect: (0,0,1250). The measurements are in mm.

4.3 Slide

The Slide technique is performed as typically seen in many touch-based systems. Object handoff can be performed in two ways. In the first method, the receiver can touch and drag the object to take possession while it is still being dragged by the original holder. Alternately, in the second method, the giver can release the object and thereafter have the receiver take it within a one second period. The one second delay allows for perceptual mistakes and premature releases of the digital object.

4.3.1 Design of Slide

As for all of the techniques, ownership of the object occurs when it is touched with a finger. The finger must maintain contact with the object in order to move the object. Releasing the object causes the object to stop, even if the object was previously in motion. Obtaining ownership of the object works on a last touch basis, that is, whoever is the last to touch the object takes ownership of the object. The object can be released for one second before it resets if it is not possessed again, to allow for finger skipping or delayed reaction by the receiver.

Figure 4.9: An illustration of the Slide technique

4.3.2 Implementation of Slide

The implementation for Slide only used the PQ Labs touch frame and the table display and did not rely on the Kinect. The touch frame provides the coordinates of the touch, which was cross-referenced with the position of the object on the display. If the touch was in contact with that object, the user could move their finger and the object would appear to move with it. This action was accomplished by updating the display with the new coordinates of the touch, and centering the object on these coordinates.

4.4 Flick

The Flick technique is similar to sliding except that objects can continue moving after being released. Flicking is a popular technique on many touch devices, such as tablets and smart phones, and is typically used for scrolling. Traditionally Flick is not treated as a synchronous handoff technique. However, Flick appears more frequently than Slide on many modern touch devices. In early pilot studies it became apparent that participants expected the objects to behave similar to the Flick featured in touch devices. Therefore, in order to properly evaluate the above-surface techniques with surface-based techniques, it was necessary to include Flick in the comparison. The above-surface techniques should perform at least as well as the common and popular Flick technique.

4.4.1 Design of Flick

As with Slide, the ownership of the object occurred when the object was touched with a finger. The finger must maintain contact with the object when the object is not already in motion, in order to cause it to move or to alter its course. Releasing the object will cause the object to carry on, on its original trajectory at the velocity that it was released at, gradually slowing down. If the object hits an edge of the table it will bounce back in the opposite direction. The object can be caught by placing a finger on the object as it moves or when it is at rest. If the object stops moving, the user has one second to grab the object before it resets to its starting location.

Figure 4.10: An illustration of the Flick technique

4.4.2 Implementation of Flick

Identical to Slide, Flick used only the PQ Labs frame and the display. The velocity and direction of the flicked object are calculated using the three previous positions for the object before release. Friction is applied to the object such that it loses 20 pixels per second of velocity. If an object collides with a table edge, it bounces off and loses 20% of its velocity in the bounce direction. The values for friction were chosen through informal testing to ensure this technique performed as well as possible.

4.5 Surface-only Force-Field

The Surface-only Force-Field (SurfaceFF), also called 2D Force-Field, was first developed by Jun [42]. This technique is identical to the design of Slide with the exception that the object drifts towards an approaching hand when it is being held. Jun and colleagues demonstrated that SurfaceFF is faster than the Slide technique.

4.5.1 Design of Surface-only Force-Field

As with the previous techniques, object ownership in the SurfaceFF technique begins when the object is touched by a user's finger. As other hands approach the object, the object begins to drift towards the approaching hand. As another finger touches the object, the object 'snaps' to the new hand. The object does not drift back to the giving hand unless that hand moves away and returns.

Figure 4.11: An illustration of the Surface-only Force-Field technique

4.5.2 Implementation of Surface-only Force-Field

SurfaceFF required the use of the Microsoft Kinect in addition to the PQ Labs frame and display. This technique is similar to sliding but contains a force-field effect in which the object drifts towards any other hand that is within a 13 cm proximity (based on Jun et al. [42] and refined through pilot studies). The Kinect sensor is used, along with the KinectArms toolkit, to smoothly shift the object from the giver to a receiver. The object is attracted to the receiver's finger with a displacement inversely proportional to the cube of the three-dimensional distance between the two subjects' fingers, using the matrix of proximity vectors (see algorithms in section 4.6.2). This attraction is applied to all other hands present above the table (e.g., when there are more than two people at the table) except for the one belonging to the person holding the object. A sum of the displacements is used to calculate a net displacement that is applied to the object. A maximum displacement is imposed to prevent the object from drifting beyond the nearest receiver's finger and beyond the reach of the giver. Additionally, once an object is transferred to a receiver, it will no longer attempt to displace to the finger of the giver. The force-field displacement effectively increases the touchable radius of the object. The maximum displacement is approximately 1.5 times the object radius.

4.6 Above-the-surface Force-Field

The Above-the-surface Force-Field (AboveFF) technique was initially proposed by Jun [42], although it was never tested. AboveFF is similar to SurfaceFF, but takes place above the surface of the table. A transfer takes place when two hands come into close proximity of each other.

4.6.1 Design of Above-the-surface Force-Field

As with all techniques, touching the object triggers object ownership. However, in AboveFF this action also removes the object from the surface of the table. The object is then represented as a semi-transparent version of itself in the corner of the table, in order to indicate which individual currently possesses the object. As the hand possessing the object approaches a different hand, the object 'snaps' to the approaching hand once the hands enter the transfer zone (an area around the giving hand). The object cannot be transferred back to the giving hand until that hand leaves and re-enters the transfer zone (an area approximately 13 cm or two times the radius of the object as proposed by Jun [42]).

Figure 4.12: An illustration of AboveFF. Once the approaching hand enters the transfer zone, the area around the hand of the object's owner, the object 'snaps' to the hand that entered the transfer zone.

4.6.2 Implementation of Above-the-surface Force-Field

AboveFF requires the use of the Kinect, in addition to the PQ Labs frame and display. This technique uses the fingertip locations found by the KinectArms toolkit, as discussed in the Kinect Implementation section 4.2. If the distance between the hands of two different individuals is 13 cm or less in the three-dimensional real-world space, a handoff event is triggered. The use of the three-dimensional distance allows one person to cross above or below another's arm without unintentionally triggering a handoff. In order to prevent handoffs from continuously repeating while two hands are within the transfer zone (i.e., transferring the object back and forth repeatedly), hysteresis is applied. This ensures the transfer does not occur again until the hands have left the transfer zone for at least one frame. The AboveFF implementation centers on three key functions that maintain key variables used in the main program. The `findFingertips` algorithm described below (full code in Appendix A.1) determines the real-world position of the fingertips of each of the hand objects above the surface of the table.

```
Algorithm findFingertips()
Determines the location of the finger tips given
Pre: curData (global)-is a copy of the kinectData
structure for this particular frame
     handTipLocations (global) - is a vector of three
floating point numbers, representing a position in three
dimensional space
     curHands (global) - is the current instance of the
hands as provided by the KinectArms toolkit
```

```
Post: handTipLocations (global) - is updated to
include the positions of the fingertips
Returns: none

void findFingertips()
  for handTip from each handTipLocations
    handTip <- -1  //initialize to offscreen
  end for

  for hand from each object in curHands
    if it is not the first hand object and not a
disembodied hand then
      start next iteration in for loop
    end if

    maxDistance <- -1

    for boundaryPoint from each boundary in hand
      distance <- distance between boundaryPoint and base
point of hand

      if distance > maxDistance
        maxDistance <- distance
        realPoint <- real world point of boundaryPoint
        handTipLocations for hand <- realPoint
      end if

    end for

  end for
```

The `calcProximityVectors` algorithm described below (full code in Appendix A.2) determines the minimum distance between fingertips (`minDistances`) and sets the proximity matrix (`proximityVectors`) as defined above. These variables are used by the main program to determine whether a handoff should occur (for AboveFF) and whether the object's position should be updated on the display (for SurfaceFF).

```
Algorithm calcProximityVectors
Calculates the proximity vectors and minimum distance
between fingertips
Pre: proximityVectors (global)-is the set of vectors
consisting of 3 floating point vectors and acts as a
mapping of each of the fingertip locations with respect to
the other fingertips forming the proximity matrix
     minDistances (global)-is the set of vectors
consisting of float vectors, this is used by the program
to determine if a handoff should occur because two hands
are close enough to trigger a handoff
Post: proximityVectors (global)-will be updated to include
```

```
the new fingertip locations with respect to each hand
      minDistances (global)-will be updated to include the
new minimum distances between each of the pairs of
fingertips
Return: none

void calcProximityVectors()
  depth <- depth of current frame of Kinect Data

  for i from 0 to total participants
    for j from 0 to total participants
      proximityVectors[i][j] <- create new
      minDistances[i][j] <- set to infinity
    end for
  end for

  for first from each curHands
    for second from each curHands while second < first
      if first == second
        start next iteration
      end if

      distance <- distance between first and second
handTipLocations
      minDistances[first][second] <- distance
      minDistances[second][first] <- distance

      firstToSecondVec <- difference between x,y,z of
second and first handTipLocations
      secondToFirstVec <- inverse of x,y,z of
firstToSecondVec

      proximityVectors[first][second]<-firstToSecondVec
      proximityVectors[second][first]<-secondToFirstVec

    end for

  end for
```

The `update` algorithm described below (full code in Appendix A.3) is triggered once for every frame captured by the Kinect. This algorithm calls the `findFingertips` and `calcProximityVectors` algorithms, determines which pairs of fingertips are close enough to trigger a handoff based on the information provided by the KinectArms toolkit, and sets the `handoffs` variable (a matrix of user pairs that have triggered a handoff). The information in the `handoffs` variable is used by the general system to update the display when a handoff is triggered.

```
Algorithm update(kinectData, time)
Determines which users handoff an object by populating the
```

```
handoff global variable to be used by the main program.
Pre: kinectData – data from the Kinect provided by the
KinectArms toolkit
     time – is the duration of the program so far, the
timer begins at the start of each technique
     minDistances (global)-is the set of vectors
consisting of float vectors, this is used by the program
to determine if a handoff should occur because two hands
are close enough to trigger a handoff
     surpressHandoff (global)-the set of vectors
indicating which pairs cannot perform a handoff
Post: kinectData – unchanged, Time - unchanged
      Handoffs (global) – updated to include the most
recent sent of pairs that have conducted a handoff
      curData (global) – updated to include the new data
received from the Kinect
      prevHands (global) – updated with the previous set
of hands received from the KinectArms toolkit
      curHands (global) – updated with the current hands
data from the KinectArms toolkit
Return: none

void update(KinectData& kinectData, unsigned long time)
  curData <- &kinectData
  prevHands <- curHands
  curHands <- kinectData.hands

  findFingertips()
  calcProximityVectors()

  handoffs <- allocate new handoff pairs vector

  for a from 0 to minDistances.size()
    for b from 0 to minDistances.size()

      bool recentHandoff <- time of most recent handoff
for either a or b is less than handoff suppression time

      if minDistances[a][b] less than minimum handoff
distance and not surpressHandoff[a][b] and not
recentHandoff
        handoffs.push_back(a, b)  //indicate occurrence
        surpressHandoffs[a][b] <- true
        surpressHandoffs[b][a] <- true
        lastHandoffTime[a][b] <- time
        lastHandoffTime[b][a] <- time
      else if minDistances[a][b] > minHandoffDistance and
minDistances[a][b] < 50000  //within boundary check
        surpressHandoff[a][b] <- false
        surpressHandoff[b][a] <- false
      end if

    end for
  end for
```

4.7 ElectroTouch

ElectroTouch (ET) is similar to AboveFF, except a touch must occur for a handoff to take place. This is an entirely new technique based on capacitive touch technology that is both cost-effective and provides a low-bandwidth, high confidence method of touch detection.

4.7.1 Design of ElectroTouch

ET requires that individuals touch in order for the object handoff to be executed. Similar to AboveFF, a semi-transparent representation of the object is placed in the corner next to the owner of the object once it has been picked up with a touch. The object is transferred from one user to another when a touch occurs. A short delay is added once the object has been transferred in order to prevent the object from being transferred back to the giver accidentally (e.g.., during a long touch).

Figure 4.13: An illustration of the ElectroTouch technique, where a handoff occurs only when two hands touch

4.7.2 Implementation of ElectroTouch

This implementation requires the use of custom ElectroTouch pads in addition to the PQ Labs frame and display. Users essentially extend an electromagnetic (EM) field by standing on wire-woven pads. The pads are two separate insulated copper wires (like that found in Ethernet cable) that are taped to a piece of cardboard measuring approximately 0.5 m × 0.5 m. One wire is for transmitting and the other wire is for receiving. The wires from the pads are connected to line inputs and outputs of a common computer sound card using a shielded electrical cable (see Figure 4.14).

The computer continuously sends sinusoidal signals, in the range of 16–19 kHz, to each of the pads (a different signal to each pad), and senses the signals coming back. In its neutral state, each pad will sense the same signal it emits. However, when users stand on the pads and make physical contact, they establish a weak electrical circuit connecting the corresponding pads. When this occurs, the sound card receives more than one signal from a pad: an original signal, and a signal of a different frequency, representing the pad of the touching user. The process is symmetric: when two people make contact, each of the two pads will be sensing the output of the other – this effect can be used to add redundancy.

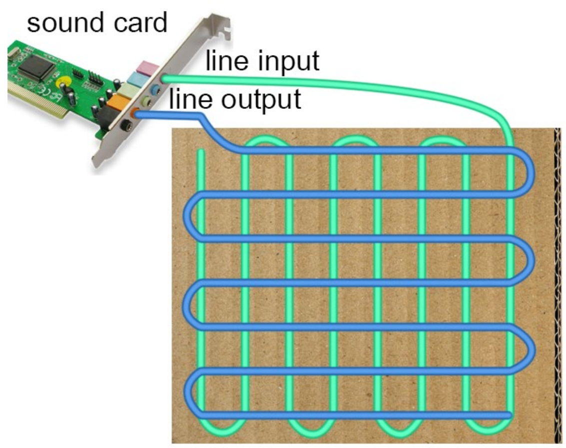


Figure 4.14: The ElectroTouch pad was created using two insulated copper wires taped to a piece of cardboard and connected to the line input and line output of a sound card.

The signals received from the pads are processed with the Fast Fourier Transform (FFT) in order to observe the signal magnitudes at all frequencies of the received spectrum. If the signals from the neighbouring pads rise above a certain dynamically-adjusted threshold, the system detects a 'touch' between those pads. Setting the threshold dynamically substantially increased the reliability of the system with people wearing dissimilar types of footwear.

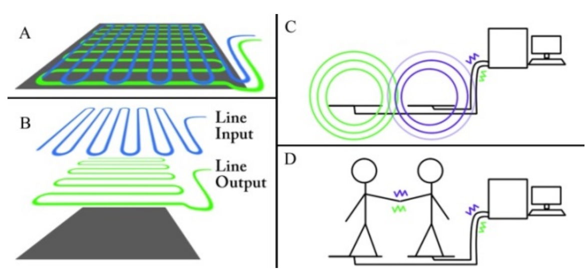


Figure 4.15: The ElectroTouch system built using antenna pads (A) connect to the line input and line output (B) of a soundcard creating EM waves (C) which are passed through a person's body and can be detected when two people touch (D).

CHAPTER 5
EVALUATION OF ABOVE-THE-SURFACE TECHNIQUES

This research used a participant study to compare the performance of surface-only handoff techniques (Slide, Surface-only Force-Field or SurfaceFF, and Flick) to above-surface techniques (Above-the-surface Force-Field or AboveFF, and ElectroTouch or ET). In order to measure performance, the study recorded time, accuracy, preference and workload. Time was measured by recording both the duration of each single handoff in addition to the time required to complete all necessary handoffs for one technique. Accuracy was measured by means of the number of times a handoff went to an unintended individual. Preferences and workload were measured through surveys of the participants.

5.1 The Participants

Eight groups of four participants (32 people total) were recruited from the local community, ages 19 to 50, with a mean age of 25.9 and a median age of 25, and heights ranging from 147 cm to 183 cm, with a mean height of 168 cm. 17 of the participants were female and 29 of the participants were right-handed. While all participants were required to use their right hand, there were no noticeable drawbacks to the participants that were left-handed since the object manipulation was on such a large scale that a high level of dexterity was not required. 22 of the participants indicated their primary pointing device was a mouse, while 9 indicated a trackpad and one indicated a touchscreen as the primary pointing device. 23 of the participants stated they had never used a digital tabletop while 20 of the 32 participants reported frequent use of other touch devices such as tablets and smart phones. The computer usage rate for participants ranged from 10 to 80 hours a week, with a mean of 35 and a median of 30 hours a week.

Each group of four participants was randomly divided into pairs. Both members in a pair acted as the giver and receiver an equal number of times during the study and performed both tasks from the left and right side of the table. Participants were located at the corners of the table during the study and were required to use only their right hand for all tasks. Each group completed all tasks in a one-pair scenario and again in a two-pair scenario.

5.2 Apparatus Setup

The study was carried out on a custom-built table that used a 60″ 1920x1028 LCD TV as its surface. As Figure 5.1 shows, a G3 PQ Labs overlay frame on top of the TV provided multi-touch sensing which caused a latency of 85ms between touch and display update. For tracking of arm locations for the force-field techniques, a Microsoft Kinect sensor was placed 125 cm above the table, pointing down at the table surface. Four ElectroTouch pads, one for each participant, were situated around the table (as shown in Figure 5.2). The study used custom software built in C++ and ran on a Core i5 Windows PC. Participants were located around the table as shown in Figure 5.3. Participants saw a simple interface with coloured transfer objects and circular drop zones (Figure 5.3 without the arrows).

Figure 5.1: The custom built table had the LCD tv inset into the center with a PQ Labs touch frame attached to the top that provided the touch interaction capability.

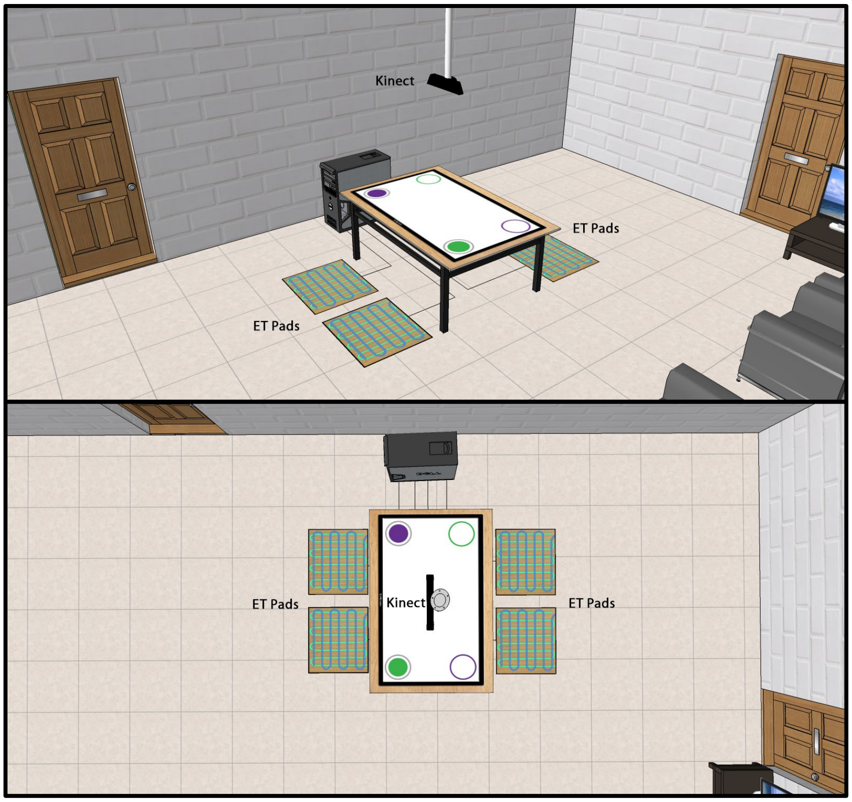


Figure 5.2: The side view (top) and top-down view (bottom) of the table, Kinect and ET pads setup.

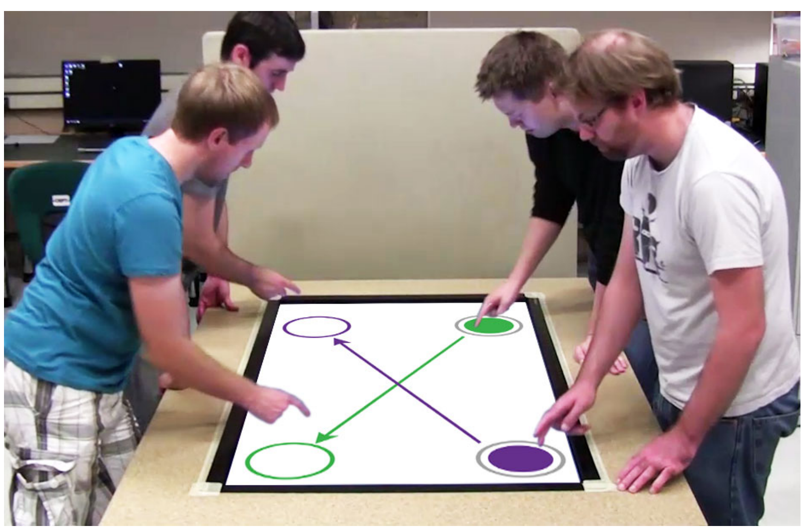


Figure 5.3: Participants were situated around the table in this manner and were shown a display like the one seen here (without the arrows).

5.3 Task

A task was chosen that represents the basic interaction underlying natural handoffs. People commonly execute handoffs without switching attention. This is particularly true for the person who does not initiate the handoff. The basic mechanism of handoff can be defined as a largely autonomous interaction involving four atomic actions: pickup, give-to, take-from, and deposit. This basic handoff mechanism underlies a wide range of possible handoff situations. Any disruption to the basic handoff mechanism in a digital context is likely to have a substantial impact on handoff performance and acceptance of the technology enabling handoff. Disruptions to the basic handoff mechanism are also likely to complicate other situation-specific handoff tasks such as determining which object to pick up, deciding who to give the object to, and other decision-making processes.

In the study, pairs carried out repeated handoff actions as shown in Figure 5.3. In each task, one person picked up or selected the 13 cm-diameter coloured object on the table and transferred it to their partner located diagonally across the table; the partner would then put the object into a circular drop zone 14 cm in diameter (sizes based on Jun et al.'s work [42] and refined through pilot studies). This sequence completed a single trial. A trial was successful if the receiver released his or her finger anywhere inside the target zone while dragging or putting down the object. If an object was left untouched on the table (other than in the start state) for more than one second, the trial was reset to its starting state.

5.4 Procedure

Participants carried out trials with all handoff techniques in both one-pair and two-pair conditions. Each session was split into two one-pair blocks and one two-pair block. A one-pair block consisted of two participants performing a series of object transfers for each of the five techniques whereas the two-pair block involved four participants completing object transfers simultaneously.

To encourage participants to perform quickly and accurately, a small element of competition was added: the system displayed the scores of the participants at the end of each series. Participants were given the impression that it was a timed event even though the session ended when the players (the losing team in the two-pair case) reached the minimum number of object transfers (the minimum numbers are detailed below). This procedure ensured that there were enough trials for each pair.

The object transfers always occurred from corner to corner (e.g., from P1 to P3 or P2 to P4 in Figure 5.3). For each technique, a series of at least 10 training trials were performed in both directions (e.g. participant A as giver, then participant A as receiver) for a total of a minimum of 20 training trials. This training was followed by a minimum of 12 actual trials in each direction (participant A as giver, then participant A as receiver) from both ends of the table (left position and right position) for a total of 48 actual trials.

Figure 5.4 outlines the procedure from start to finish where four participants are designated as P1, P2, P3 and P4. First, P1 and P3 perform the 10 training trials for one technique with P1 as the giver (A), then again with P3 as the giver (B). Then P1 and P3 perform the minimum of 12 actual trials with P1 as the giver (A) and again with P3 as the giver (B). P1 and P3 then switch ends of the table and perform the minimum of 12 actual trials with P1 as the giver (C) and again with P3 as the giver (D). P2 and P4 repeat this same process, where P2 is the giver for 10 training trials (E) and P4 is the giver for 10 training trials (F), then again for the actual trials (E and F). The P2 and P4 switch ends of the table and perform the actual trials again with P2 as the giver (G) and again with P4 as the giver (H). Once all techniques have been completed for the one pair condition, training is conducted for the two-pair condition for one of the techniques. First, P1 and P2 act as the givers (I) and the trials continue until the team with the least number of completed trials reaches the minimum 10 trials. The training then continues with P3 and P4 as the givers (J) until the team with the least number of completed trials reaches the minimum 10 trials. Once the training is complete, P1 and P2 again act as the givers (I) and continue to complete trials until the team with the least number of completed trials reaches the minimum of 12 trials. P3 and P4 then act as the givers (J) until the minimum number of trials is reached. P3 and P4 then switch positions, as do P1 and P2. P1 and P2 act as the givers again (K) until the minimum number of trials is reached. P3 and P4 then act as givers (L) until the minimum number of trials is reached. This entire process (from

I to L) is repeated for all the remaining techniques. Order of techniques were counterbalanced using a Latin square design. This process ensured that each participant performed a minimum of 680 trials ((20 training + 48 transfers) × 5 techniques × 2 blocks).

Participants filled out a consent form (see Appendix B.1) and a simple demographics survey (see Appendix B.2) before the trials began. After completing the trials for each technique, each participant completed a NASA Task Load Index (TLX) survey (see Appendix B.3) which assesses workloads of operators for specific tasks while reducing the subject variability between subjects [34]. When a pair finished the one-pair block (all five techniques), and again after finishing the two-pair block, they individually filled out a subjective-response questionnaire, ranking the five techniques on scales of naturalness, preference, and learnability. Once all trials were complete, participants stated overall preferences for the techniques in the one-pair and two-pair scenarios.

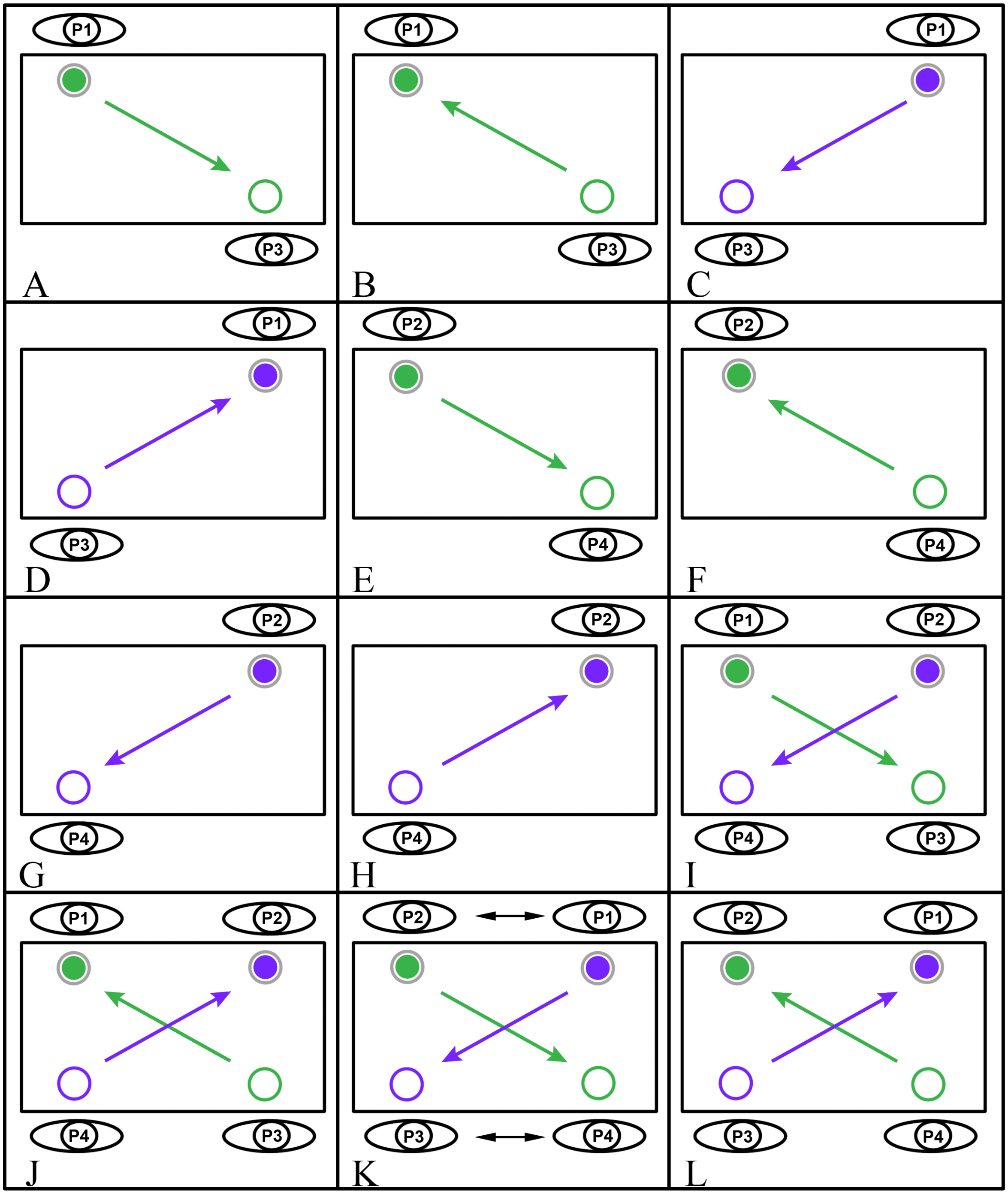


Figure 5.4: An illustration of the entire process for each technique. First in the one-pair block composed of training and actual trials (A-H) and again in the two-pair block (I-L).

5.5 Study Design

This research used a repeated-measures factorial design with two within-participants factors: handoff technique (Slide, Surface-Force-Field, Flick, Above-Force-Field, and ElectroTouch), and number of pairs (one or two pairs). Two dependent variables were recorded by the system: mean object transfer time (for all conditions), and accidental handoff rate (for two-pair conditions). Mean object transfer time was calculated by dividing the total elapsed time between each consecutive pair of successful deposits by the total number of successful deposits. Measuring elapsed time between deposits was crucial in the two-pair conditions, since the sender commonly waited to pick up the object in order to avoid a collision with the other pair. These pre-pickup delays are indicative of increased coordination effort (turn-taking), reduced fluidity of handoff, and reduced handoff throughput. As this measure utilizes successful deposits, it incorporates time added due to errors. The accidental handoff rate was used only for the two-pair conditions, and is defined as the total number of times the object was transferred to the wrong person, divided by the total number of successful deposits.

An RM-ANOVA was applied to test for the effects of handoff technique and number of pairs on time per handoff, to test for the effects of handoff technique on accidental handoff rate, and to look for interactions. Planned Bonferonni-corrected post-hoc t-tests analyzed interactions between the surface-based techniques, between the above-the-surface techniques, and between the best surface-only and the best above-the-surface techniques. Subjective analysis included NASA Task Load Index (TLX) ratings from each participant for each technique (in the one-pair and two-pair conditions) as well as participant rankings of subjective preference, naturalness, and learnability for each technique in the one and two-pair conditions. One participant failed to complete all the TLX surveys and therefore, all the responses of that participant were removed from the analysis. All TLX responses (i.e., workload) for each technique were averaged. The summary statistics of these findings are reported below.

5.6 Results

5.6.1 Handoff Transfer Time

Mean object transfer times, with outliers removed (outside 3 standard deviations, 156 of 8040 samples removed) for each technique and group size, are shown in Figure 5.5. RM-ANOVA found main effects of Handoff technique ($F_{4,28} = 261.96$, $p < .001$) and Number of pairs ($F_{1,7} = 18.62$, $p < .001$), as well as an interaction ($F_{4,70} = 86.11$, $p < .001$).

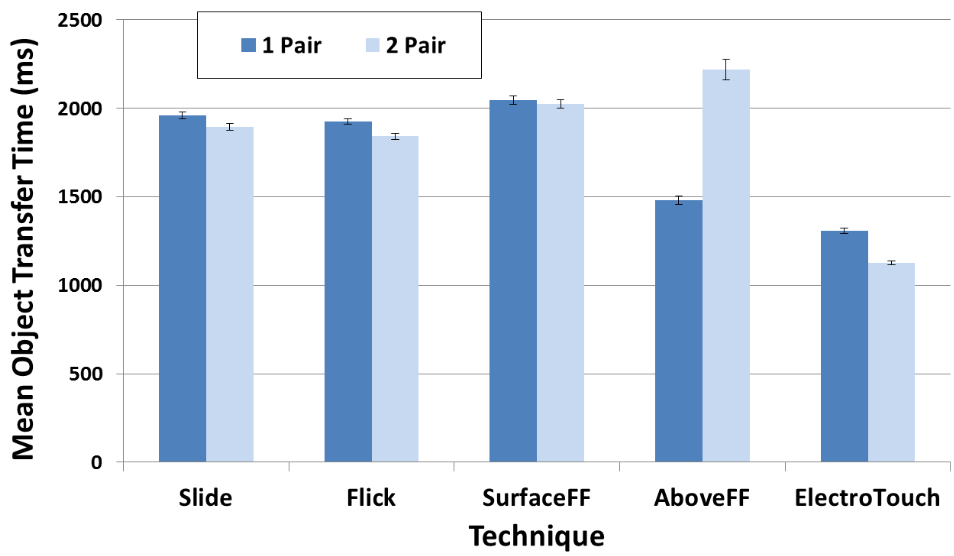


Figure 5.5: Mean object transfer time for both techniques in the one-pair and two-pair conditions. Error bars indicate standard error.

Planned post-hoc t-tests (Bonferroni-corrected, $\alpha = 0.003$) indicated that Slide and Flick were not significantly different in either group size (one-pair $p = .16$, two-pair $p = .06$), but that Flick was faster than SurfaceFF in both group sizes ($p < .001$), and Slide was faster than SurfaceFF for the two-pair condition ($p < .001$). For above-the-surface techniques, ElectroTouch was faster than AboveFF (both $p < .001$), and ElectroTouch was also faster than the fastest surface-based technique (i.e., Flick) for both the one-pair and two-pair conditions (both $p < .001$). Comparing the techniques within the group sizes, there were no significant differences for Slide ($p < .05$) or SurfaceFF ($p > .05$). Flick ($p < .001$) and ElectroTouch ($p < .001$) were faster in the two-pair condition and AboveFF was slower ($p < .001$).

In summary, ElectroTouch was the fastest technique for both one-pair and two-pair conditions. AboveFF was the second-fastest technique for one pair but the slowest technique for two pairs. All of the surface-only techniques showed similar mean transfer times, with Slide and Flick being slightly faster than SurfaceFF.

5.6.2 Accidental Handoff Rate

Mean accidental handoff rates for each technique are shown in Figure 5.6. RM-ANOVA tests found a main effect of Handoff technique ($F_{4,28} = 199.33$, $p < .001$). Planned post-hoc t-tests (Bonferroni-corrected $\alpha = 0.002$) showed significant differences between all techniques except Flick and AboveFF ($p = .03$). These results show that ElectroTouch has the lowest accidental handoff rate.

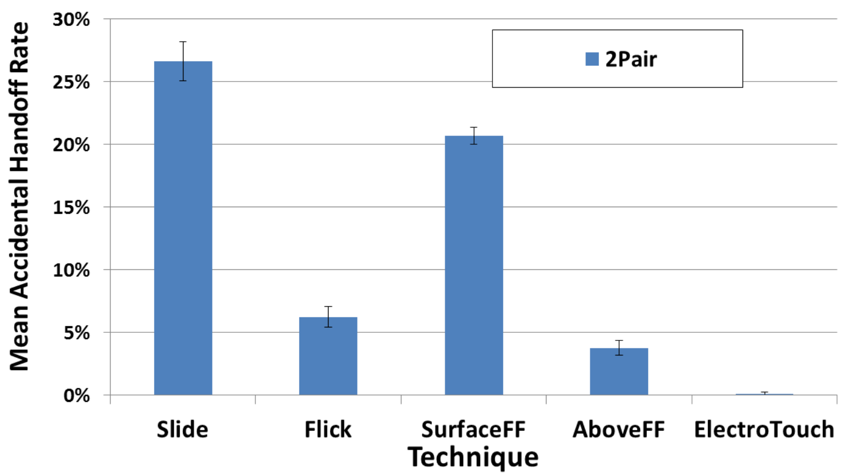


Figure 5.6: The mean accidental handoff rate in the two-pair condition.

5.6.3 TLX Responses

The TLX individual scores were collapsed into an overall mean [34]. RM-ANOVA conducted for the independent variables (pairs and technique) with the dependent variable (workload) showed that all effects were significant ($p < .01$). Mauchly's test indicated that the assumption of sphericity was violated only for the main effect of technique and therefore, the degrees of freedom for this effect were corrected using the Huynh-Feldt estimates of sphericity. There was a significant main effect for number of pairs across all techniques ($F_{1,30} = 18.85$, $p < .001$) which indicated an increase of the number of pairs increased the workload as well (see Figure 5.7). There was also a significant main effect of the technique (F4,120 = 3.72, p < .01). The post-hoc pair-wise comparison revealed that only the difference between AboveFF and ElectroTouch was significant, with ElectroTouch having a lighter workload (see Figure 5.8). Finally, there was a significant interaction effect between the user and technique (F4,120 = 6.32, p < .001), showing that the number of users had an effect on each of the techniques. The post-hoc analysis revealed there was a significant difference only in the two-pair cases (see Figure 5.9). First, there was a significant difference between SurfaceFF and ElectroTouch (p < .05). There was also a significant difference between AboveFF and Slide (p < .01), and AboveFF and Flick (p < .01). Finally, there was also a significant difference between ElectroTouch and AboveFF (p < .001).

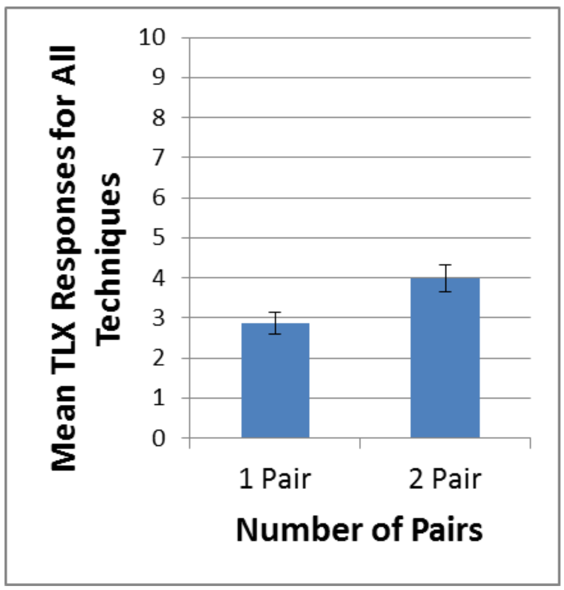


Figure 5.7: The mean TLX responses of all workloads for all techniques. According to the TLX scale 0 indicates a low amount of effort and 10 indicates a high amount of effort.

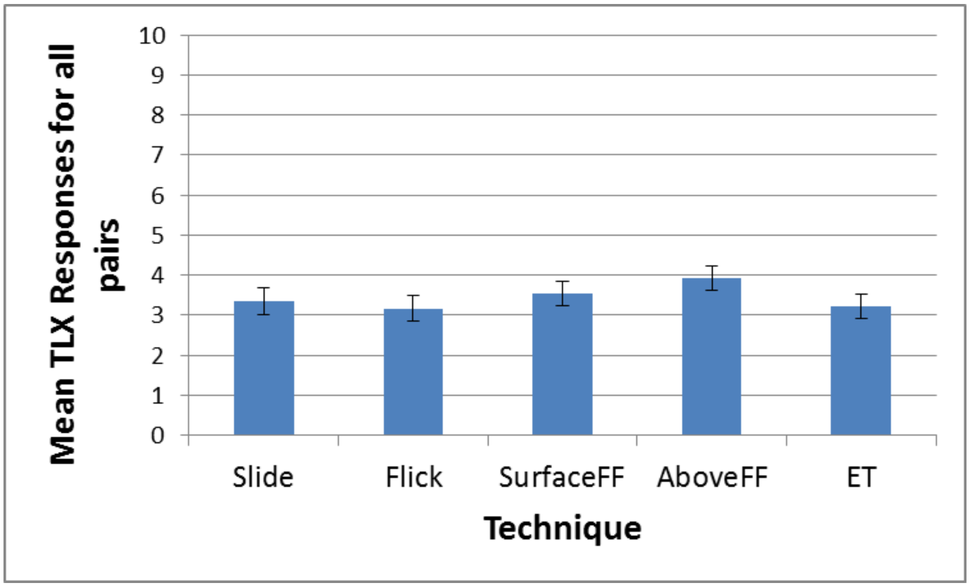


Figure 5.8: The mean TLX responses of all workloads for all pairs. These include the techniques Slide, Flick, Surface-only Force-Field (SurfaceFF), Above-the-surface Force-Field (AboveFF), and ElectroTouch (ET).

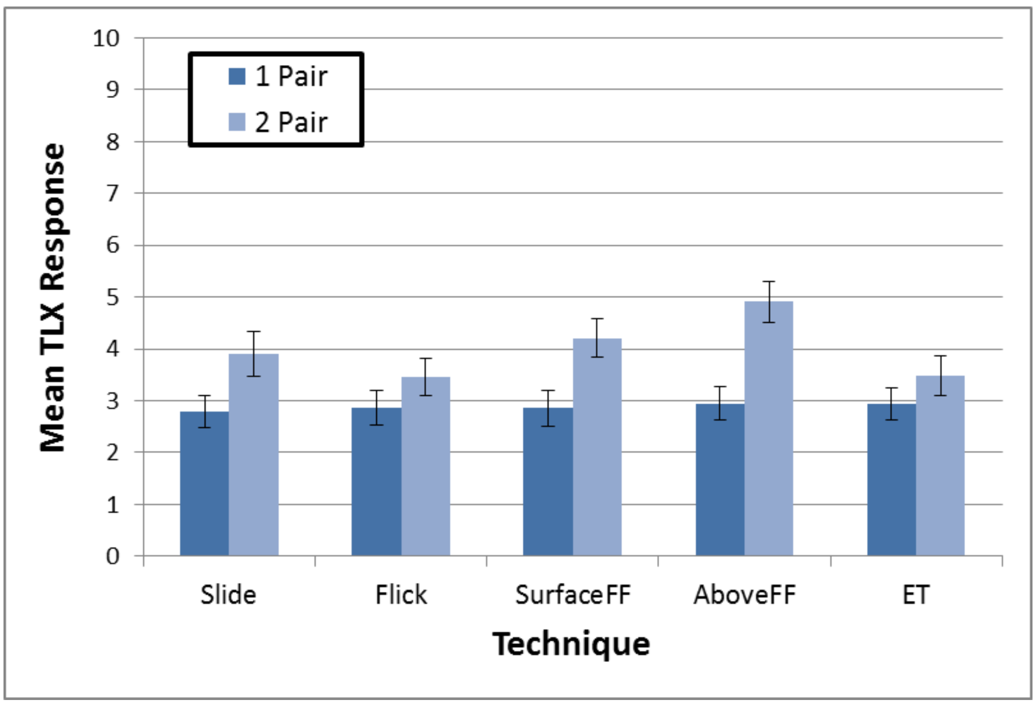


Figure 5.9: The mean TLX responses for all participants for each technique: Slide, Flick, Surface-only Force-Field (SurfaceFF), Above-the-surface Force-Field (AboveFF) and ElectroTouch (ET).

5.6.4 Subjective Responses

Participants also ranked each technique in terms of learnability, naturalness and preference. These results are presented in Figure 5.10 and show that people generally favoured Flick and ElectroTouch in both group sizes. Participants' overall subjective rankings of which techniques worked best for one-pair situations and two-pair situations are shown in Figure 5.11.

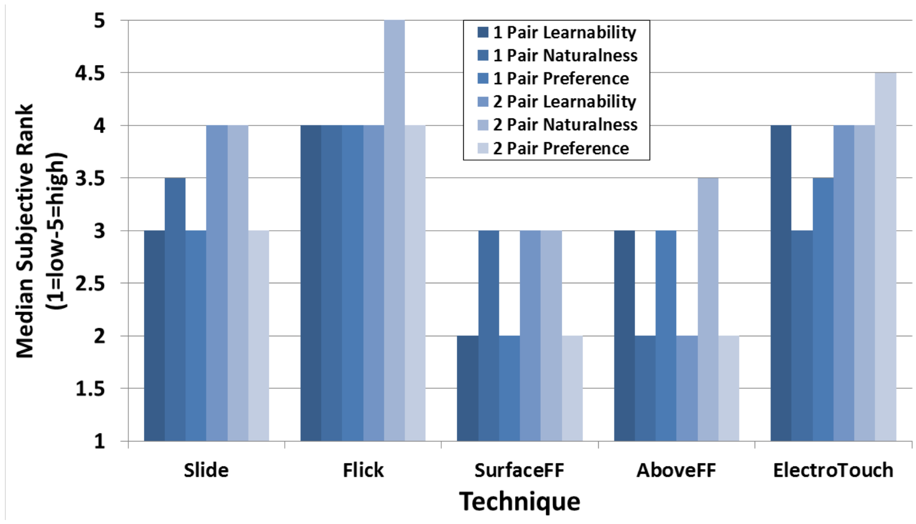


Figure 5.10: Median subjective rankings on a 5 point scale for technique preference in one and two pair conditions (1=low, 5=high).

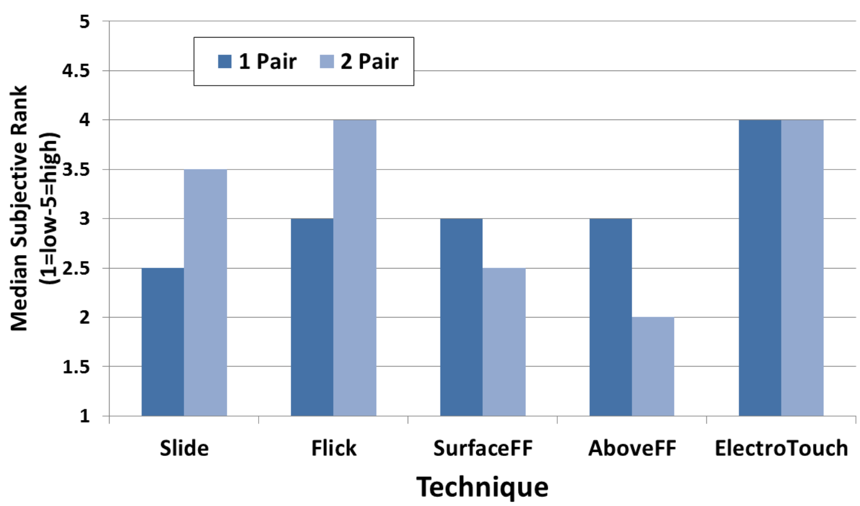


Figure 5.11: Median subjective rankings on a 5 point scale for technique performance in one and two pair conditions.

CHAPTER 6
DISCUSSION

This chapter focusses on explaining and assessing the results of the evaluation of the five techniques: Slide, Flick, Surface-only Force-Field (SurfaceFF), Above-the-surface Force-Field (AboveFF), and ElectroTouch (see Figure 6.1). First, a summary of the results are presented. It reiterates which techniques are faster and how users perceive these techniques. An explanation of the results follows, which reveals several research observations: why the above-the-surface techniques performed better, why ElectroTouch was the best of all techniques, why the Flick technique was the best of all surface techniques, which technique requires the most effort and the errors that occurred with each of the techniques. Subsequent sections reveal how the AboveFF and ElectroTouch techniques generalize to other devices and to real-world implementations, followed by a discussion of the limitations of the system for this research.

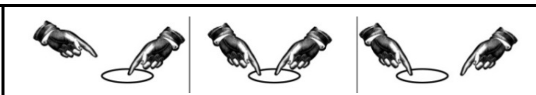
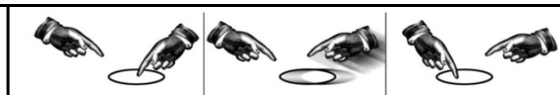
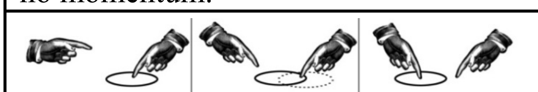
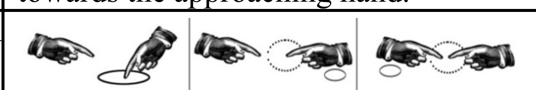
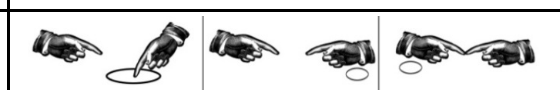
Surface		
	A. The Slide technique – the object has no momentum.	B. Flick – object obtains momentum from the movement of the hand.
		
	C. Surface-only Force-Field (SurfaceFF) – the object 'drifts' towards the approaching hand.	
Above		
	D. Above-the-surface Force-Field (AboveFF) – considers handoff a tracking technique and observes the location of the hands.	E. ElectroTouch – considers handoff as a trigger technique using touch as the trigger event.

Figure 6.1: A list of all the techniques being evaluated.

6.1 Summary of Results

Chapter 5 described the evaluation of two new innovations (AboveFF and ElectroTouch), against three traditional techniques (Slide, Flick and SurfaceFF). This evaluation revealed five unique findings. First, Above-the-surface handoff techniques are faster than surface-only techniques in the one-pair condition and ElectroTouch is faster than surface-only techniques in the two-pair condition. This finding may seem counter-intuitive since the shortest distance between two points (i.e., the start position and target zone) is a straight line which would suggest that surface techniques should be faster. However, there are a number of other factors involved here as will be shown in the explanation section. Second, ElectroTouch was better than any other technique both for speed and accuracy. This feature was not only noticeable in the collected data but the differences in performance were also apparent through participant observation. Individuals using ElectroTouch moved much faster than when they used any other technique. Third, Flick was the best of the surface-only techniques which is perhaps why it is commonly used in touch devices such as tablets. Fourth, based on the NASA Task Load Index (TLX) surveys there was no substantial workload increase in using above-the-surface techniques except for AboveFF in the two-pair scenario. And fifth, there was no substantial difference in the preference, learnability, and naturalness of the various techniques.

What follows is an interpretation and explanation of these results, a discussion of the prominent errors that occurred, a consideration of how these techniques can be generalized for use in the real world with a speculation of future possibilities for these techniques, and a report on the limitations of such techniques.

6.2 Explanation of Results

The objective of this section is to clarify and explain four distinct findings from the results that answer four questions: why above-the-surface techniques were better, why ElectroTouch performed the best of all techniques, why flick was the best performing surface-only technique, and which technique requires the most effort.

6.2.1 Explanations for the Performance of Above--surface Techniques

The above-the-surface handoff techniques had shorter completion times and reduced errors compared to surface-only techniques. The performance gains for the above-the-surface techniques were most likely due to their success in solving the two main problems of surface-based handoff – friction and interference. Friction was a noticeable problem in the study and a main cause of poor performance. This is a significant concern because object transfer often happens in an outward direction. This outward direction requires that people carry out a ‘pushing’ action with their finger which incurs much higher friction than a ‘dragging’ action [10]. Similarly, interference was clearly a common problem for the surface techniques in the two-pair condition. There were many situations where all four hands were in close proximity to one another, forcing people to wait and causing accidental handoffs (see Figure 6.2). In contrast, the above-the surface techniques allowed participants to move quickly to their chosen handoff location in three-dimensional space, a location where there was no interference from the other pair.

Figure 6.2: Participants reach a coveted area for exchanging objects from corner to corner creating substantial interference and causing a series of collisions to occur.

6.2.2 Explanations for ElectroTouch as the best Above-surface Technique

ElectroTouch performed well for several reasons. First, accidental handoffs rarely occurred. The positive tactile feedback that participants received when transferring an object (via touching their partner’s hand) made it much easier for them to carry out the handoff and much easier to determine that a handoff happened correctly. Also, the touch sensor was sufficiently robust that people were confident that their touches would be registered. Second, tactile feedback also allowed participants to speed up their transfers. It allowed people to focus on the task of pick-up or put-down rather than on the exchange itself. Touch notified the participant that the exchange had taken place and that they could proceed with the next stage of the transfer. Third, ElectroTouch allowed for a wide variety of hand postures and methods for touching such as the ‘fist bump’ or the ‘hand slap'. This capability provided users with considerable flexibility when exchanging digital objects. As the trials continued, participants became so comfortable with the versatility of ElectroTouch that they could focus on the task of pick-up and deposit without moving their attention to focus on the handoff (see Figure 6.3).

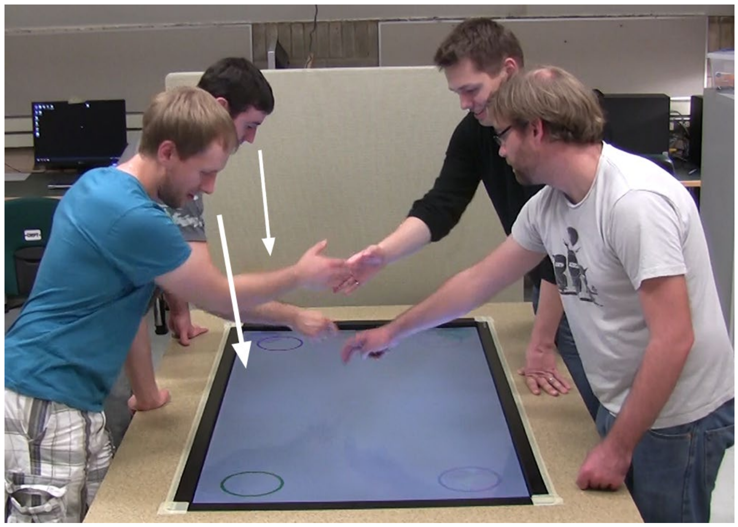


Figure 6.3: Participants can focus on the task using ET and do not have to divert attention in order to complete the handoff. In this picture, the receiving participants simply wait for the tactile feedback before completing the task of depositing the object.

6.2.3 Explanations for Flick as the best Surface-based Technique

Flick was the best-performing and most-preferred of all the surface-only techniques. It was not remarkably faster than the other surface-only techniques but it had substantially fewer errors (a low accidental-transfer rate). The reason for the low accidental-transfer rate arises from the technique's design – people were able to stay out of each other's way by flicking the object from their own side of the table. We did notice other types of errors, however, in particular when users missed 'catching' the flicked object. Such misses suggested that, although the handoff speed of Flick could be increased with higher-velocity motion, this speed increase could cause other difficulties for the technique. Participants also enjoyed the Flick technique. There were several positive comments from participants such as "Flick is the most fun and natural", and "Flick works very well because the [objects] don't get in the way". It was evident that people tended to play with Flick much more than the other surface-based techniques.

6.2.4 Explanations for TLX Responses

The TLX surveys revealed no substantial difference in the workload for all of the techniques with the exception of AboveFF in the two-pair scenario. In the two-pair scenario, AboveFF showed an increase in the overall workload compared to Slide, Flick and ElectroTouch. There was no significant difference between SurfaceFF and AboveFF although ElectroTouch used significantly less effort than both SurfaceFF and AboveFF. These differences were expected and illustrate the difficulties with the force-field methods when there are multiple groups around the table. In the SurfaceFF method, the object *drifts* between the approaching hands, granting little additional benefit to the intended recipient. This difficulty is amplified when moving force-fields away from the surface of the table. In AboveFF, participants had to take extra care not to accidentally transfer an object which resulted in extending additional effort. ElectroTouch, however, required significantly less effort than the force-field techniques and had no significant workload difference with any of the other techniques. This result suggests that between Slide, Flick and ElectroTouch, the fastest and least error-prone technique should be used.

6.2.5 Explanations for Errors

The most significant error for a transfer technique occurs when the object is given to the incorrect person. This is the error that was tracked in the evaluation section as the mean accidental handoff rate (see Figure 5.6). The planned post-hoc t-tests revealed that Flick and AboveFF had a similar accidental handoff rate. However, other error types that were differed between the techniques. These errors help to explain why Slide and SurfaceFF had a significant increase in accidental handoffs.

The technique Slide suffered from a number of issues due to the requirement for constant contact with the surface. First, the inactive fingers, and occasionally the wrists, of the participants would accidentally come in contact with the surface during the handling of the object. This unintended contact caused the object to stop in place, due to the last touch implementation. Unfortunately, due to the touch table technology, this problem could not be avoided. Second, the friction on the table increased as individuals moved the object away from themselves causing the finger to ‘skip’ along the surface. This skip would cause the participants to temporarily release and re-obtain the object. And third, taking the object from the giver would occasionally fail if the receiver placed their finger at the same approximate location as their partners, or if other parts of the hand touched the surface first outside the boundary of the digital object.

In the Flick technique errors occurred when the sender 'threw' the object too fast which caused the receiver to miss the 'catch'. Missing the 'catch' would cause the object to 'bounce' off of the edges of the table which increased the target tracking difficulty as it does in the real world. Some participants, however, became exceedingly good at flicking the object at the right speed, to the point where the object would land almost perfectly in the target zone. There was one additional problem with this technique. The algorithm used to calculate the exit velocity of the flicked object uses the previous three locations of the participant's finger. Due to the limitations of the touch surface (i.e., not receiving all the finger locations), flicking the object far too quickly would result in a very slow moving object. This resulted in the Flick not being as responsive as it is in the real world.

The errors that occurred in the Surface-only Force-Field technique were largely due to interference. During the two-pair task the object would not drift directly towards the intended receiver if all the participants were reaching towards the center at once due to the net displacement design discussed in Chapter 4. The interference caused by the multiple approaching hands caused the participants to ignore the properties of the force field almost entirely and they treated the technique similar to Slide.

The Above-the-surface Force-Field was also not immune to the errors discovered with SurfaceFF. AboveFF encountered errors due to the occlusion of participants' hands (i.e., higher-up arms blocking the Kinect camera) which sometimes led to handoffs to the wrong participant. This type of error was avoidable with correct coordination between participants but required more practice and understanding.

Participants made fewer errors with ElectroTouch than with any other technique. Accidental handoffs did occur but were very rare. People are quite good at avoiding accidental touches and, as Figure 5.6 shows, this type of error did not occur frequently. However, participants were observed attempting to pick up the object too early in the process, and placing the object down in the incorrect location. These errors were attributed to the high transfer rate achieved by participants using ElectroTouch.

6.3 Generalizability

The implementation and results of the above-surface techniques generalizes in three directions: to current implementations of digital touch tables, to other sensing technologies, and to other table scenarios.

1. Above-surface techniques can be implemented with existing hardware and software.

Both ElectroTouch and Above-the-surface Force-Field are easy and affordable to implement in terms of both software and hardware. Therefore, adding these capabilities to any touch table or other large display device is relatively straight-forward. The ElectroTouch pads are flexible and could be placed on any surface where a person may be sitting or standing and will work through most types of footwear (even as thick as a phonebook). Similarly, the Kinect is a relatively affordable device that can be mounted above or in front of the interaction surface, providing depth information in order to determine the proximity of the hands. However, while both techniques are practical, the present research demonstrates that the direct touch feedback provided by ElectroTouch is an effective cue for handoff without tangible objects.

2. Above-the-surface Force-Field generalizes to other sensors.

The findings for the AboveFF technique (both the speed and the high error rate) will likely generalize to other implementations and sensors as well. The Kinect is a low-resolution device compared to other sensors (such as a Vicon tracker) but it was sufficient in this implementation of AboveFF to provide reliable arm tracking and an effective force-field mechanism. The main problem with the AboveFF technique was occlusion. This issue will arise even with much more expensive sensors which also rely on line-of-sight cameras (i.e., multiple cameras will reduce but not remove occlusion).

3. Above-surface techniques generalize to other table scenarios.

In terms of the generalizability of the techniques to other tasks and table scenarios, one obvious issue is the effective range of the techniques. ElectroTouch, Slide, and the Force-Field techniques all rely on people being able to bring their hands into touch or close proximity. This requirement means that on large tables, it will be difficult or impossible to transfer objects with these methods. However, the Flick technique is not overly affected by distance (depending on the amount of virtual friction) and could easily be used to transfer objects over larger distances. Yet both ElectroTouch and AboveFF could be easily extended with physical objects. If an individual holds any kind of stick, wooden or otherwise, their 'arm' could be extended for the AboveFF technique providing it is wide enough to be detected by the Kinect. The fingertip location determined by the KinectArms toolkit will simply be positioned at the end of the stick. Similarly, the participant's reach in ElectroTouch can be extended by holding any type of conductive material such as a metal rod or even most smartphones.

It is noteworthy that the handoff techniques used here are not mutually exclusive. The best way to improve handoff performance in real-world situations is likely to implement multiple techniques that can be used in different work contexts. For example, ElectroTouch can work well with surface based techniques since sliding actions can be differentiated from pickup actions and, therefore, the system would be able to support both kinds of interaction. A table that incorporates the ability to Flick an object, as well as pick up an object to be moved unencumbered to a different user, would be a powerful solution to collocated collaborations.

6.4 Limitations

The five techniques created in Chapter 4, and the system used to evaluate those techniques, are not without limitations. The primary drawback to the system implementation was the visual representation of who was 'holding' the object once it had been picked up from the table's surface. In this version of the system, once the object was picked up it appeared as a semi-transparent version of itself in the corner of the table next to the person who owned the object (see Figure 6.4). This feature required that the participants look away from the handoff area in order to determine if they had received the object or not. Some participants would therefore ignore the representation, since it required additional effort, and deposit objects that they did not yet possess. Such visual representation is an important consideration for the practical application of above-the-surface handoff. This visualization occasionally led to confusion and will need to be carefully designed in future applications. In general, any system that uses virtual pick-up from the table surface needs to provide feedback about the state of that activity. There are several possibilities that would work well for different applications. For example, an object above the surface could be represented as a semi-transparent object that appeared directly beneath the hand hovering above the table. Several possibilities are explored in Chapter 7.

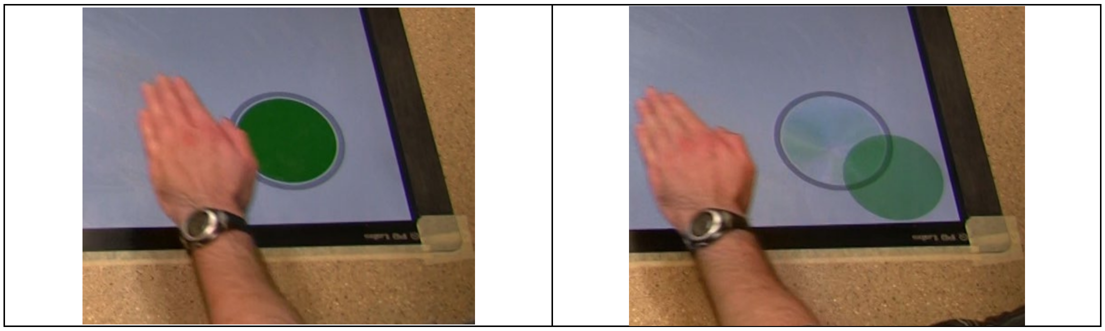


Figure 6.4: The object on the surface of the table (left) rests inside a grey outline zone. One the object is picked up and 'off' of the table, the same object is represented as a semi-transparent version of itself (right).

In addition to the object representation, the system also had a number of technical limitations due to the resolution, frame rate, occlusion, and high-bandwidth requirement of the Kinect subsystem. The current Microsoft Kinect uses a low resolution and low frame-rate RGB-video and depth camera which can cause gaps in the information if people move too quickly. This was not a significant issue for the evaluation of the techniques but may present an issue in more complex environments. The new version of the Kinect will feature a higher frame rate and higher resolution which may resolve these concerns. Issues such as occlusion, as discussed in the generalizability section, will exist for devices such as the Kinect and are caused by cameras requiring line-of-sight. Because occlusion can occur from almost any angle around the digital table, multiple cameras will not resolve this issue significantly. Also, the Kinect subsystem, as with other camera systems, requires a number of processing steps to occur for every frame of video captured. This need results in a high overhead of processing and results in a high-bandwidth requirement.

The limitations of the Kinect did reduce the robustness of the system and caused both unintended handoffs and intended-handoff failures. A number of these issues are not easily resolved, even with other types of sensors such as infrared trackers, due to the occlusion that occurs with multiple people in a small workspace (such as around a tabletop). If systems to support collaborative interactions are to remain trackerless, and not rely on touch, then a novel sensing technology is required. These problems with the depth-based sensor argue for systems like ElectroTouch that provide robust sensing of a very particular event rather than a general-purpose sensor like the Kinect that provides a great deal of information that must be processed in order to be useful. In the case of object transfer, the low-bandwidth but robust sensor proved to be the better approach.

ElectroTouch has one obvious limitation. It requires that people stand on the antenna pads thus reducing their ability to walk around the table. However, the technology underlying ElectroTouch is not tied to these fixed pads and could be made mobile to allow user movement. For example, a set of smaller pads could be joined together to cover a much larger area, allowing user movement anywhere around the table. Also, a mobile version of the device could be produced using a smartphone and a smaller antenna where the smartphone processes the electromagnetic signals and sends touch events to the table computer.

There was one final limitation in the evaluation of techniques used in the present research. Since each technique presented their own unique set of errors, identifying and comparing these errors was quite difficult in practice. For instance, the finger skipping issue in the Slide technique was not present in the above-surface techniques. Future studies would benefit from having these error types categorized and quantitatively assessed.

CHAPTER 7
REPRESENTING DIGITAL OBJECTS ABOVE THE SURFACE

One difficulty that emerges when deciding to use the space above the table for interaction is the representation of the digital object. Once an object has been 'picked up' by a user, how is it represented on the table? Wilson et al. [86] added physical properties to the digital objects displayed on the table, giving real-world attributes to these objects to help users understand the effects of object manipulation. Hilliges et al. [35] extended similar realism by adding support for manipulating the objects in 3D space. They used arm shadows, object shadows and transparency in order to provide visual feedback to the user when the object is 'lifted' from the surface.

7.1 Design

When representing objects that are no longer on the surface of the digital display, some design goals should be followed. First, a participant should be able to determine who has the object with minimal effort. Second, determining whether the object is on the surface of the table or possessed by another user should be obvious, allowing users to make this distinction quickly and with little effort. For the purposes of the present research the guideline that one participant should not be able to hold more than one object at a time was added.

Design ideas in the present research for representing objects above the surface of the table were developed through the process of low to high-fidelity prototyping. First, a wide array of sketches was created to illustrate possible design ideas. The top eight sketches were converted into low-fidelity paper prototypes (see Figure 7.1). These paper prototypes were displayed to several HCI experts (graduate students in the HCI lab) in order to evaluate their potential (see Figure 7.2) based on surveys and interviews.

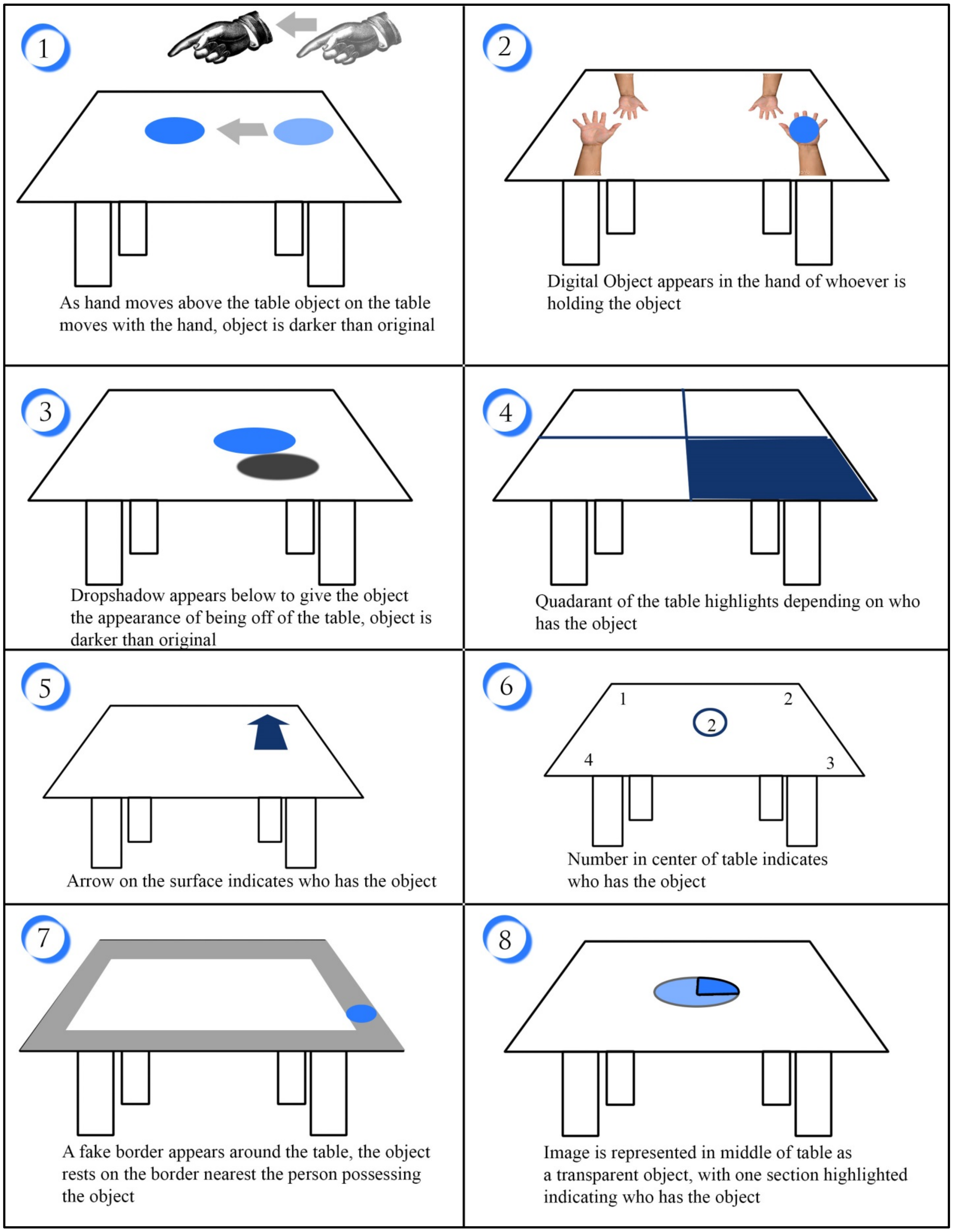
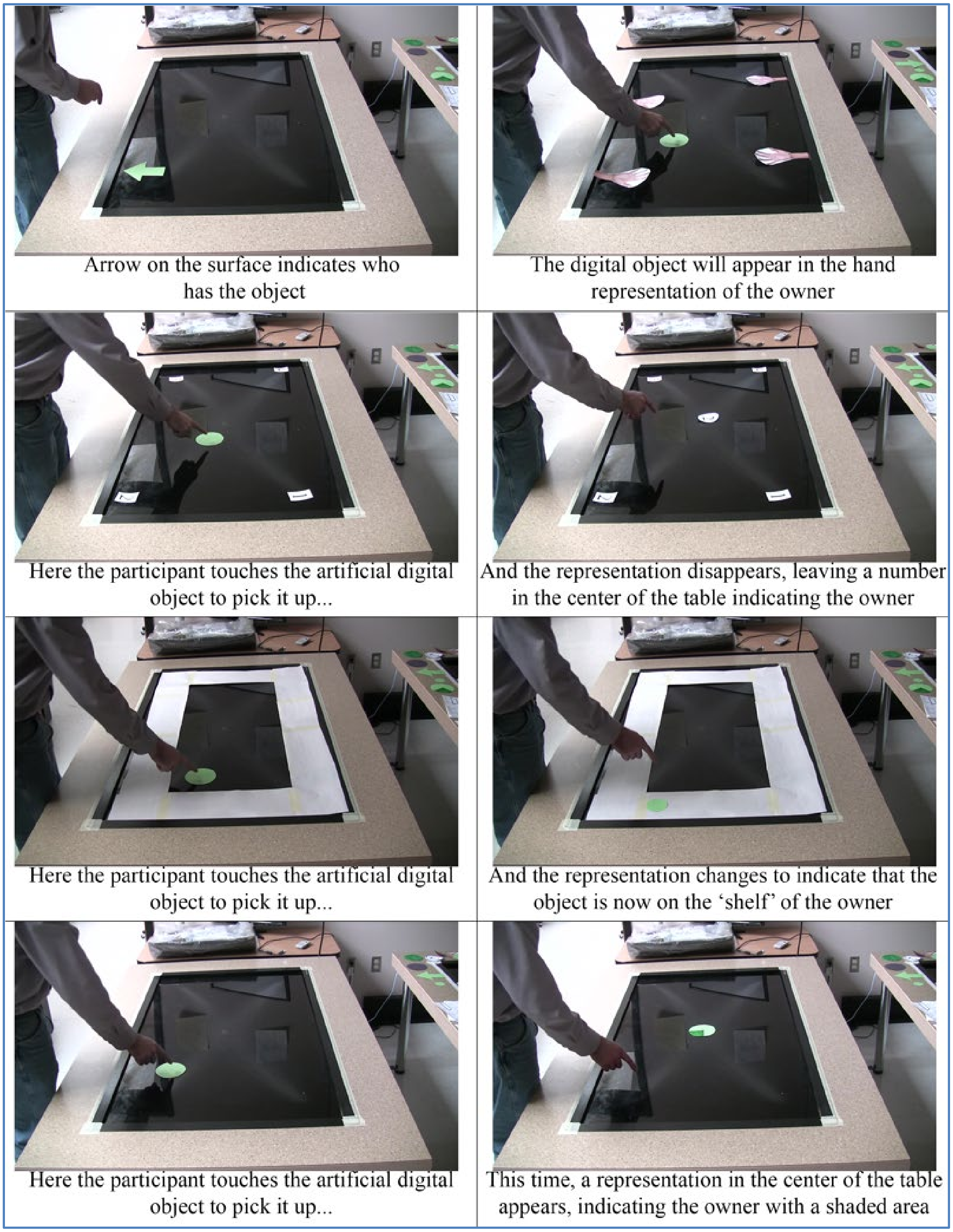


Figure 7.1: Design ideas that were converted into paper prototypes.



Arrow on the surface indicates who has the object

The digital object will appear in the hand representation of the owner

Here the participant touches the artificial digital object to pick it up...

And the representation disappears, leaving a number in the center of the table indicating the owner

Here the participant touches the artificial digital object to pick it up...

And the representation changes to indicate that the object is now on the 'shelf' of the owner

Here the participant touches the artificial digital object to pick it up...

This time, a representation in the center of the table appears, indicating the owner with a shaded area

Figure 7.2: Some of the paper prototypes that were displayed to Human Computer Interaction experts for design feedback.

The design evaluations from the HCI experts revealed that a single representation might not be sufficient. Prototypes 1 and 3 (from Figure 7.1) have little meaning if the user's hand is not moving or above the surface of the table. Prototype 6 requires too much effort to determine who is in possession of the object. Although prototypes 2 and 7 have a good deal of potential, they also eat up valuable surface real-estate. The highest preferences were given to prototypes 4 and 5 that require little effort to understand who possesses the object; however, the experts also showed interest in techniques 1 and 3. The HCI experts also reported that it was easy to determine who had the object and whether the object was on or above the surface.

Based on feedback from the HCI experts, three techniques were developed for implementation and further evaluation. The first technique combined variations of prototypes 1, 3 and 5 from Figure 7.1. In this technique, when an individual picks up the object the representation on the surface becomes semi-transparent and varies in size and position. The object varies in size as the individual's hand moves closer or farther from the surface of the table. It also changes position as the hand moves above the table so that the object always appears directly below the individual's hand. If the individual's hand moves away so that it is no longer above the surface of the table, an arrow appears on the table indicating who has the object (see Figure 7.3 and Figure 7.4). Using a size variation rather than the shadow in prototype 3 provides the same information to the user without the added confusion presented with an additional object on the surface (i.e., the shadow object). The second technique was based on prototype 4 and was a popular choice among the HCI experts. This technique highlights the region of the table that belongs to the owner of the object once it has been 'picked up' (see Figure 7.5). The third technique was based on prototype 8 which combines the representation of who possesses the object with what the object looks like. This technique displays a representation of the object in the center of the screen, with a portion of the object highlighted indicating the current owner of the object (see Figure 7.6). In the second and third technique, each quadrant is only capable of indicating the possession of a single object (i.e., quadrants cannot be shaded by two different colors) and reinforces the design goal that one individual cannot possess two objects at the same time.

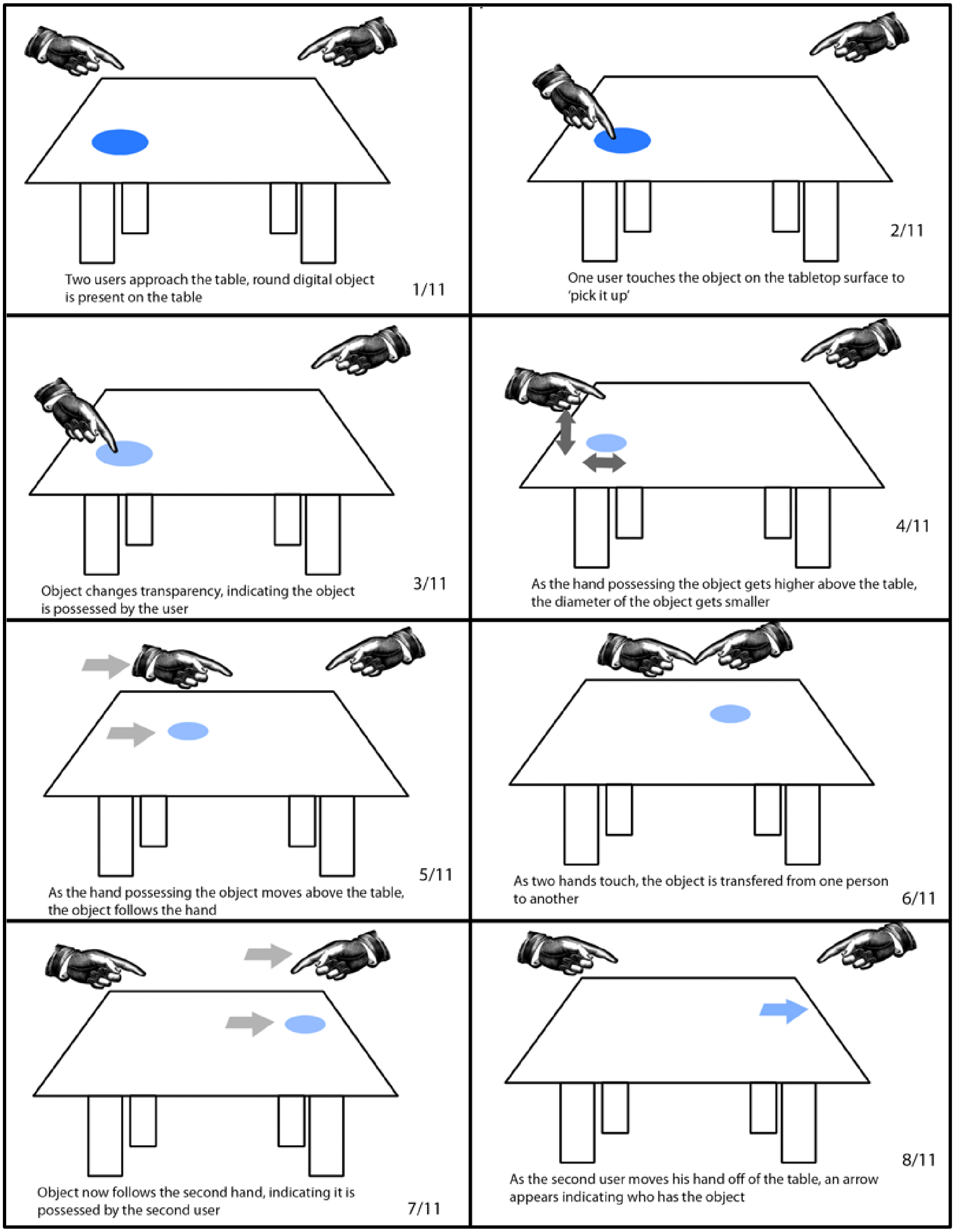


Figure 7.3: Eight of the eleven stages of the first technique. The object becomes smaller and semi-transparent the farther the hand is away from the table.

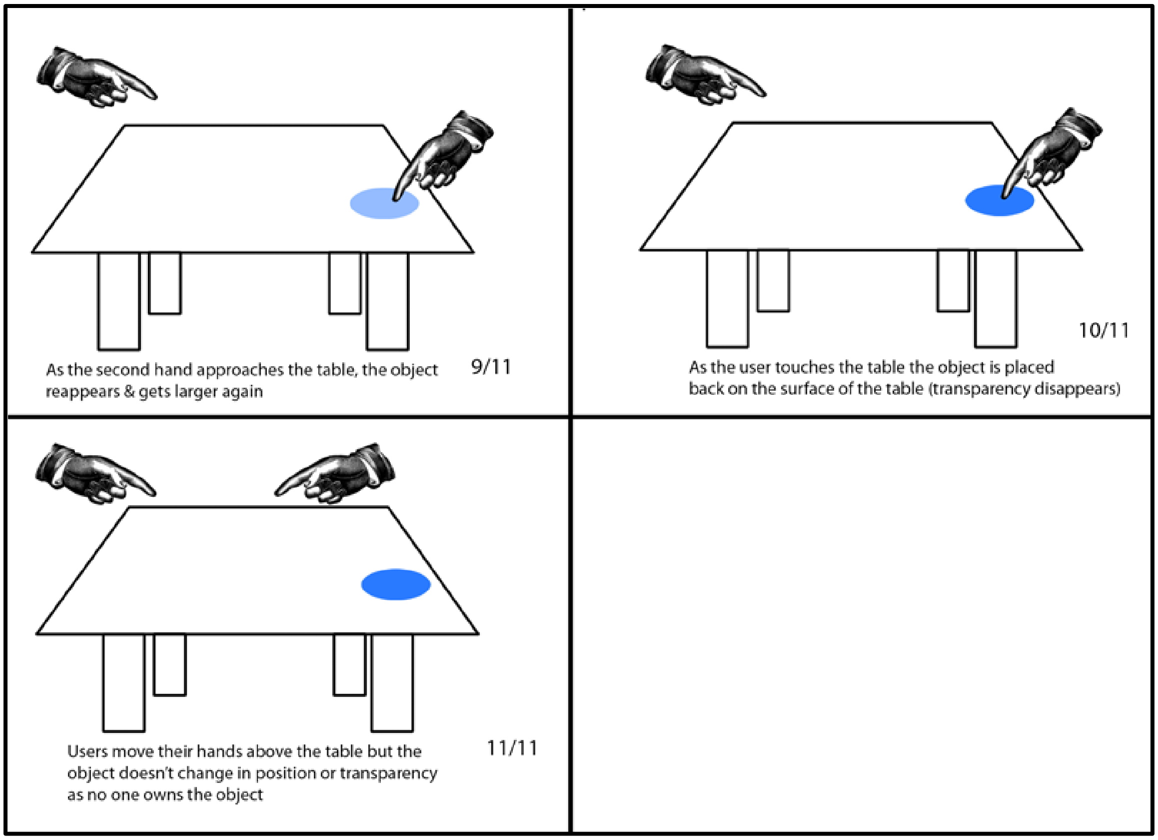


Figure 7.4: Stages nine to eleven of the first technique.

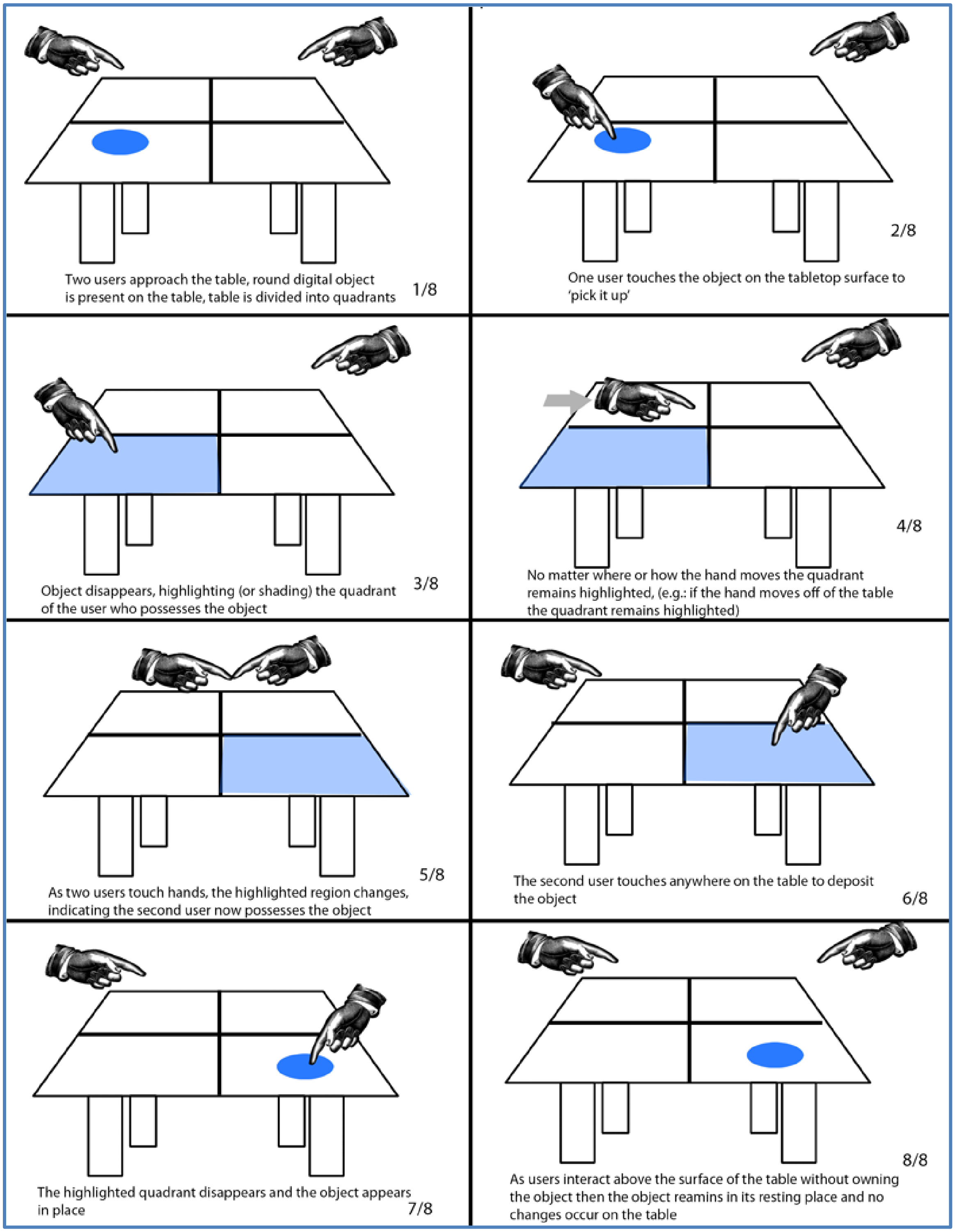


Figure 7.5: All the stages of the second technique of digital object representation.

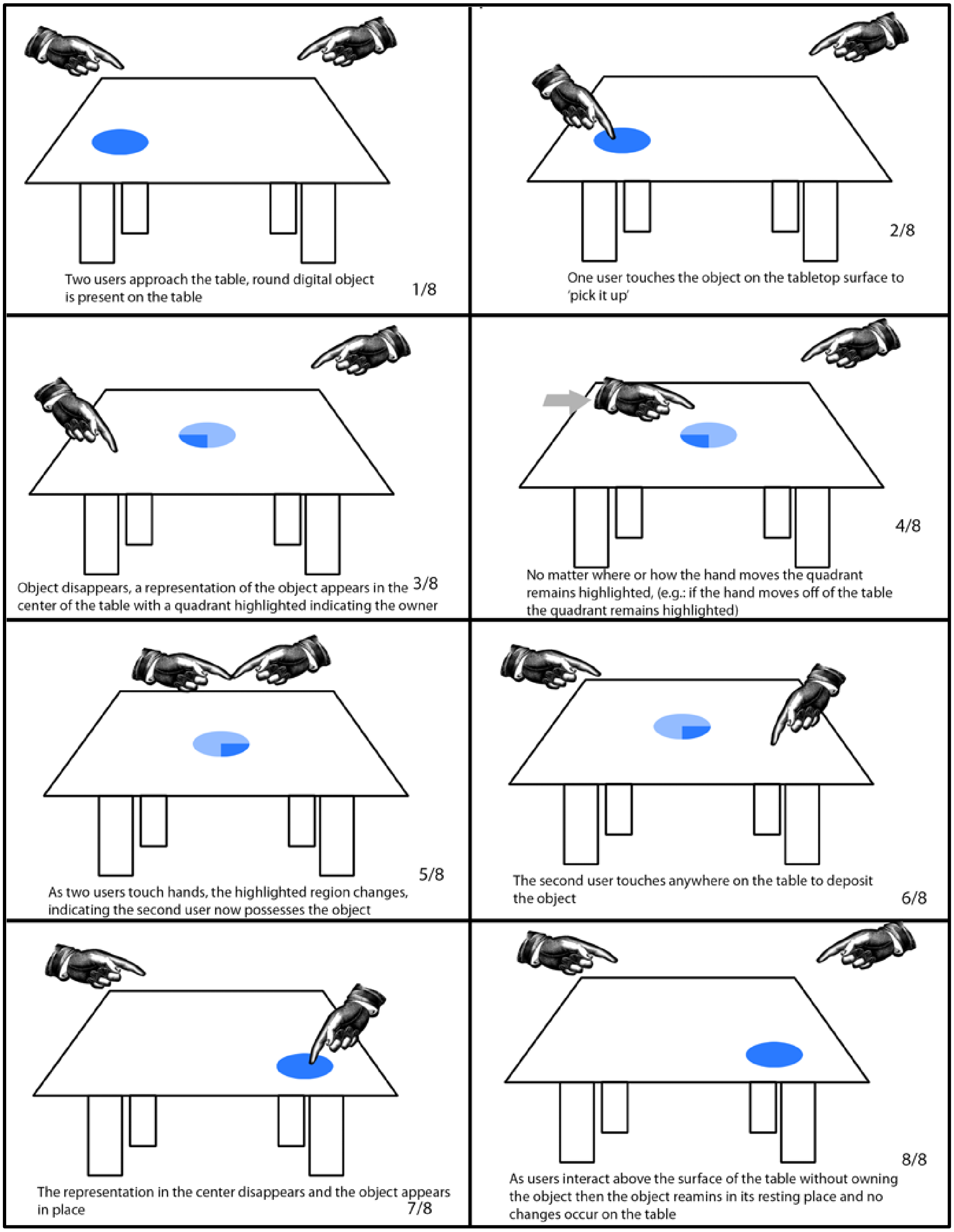
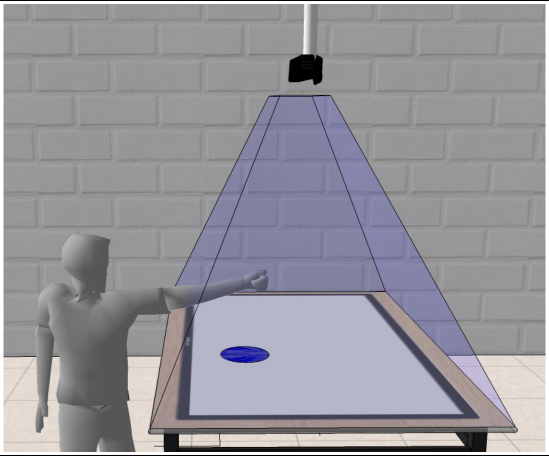


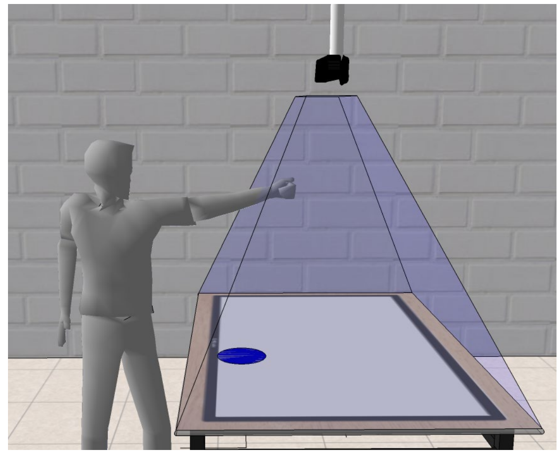
Figure 7.6: All the stages of the third technique of digital object representation.

7.2 Implementation

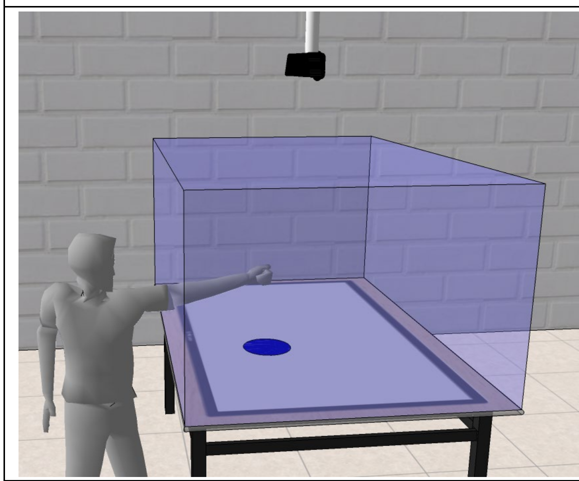
Technique 1 required the use of the Kinect camera. It was used to track the position of the finger tips and provided both the x and y coordinates in addition to the depth information. Unfortunately, the x and y coordinates provided by the Kinect are relative to the Kinect's viewing area (see Figure 7.7 A and B). This causes the x and y coordinates to shift, even though the individual's arm is simply moving closer to the Kinect. For this reason, position information from the Kinect was translated into real-world coordinates to simulate the correct perspective (see Figure 7.7 C and D). This co-ordinate information then enabled the program to draw a semi-transparent version of the object on the surface of the table in the approximate position of the user's fingertips. This information is re-drawn every frame to give the illusion that the object is following the fingertips of the participant's hand. As the user's hand moves away from the table the object gets smaller and, as the hand is moved towards the table, the object gets larger, returning to its original size when contact with the table is made. If the user possessing an object moves that hand out of the range of the Kinect, an arrow appears indicating who possesses the object.



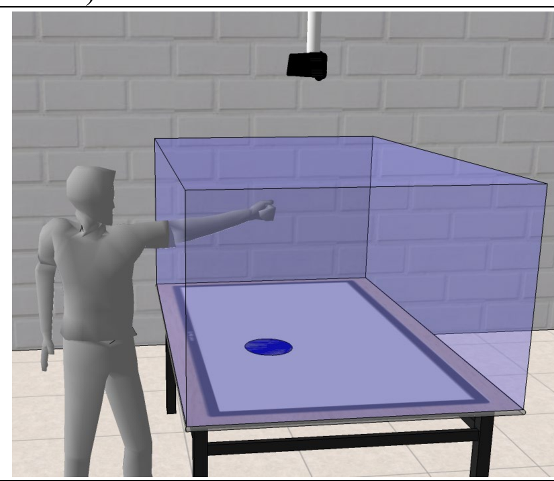
A. According to the perspective of the Kinect the object appears directly beneath the user's hand (a specific x and y coordinate).



B. According to the Kinect's perspective, as the user's arm moves higher the x and y coordinate have changed (the hand is now closer to the edge of the Kinect's viewing radius).



C. After the perspective transformations, the object appears directly below the user's hand.



D. As the user's arm is raised the object continues to appear directly beneath their hand.

Figure 7.7: Using the coordinates directly from the Kinect to place an object on screen causes the real-world perspective to be skewed (A, B). Translating the Kinect perspective into real-world coordinates prevents this deviation (C, D).

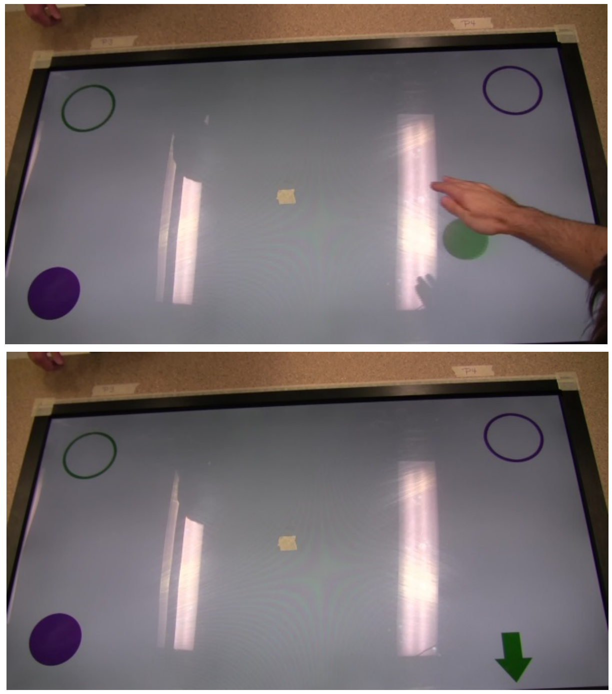


Figure 7.8: Technique 1, the user who possesses the object moves their hand and the object follows (left). Moving the hand away from the surface causes an arrow to appear, indicating who possesses the object (right).

For techniques 2 and 3, the system could rely predominantly on the information provided by ElectroTouch. Once a user possessed an object, regions of the screen or circle were filled with the color of the object based on the location of the user. When a user exchanged the object with another user, the information about the exchange provided by ElectroTouch triggered the change in the graphical representation.

Figure 7.9: Using Technique 2, the green digital object has been exchanged from user 1 to user 3.

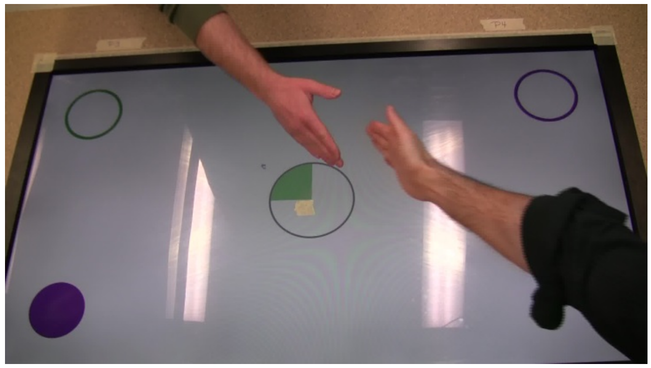


Figure 7.10: Technique 3 shows that user 3 just received the green digital object

7.3 Evaluation

In order to evaluate the three techniques, participants were brought in one at a time. They completed a consent form (Appendix C.1) and a short demographics survey (Appendix C.2) before the study began. Screenshots of a variety of scenarios were then displayed and participants chose the appropriate owner of the object, which was either one of four users around the table, represented as markers, or resting on the table itself. Participants input their responses on a custom keyboard and were encouraged to complete each task as quickly as possible.

Each task displayed 35 different images and the first 5 images were used for training purposes. The program recorded the time between when the image was displayed and when the user pressed a key. For each task only certain keys were displayed to the participant and the program accepted input only from those keys. This procedure would help to eliminate any accidental or mistyped keys. Additionally, for each task a mixture of each of the techniques was used and the participants were asked to focus only on the position of the green object.

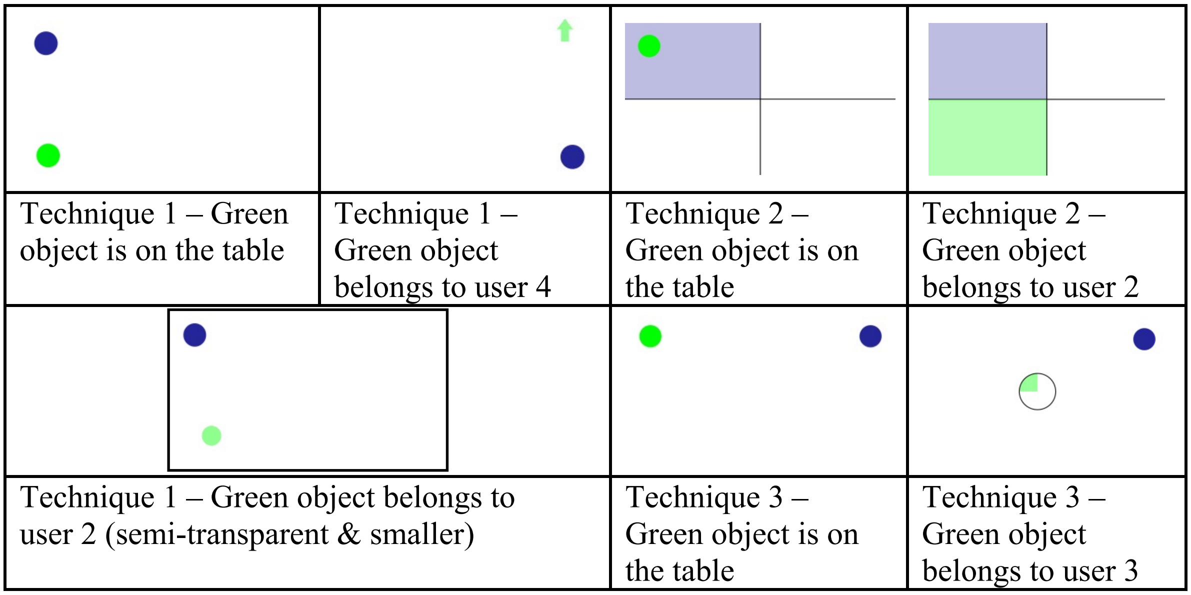


Figure 7.11: Examples of the representations used in the task implementation

Three separate tasks were created to record participant information. The first task asked participants to indicate whether the digital object was on the surface of the table or possessed by any user. For this task, participants could press either the 't' key, indicating the object was on the table or the 'p' key, indicating the object was possessed by an imaginary user (it did not matter which user). The second task had participants determine which user possessed the object, assuming there were four users around the table. In this case, there were no instances of the object resting on the surface of the table. Participants entered 'P1', 'P2', 'P3', or 'P4' on a custom keyboard interface to indicate whether the object was owned by the user at position 1, the user at position 2, the user at position 3, or the user at position 4. The positions of these keys were mapped to the positions of the imagined users in order to aid in faster response times. The third task had participants determine whether the object was on the surface of the table or possessed by a specific user. If a user possessed the object, the participant was required to identify which user had the object. For this task, participants entered 'P1', 'P2', 'P3', 'P4', or 'Table' on a custom keyboard (where the 'Table' key was located in the center of the 'P1'-'P4' keys).

In addition to the speed and error data collected in the evaluation, participants were asked to complete a survey in order to rank each technique in three ways: how easy it was to understand who had the object; how easy it was to understand whether the object was on or off of the table; and their general preference (Appendix C.3). This activity gives a subjective ranking of the techniques and helps to determine whether a technique is preferred regardless of its performance. Finally, the participants were asked open-ended interview questions in order to provide qualitative data (Appendix C.4). This information was useful in two particular ways: to determine why the participants favored a particular method regardless of how it performed; and to assist in pointing out flaws in the techniques.

For this project, 8 volunteers were recruited (mean age 29.1, 5 male, all right-handed) from the University of Saskatchewan. All participants used a mouse as their primary pointing device (with one participant selecting both a mouse and trackpad). All participants had at least some experience with tabletop devices and two of those participants indicated they had a lot of experience using digital tables. Additionally, five participants had a lot of experience using touch devices, such as touch pads or smartphones, while the remaining three had only occasional experience with such devices.

The study began by informing the participants of the goal of the project: to determine the best technique for representing a digital object on the display once it has left the surface of the table. Participants received instruction on the behaviour of the three techniques and were given an opportunity to interact with each one. Once participants were comfortable with each of the techniques, they performed three timed tasks to recognize: whether the object was on or above the table (task 1), who possessed the object among four users (task 2), and who possessed the object among four users or whether the object was on the surface of the table (task 3 - a combination of tasks 1 and 2). After completing the three timed tasks, the participants completed the ranking survey and then were asked the interview questions.

7.4 Results

The differences in timing and errors for the task evaluations were not significant. Participants performed each of the techniques performed similarly to each other in terms of time (Figure 7.12) and the error rates of each technique were largely indistinguishable (Figure 7.13). There was a slight difference in the errors for task 1 for the first technique. This result was directly caused by the limitations of the evaluation to represent the scenario presented in Figure 7.14 (C). This figure shows the screenshots for three scenarios for the first technique. The third scenario in this figure illustrates the first technique when a user possesses the object with their hand hovering over the surface of the table. The object is semi-transparent and smaller than the original version. However, without the additional visual cues (i.e., the user's arm hovering over the table), this screenshot was often mistaken for the object being on the surface of the table. The errors caused by this scenario would perhaps be reduced or even eliminated in the real-world use of this technique because the additional visual cues would be present.

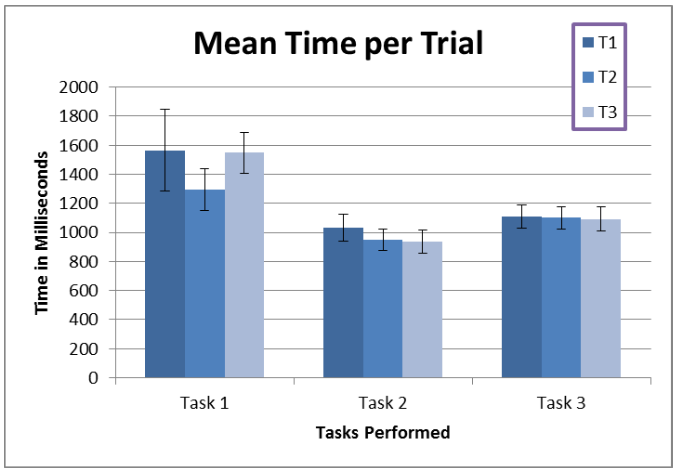


Figure 7.12: The mean time per trial for technique 1 (T1), technique 2 (T2) and technique 3 (T3). Error bars indicate standard error.

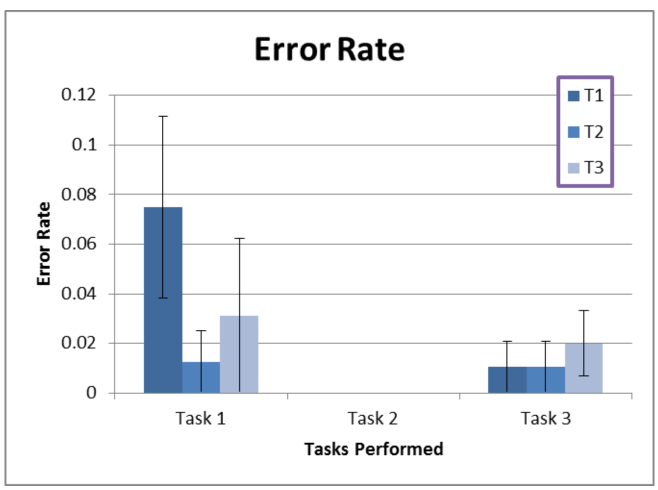
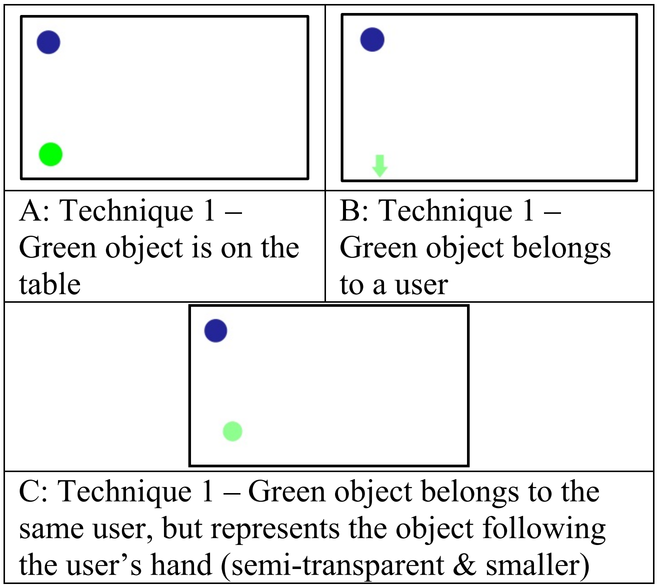


Figure 7.13: The error rate for technique 1 (T1), technique 2 (T2), and technique 3 (T3).



A: Technique 1 – Green object is on the table

B: Technique 1 – Green object belongs to a user

C: Technique 1 – Green object belongs to the same user, but represents the object following the user's hand (semi-transparent & smaller)

Figure 7.14: Screenshots for three different scenarios for technique 1. In A, the object is on the surface of the table because it is at its original opaqueness level and size. In B, the object has been removed from the table, and the owner has removed his hand from above the table, causing the arrow to appear. In C, the object is semi-transparent and smaller, indicating that the user possesses the object and that the object is following the hand of the user.

The survey results showed a greater difference between the techniques. Techniques with stronger visual cues tended to be given preference. Participants were asked to rank each technique on three different aspects: how easy it was to understand who possessed the object (Possession by Person in Figure 7.15), how easy it was to understand whether the object was on or off the table (Table/Person Possession in Figure 7.15), and general preference (Preference in Figure 7.15). Techniques 2 and 3 were ranked the same for preference, and the techniques with stronger visual cues were the easiest for participants to understand where the object resided.

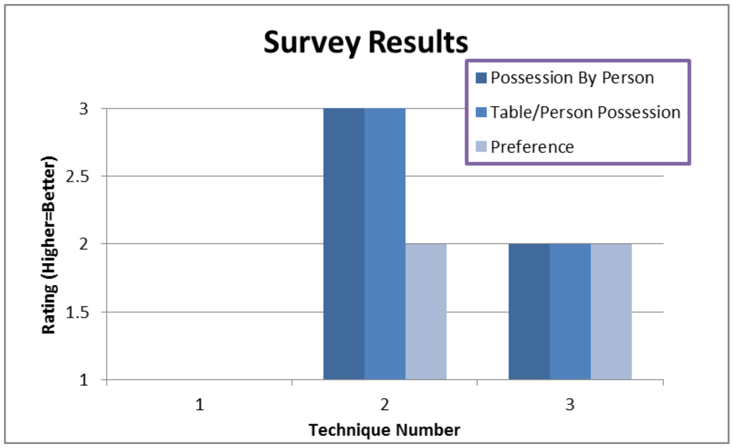


Figure 7.15: Rankings in terms of: how easy it was to understand who possessed the object (Possession By Person), how easy it was to understand whether the object was on or off the table (Table/Person Possession), and general preference (Preference).

The interviews showed that the participants generally found the techniques difficult to rank, indicating that the actual differences in the rankings might be marginal. Some participants felt there was a disconnection between the techniques and the tasks. Participant 7 remarked that "I wasn't actually performing handoff [for the task], so that might lead me to change my preferences". Similarly, participant 3 remarked that "it was different when I was observing versus actually using it", and that technique 3 was much better for an observer, but as a participant, technique 1 was better.

The narrow gaps between technique 2 and 3, as seen in Figure 7.15, are echoed in the interview responses. Some users, such as participants 2 and 3, indicated that technique 2 is obvious making the decision process easier but it was very "loud". Participant 2 preferred technique 3 because it was more subtle and would not interfere with other interactions or objects on the surface.

A number of participants identified a difficulty with the task in regards to technique 1. Participant 3 summarized the issue, "It was almost harder in some of those example slides to tell who possessed it because the arm wasn't there". Participant 8 also commented in the same tone, "I did try it [technique 1], but I think if I'm interacting with it, it will be a lot different because … I see it moving". Some participants felt that technique 1 was hard to judge since it relies on the object having additional visual cues that were not present in the task (e.g., the arm above the table, or the object moving).

Participant 5 noted that their opinion might change, depending on the situation. Some participants commented on the uniqueness of technique 1 since it not only shows who has the object but where the object is. Along with participants 4, 5, and 6, participant 3 indicated that the semi-transparent versus the opaque versions of the object in technique 1 made it quite difficult to determine whether the object was on the table or not.

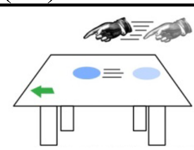
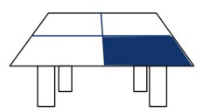
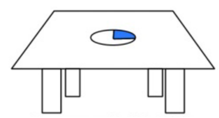
Technique 1 (T1)	Technique 2 (T2)	Technique 3 (T3)
		

Figure 7.16: T1 shows as the hand moves above the table, the object moves below; if the hand leaves the table an arrow appears. T2 highlights the quadrant of the owner of the object. T3 uses a representation of the object with a section highlighted indicating who has the object.

7.5 Conclusions

From the evaluation results, a number of conclusions can be made.

1. The first technique offers a rich representation providing more information than the other techniques.

With the first technique users can see where the object is located in addition to who has the object. This technique also keeps the representation of the object on the display, making it a good candidate for situations where there are a diverse set of objects. However, this technique requires more resources than the other techniques and relies heavily on the accuracy of the Kinect camera. Participants also found the subtlety of the semi-transparent and opaque object to be too difficult to distinguish during the evaluation task. While this representation was chosen from the feedback received in the paper prototype stage, it could be modified to make this difference much more obvious. Additionally, participants commented on the obvious drawback of this technique in the evaluation. There was no arm above the table and the object was not moving for the screenshots being displayed. While this observation is true, it is suspected that participants would also take longer since determining who had the object would require looking both at the surface for the object, then at the arm above the object, or require the participants to wait to see if the object begins to move.

2. The second technique was visually more dominant than the other techniques.

While technique 2 provided the most obvious possession indicator, participants generally thought it consumed too much of the surface space even though the section being colored was semi-transparent, allowing participants to see objects on the surface of the table in that section. Additionally, there was no representation of the object's shape once it had left the surface of the table. If there were multiple types of objects (photos, documents, etc.) it would be difficult to know who had which object once the object was removed from the surface. None of the participants seemed to notice this issue at all which suggests the multi-object scenarios should still be tested.

3. The third technique provides a compromise between the first and second technique.

Technique 3 did not take up much surface space and still provided clear information on who possessed the object. This representation was also semi-transparent and would allow users to see other objects underneath if the center portion of the table was needed. Technique 3 also provided an advantage as it did not require participants to divert their attention to a different portion of the table for exchanges and did not require a long assessment period for determining who has the object. However, this technique did occupy the center portion of the table which is very valuable display space and may be occluded during interactions such as above-the-surface handoffs.

4. The three techniques performed equally well.

Participants were easily able to identify who possessed the object or whether the object was on or above the surface of the table. The evaluation results revealed that participants had no difficulty in making the distinction of who possessed the object, or whether the object was on or above the table, except in the special circumstances of technique 1 previously mentioned. In a performance-based task, the technique that offers the most obvious representation and lowest resource consumption, such as technique 2, would be the recommended choice. However, in a leisure situation, such as a display booth at a museum, having the additional information would be more pleasant for the user's experience.

The research in this chapter has shown that there are a variety of practical and effective representations of digital objects above the surface of the table. In the three representations chosen for the evaluation, participants were able to identify the owner of and location of the object with little difficulty. The ease of this identification indicates that above-surface object embodiment allows for a variety of representations subject to creative design and driven largely by the objective of the application.

CHAPTER 8
GENERAL DISCUSSION, FUTURE WORK, AND CONCLUSIONS

This chapter presents the achievements of the present research by providing a general discussion, outlining several areas of future work and presenting concluding remarks.

8.1 General Discussion

The following section provides a general discussion on the applicability of the present research to current technologies. It does so by reviewing five areas of research activity: commenting on the existing difficulties with current digital tables, assessing the value of low-bandwidth sensors, confirming the importance of existing techniques such as flick, commenting on the challenges with depth-based sensors, and commenting on object representation for above-surface interactions.

8.1.1 Friction and Interference

Friction and interference continues to be an issue even with modern touch tables. Despite advancing table technologies, friction caused by sliding a hand or finger across the table continues to be a problem. It is a problem that is particularly noticeable when pushing an object away from the body [10]. Interference also remains an issue due to the occlusions and collisions that occur with multiple users gathered around a single table. Typically, previous research has focussed on studies involving only two people around a single table. Yet interference increases as more individuals are added (a likely possibility as touch tables continue to grow in size). The ability to move nearly-synchronous, multi-person interactions, such as handoff, off of the surface of the table greatly reduces friction (it does not eliminate friction entirely as other forms of friction still exist such as air friction). While moving interactions above the surface will not eliminate interference, it will reduce it and create convenient, natural, and intuitive ways for resolving conflicts, which is the goal in dealing with interference [37].

8.1.2 Value of a Low-bandwidth, High-confidence Sensor like ElectroTouch

The evaluation in chapter 5 revealed that ElectroTouch was the best technique in terms of performance for above-surface handoffs (see Figure 5.5). However, there are also a number of other features that makes ElectroTouch a highly desirable technique to implement on digital tables. First, ElectroTouch is a low-bandwidth, high-confidence sensor. ElectroTouch is a low-bandwidth sensor as it only transmits and receives the necessary information for detecting contact, information that does not require a large amount of processing in order to determine the results. ElectroTouch is also a high-confidence sensor. The only error to occur with ElectroTouch during the evaluation (see Figure 5.6) was a single error caused by an accidental touch to the wrong recipient. Second, ElectroTouch is extremely low-costing and can be implemented in a variety of circumstances. An ElectroTouch pad can be built using scrap materials and made to form around any type of surface (see Figure 4.14). Its robustness allows it to be used under carpets and other surfaces thus creating interactive areas around a home or office. Third, ElectroTouch can be adapted for any group size and is not constrained to the area visible by a camera. It also is not subject to occlusion, something that increases as the number of users increase with line-of-sight solutions. As a low-bandwidth, high-confidence sensor, ElectroTouch has numerous possibilities. Using only a computer sound card, insulated copper wire and pieces of cardboard, developers can add a new dimension to touch tables or to everyday environments.

8.1.3 Importance of Flick

While the present research revealed that above-surface handoffs can perform faster than surface-only handoffs, it does not negate the effectiveness of certain surface-only interactions. Participants experienced a high enjoyment factor with Flick. They found it to be fun and played more with this technique (e.g., treating it like a table-hockey game). Besides the enjoyment of Flick, it is also capable of passing objects at longer distances even though 'catching' the flicked object might be problematic. Additionally, for the purposes of above-surface techniques, it would be practical to include Flick alongside whichever above-surface technique is used. This ability would allow for objects to be 'tossed' across the table for long distance handoffs while maintaining the effectiveness, performance and precision of above-surface techniques.

8.1.4 Depth-based sensing issues

The present research revealed a number of issues that pertain to depth-based sensors for use with interactions above the surface of a digital table. The alternatives to depth-based sensors are special gloves or physical objects that are tracked by infrared (IR) cameras. While this type of IR tracking can give accurate information, it is cumbersome and inconvenient and is therefore likely not to be used. Trackerless technologies are the preferred method for following arm and hand movements as they allow for the walk-up and use interactions that are found around real-world tables.

There are a number of issues with depth-based sensing. First and foremost, occlusion for line-of-sight cameras, depth-based or otherwise, continues to be a problem. As digital tables get larger and more affordable, more of them will be used in public areas such as museums and theater lobbies. Larger tables also mean that more individuals can gather around a single table which causes line-of-sight cameras to be blocked by arms, hands, or even heads. People lean over and interact with the table, occluding the interaction that takes place on and above the table. Second, line-of-sight cameras provide a good deal of additional information superfluous to the handoff interaction. This additional information needs to be filtered out from the camera's data such as a person's head, a person's hat, or other objects resting on the surface of the table. Third, this type of tracking technique requires a lot of additional processing in order to run the appropriate filters, conduct position transformations (e.g., camera-space to real-world space), and manipulate large amounts of data (e.g., a large number of frames consisting of sizeable images to be analyzed and manipulated). While depth-based sensing seems like the obvious choice for above-surface tracking, it is not implemented without the difficulties mentioned above.

8.1.5 Representing Digital Objects

One difficulty that emerges when adding interactions with digital objects above the surface of tables is how the 'off-table' state is represented. The formative studies in Chapter 3 revealed that people maintain mental models of digital objects once the objects have been removed from the surface. However, as a transfer occurs it becomes important to know who received the object. ElectroTouch provides tactile feedback that indicates the object has been exchanged. Unfortunately, AboveFF has no similar feedback system, and how the object is represented during the handoff becomes very important. In Chapter 7 various object representations were evaluated in order to reveal possible above-table representations. Through this evaluation, off-table digital object representation was determined to be largely task-based. Given adequate time, individuals were able to determine where the object resided or to whom the object belonged. In tasks that allow for leisurely interactions, using a semi-transparent representation that follows the hand around the table would be appropriate. For performance-based tasks, indicators that simply highlight the owner would suffice.

8.2 Future Work

The present research provides opportunities for further development in several ways. First, extended versions of the ElectroTouch technology can be built to allow for greater mobility among users. Second, AboveFF can be refined to utilize an adaptive force-field that shrinks as the number of arms in the above-table space grows, to reduce the frequency of handoff errors. Third, combinations of the techniques presented in this research can be developed to provide improved table interactions in a variety of large and small tabletop environments. Finally, further research can be conducted regarding off-table object representation to include task-based evaluation.

8.2.1 Extending ElectroTouch

There are several possibilities for extending ElectroTouch. The first challenge will be to remove the restriction of requiring individuals to stand in one place. In order to remove this restriction, smaller versions of the ElectroTouch pad can be built allowing the pads to be tiled next to each other to form a grid across a surface. Using a radar-style sweeping motion, signals can be sent and received from groups of tiles in a short time interval. This radar-style detection would allow individuals to move about freely across a floor covered with the small ElectroTouch pads. An alternative approach to the radar-style mini-ElectroTouch pads would be to adapt a smartphone. The smartphone could be the device that generates and searches for user-specific signals. This design would not only allow for the free-range of motion but could also act as a personal identification device.

Once the motion limitation of ElectroTouch has been resolved, creating entire environments (such as a home, office or business) that are ElectroTouch based would be trivial. Even in its current state, ElectroTouch pads can be placed under carpets or other surfaces. An ElectroTouch environment would provide contact detection as individuals interacted with one another. In turn the contact detection could be used to exchange business card information with a handshake, or to split a cheque at a restaurant by giving a group high-five.

8.2.2 Above-the-surface Force-Field Refinement

The present research revealed difficulties with the AboveFF technique. Using proximity to trigger the handoff in a tracking technique can result in the frequent occurrence of accidental handoffs if unintended recipients get too close to the giver. It is possible to reduce the likelihood of the accidental trigger by creating a dynamic force-field zone. The KinectArms system can recognize the number of hands above the surface of a table. If only two hands are detected the force-field zone, or the proximity area around the hand could be increased. As the number of hands above the table increases, the force-field zone could decrease, requiring higher precision but reducing accidental transfers.

8.2.3 Technique Combination

It is erroneous to assume that ElectroTouch is the only handoff technique for digital tables. The true power for improving handoffs around digital tables comes from combining the techniques to allow for multiple features. For instance, a combination of Flick and ElectroTouch would allow users to engage in long distance and near proximity handoffs respectively. Handoffs that are beyond the reach of a user’s arm could implement Flick, where momentum would carry the object beyond the reach of the user. When users are within arm’s reach of one another the ElectroTouch technique could be used, which provides better performance and a natural way to resolve interference.

8.2.4 Further work in Object Representation

One final frontier remains in digital object handoff, that is, how the digital object is represented in order to present information that it is no longer on the surface of the table and belongs to a particular user. While this issue was discussed in detail in Chapter 7, several studies should still be conducted focusing on representations for different tasks. For instance, the requirements for object representation using a leisure photo-sharing application will differ from the time-sensitive tasks of an emergency vehicle dispatch. For the photo-sharing application, it may be important to have a representation of the actual photo that is being held whereas for the emergency vehicle dispatch the types of objects may be reduced allowing for generic indicators to be implemented. For future work to continue along these lines, a representational taxonomy should be created that focuses on the purpose, as well as enjoyment level, for each representation technique.

8.3 Conclusions

The problem addressed in this thesis was stated as follows: object handoff at digital tables is slow and error-prone when using surface-based techniques. The present research has shown that using traditional techniques for digital object handoff in collocated collaborative settings can be slow, create co-ordination difficulties, and foster interference that increases task completing times. These difficulties increase as the number of people around the table increases. One possible solution to these difficulties is to use the space above the surface of the table in order to conduct object handoff. There are two methods for classifying handoffs in order to develop above-surface techniques. One method is to classify handoff as a tracking technique where the movements of hands are monitored from the time an object is picked up until the object is deposited. This method requires a tracking technology, such as depth-based cameras, and also requires a trigger method to be incorporated into the tracking technology such as using proximity to initiate the object transfer. The second method is to classify handoff as a trigger-only action. This approach reduces the amount of information that needs to be processed and allows for the use of unique innovations that are not subject to occlusion.

8.3.1 Summary of Thesis

This thesis focused on the creation of two new techniques for the above-surface handoff. The first technique, AboveFF, classified handoff as a tracking technique using proximity to initiate the transfer. The second technique, ElectroTouch, classified handoff as a trigger technique using touch to initiate the transfer. AboveFF was initially proposed by Jun [42] but was never evaluated until now. Through the present research it was determined that AboveFF works well with two people and improves handoff over surface-only interactions. However, as more individuals are added around the table, the AboveFF technique begins to suffer due to the occlusions of the hand that caused accidental handoffs to occur. The AboveFF will benefit from future implementations that adjust the size of the force-field dynamically whereby fewer hands results in a larger force-field. AboveFF can also be adapted to extend the reach of individuals if the table is quite large and there are only a few users.

The second technique, ElectroTouch, is a system that detects person-to-person physical touch using low-bandwidth costs that provide high-reliability. This technique provides users with tactile feedback that confirms the object has been handed from one person to another. While the current implementation of ElectroTouch does not allow for much movement, there are a number of adaptations that can be performed on the ElectroTouch system to make it much more flexible. These adaptations include using tiled, mini-pads that can be sensed in groups using a fast sweeping motion and implementing ElectroTouch through a smartphone device.

8.3.2 Contributions

The primary contribution of the present research is the development of novel above-the-surface handoff techniques, AboveFF and ElectroTouch, and the empirical evaluation of their effectiveness both in terms of time and errors.

The present research also made several secondary contributions:

- First, it provided empirical evidence about the performance characteristics of three traditional surface-based transfer techniques.
- Second, it demonstrated a new tracking technology, ElectroTouch, that can provide physical contact sensing easily and inexpensively.
- Third, it introduced limitations of depth-camera-based sensing.
- Fourth, it documented the value of object flicking for surface-only handoff when several people are working at the table.
- Fifth, it offered recommendations for the representation of objects above the surface of the digital table and revealed that visualizations are task dependent.

8.3.3 Concluding Remarks

The problem addressed in this thesis was: object handoff at digital tables is slow and error-prone when using surface-based techniques. The solution presented in the present research was to use the space above the table to improve performance for digital object handoff. Improving performance with digital object handoff is accomplished by classifying handoff as either a tracking-based technique, as was accomplished with the Above-the-surface Force-Field technique, or a trigger-based technique, as was accomplished with the ElectroTouch technique. The present research showed that above-surface techniques improve performance over surface-based techniques and that ElectroTouch performed the best of all techniques, providing a low-bandwidth, high-confidence solution to the problems of friction and occlusion. By examining handoffs in formative studies, by developing and evaluating two new techniques, and by examining and evaluating digital object representations, the present research revealed relevant, efficient, effective and affordable ways to provide above-surface digital object handoff.

REFERENCES

[1] Agarawala, A. and Balakrishnan, R. (2006). Keepin' it real: pushing the desktop metaphor with physics, piles and the pen. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 1283-1292. doi:10.1145/1124772.1124965

[2] Aliakseyeu, D., Irani, P., Lucero, A., and Subramanian, S. (2008). Multi-flick: an evaluation of flick-based scrolling techniques for pen interfaces. *Proceedings of the SIGCHI conference on Human factors in computing systems*, 1689-1698. doi: 10.1145/1357054.1357319

[3] Anderson, P.A., Leibowitz, K. (1978). The Development and Nature of the Construct Touch Avoidance. *Nonverbal Behaviour*, 3(2), 89-106.

[4] Basili, P., Huber, M., Brandt, T., Hirche, S., and Glasuer, S. (2009). Investigating Human-Human Approach and Hand-Over. *Human Centered Robot Systems, COSMOS*, 151-160.

[5] Baudel, T., and Beaudouin-Lafon, M. (1993). Charade: Remote control of objects using free-hand gestures. *Communications of the ACM*, 36(7), 28-35. doi:10.1145/159544.159562

[6] Becchio, C., Sartori, L., and Castiello, U. (2010). Toward You: The Social Side of Actions. *Current Directions in Psychological Science*, 19, 183-188.

[7] Bekker, M. M., Olson, J. S., & Olson, G. M. (1995). Analysis of gestures in face-to-face design teams provides guidance for how to use groupware in design. *Proceedings of the 1st conference on Designing Interactive Systems*, 157-166.

[8] Benko, H., Jota, R., and Wilson, A. (2012). MirageTable: freehand interaction on a projected augmented reality tabletop. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 199-208. doi:10.1145/2207676.2207704

[9] Campbell, L.W. (2001). *Visual Classification of Co-Verbal Gestures for Gesture Understanding* (Doctoral dissertation, Massachusetts Institute of Technology, 2001). Retrieved from http://dspace.mit.edu/bitstream/handle/1721.1/8707/49849552.pdf

[10] Carnahan, H., & McFadyen, B. J. (1996). Visuomotor control when reaching toward and grasping moving targets. Acta Psychologica, 92(1), 17-32. doi:10.1016/0001-6918(95)00006-2

[11] Cockburn, A., Ahlström, D., and Gutwin, C. (2012). Understanding performance in touch selections: Tap, drag and radial pointing drag with finger, stylus and mouse. *International Journal of Human-Computer Studies*, 70(3), 218-233. doi:10.1016/j.ijhcs.2011.11.002

[12] Cohn, G. Morris, D., Patel, S. N., and Tan, D.S. (2011). Your noise is my command: sensing gestures using the body as an antenna. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 791-800. doi:10.1145/1978942.1979058

[13] Cohn, G., Morris, D., Patel, S., and Tan, D. (2012). Humantenna: using the body as an antenna for real-time whole-body interaction. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1901-1910. doi:10.1145/2207676.2208330

[14] Chen, W.-T., Chuang, H.-R. (1998) Numerical computation of the EM coupling between a circular loop antenna and a full-scale human-body model. *IEEE Transactions on Microwave Theory and Techniques*, 46(10), 1516-1520. doi: 10.1109/22.721159

[15] Crusca, A.H., and Wetzel, C.C. (1984). The Midas Touch: The effects of interpersonal touch on restaurant tipping. *Personality and Social Psychology Bulletin*, 10, 512-517.

[16] Dietz, P., and Leigh, D. (2001). DiamondTouch: a multi-user touch technology. *Proceedings of the 14th annual ACM symposium on User interface software and technology*. 3(2), 219-226. doi:10.1145/502348.502389

[17] Doucette, A., Gutwin, C., Mandryk, R.L., Nacenta,M., and Sharma, S. (2013). Sometimes when we touch: how arm embodiments change reaching and collaboration on digital tables. *Proceedings of the 2013 conference on Computer supported cooperative work*, 193-202. doi:10.1145/2441776.2441799

[18] Efron, D. (1941). *Gesture and Environment*. Morningside Heights, NY: King's Crown Press.

[19] El-Sawah, A., Joslin, C., Georganas, N.D., and Petriu, E.M. (2007). A Framework for 3D Hand Tracking and Gesture Recognition using Elements of Genetic Programming. *Fourth Canadian conference on Computer and Robot Vision,* 495-502. doi:10.1109/CRV.2007.3

[20] Endo, S., Pegman, G., Burgin, M., Toumi, T., and Wing, A. M. (2012). Haptics in between-person object transfer. *Haptics: Perception, Devices, Mobility, and Communication*, 103-111.

[21] Erdmann, M. (1998). An exploration of nonprehensile two-palm manipulation. *The International Journal of Robotics Research*, 17(5), 485-503.

[22] Fleck, R., Rogers, Y., Yuill, N., Marshall, P., Carr, A., Rick, J., and Bonnett, V. (2009). Actions speak loudly with words: unpacking collaboration around the table. *Proceedings of the ACM International Conference on Interactive Tabletops and Surfaces*, 189–196. doi:10.1145/1731903.1731939

[23] Fisher, J.D., Rytting, M., and Heslin, R. (1976). Hands Touching Hands: Affective and evaluative aspects of an interpersonal touch. *Sociometry*, 39(4), 416-421. Retrieved from http://www.jstor.org/stable/3033506

[24] Geissler, J. (1998). Shuffle, throw or take it! working efficiently with an interactive wall. *Conference on Human Factors in Computing Systems: CHI 98 conference summary on Human factors in computing systems*, 18(23), 265-266. doi:10.1145/286498.286745

[25] Genest, A.M. and Gutwin, C. (2011). Characterizing Deixis over Surfaces to Improve Remote Embodiments. *Proceedings of the 12th European Conference on Computer Supported Cooperative Work*, 253-272. doi:10.1007/978-0-85729-913-0_14

[26] Genest, A.M., and Gutwin, C. (2012). Evaluating the effectiveness of height visualizations for improving gestural communication at distributed tabletops. *Proceedings of the ACM 2012 conference on Computer Supported Cooperative Work*, 519-528. doi:10.1145/2145204.2145285

[27] Genest, A. M., Gutwin, C., Tang, A., Kalyn, M., and Ivkovic, Z. (2013). KinectArms: a toolkit for capturing and displaying arm embodiments in distributed tabletop groupware. Proceedings of the 2013 conference on Computer supported cooperative work, 157-166. doi:10.1145/2441776.2441796

[28] Genest, A.M., Kalyn, M., and Ivkovic, Z. (2012). KinectArms. [Software]. Available from https://github.com/AaronGenest/KinectArms.

[29] Grabowski , P., Rutherford, D., and Mason, A. (2011). Modeling Prehension for Physical Collaboration in Virtual Environments. *Presence: Teleoperators and Virtual Environments*, 20(6), 577-590.

[30] Gutwin, G., and Greenberg, S. (2002). A Descriptive Framework of Workspace Awareness for Real-Time Groupware. *Computer Supported Cooperative Work*, 11(3), 411-446. doi:10.1023/A:1021271517844

[31] Hall, E.T. (1966). *The Hidden Dimension*. Garden City, NY: Doubleday.

[32] Hall, P. S., and Hao, Y. (2006). Antennas and propagation for body centric communications. *First European Conference on Antennas and Propagation*, 1-7. doi:10.1109/EUCAP.2006.4584864

[33] Hand: power and precision grips. [Art]. (2010). *Encyclopedia Britannica Online*. Retrieved July 8, 2013, from http://www.britannica.com/EBchecked/media/73005/A-fully-opposable-thumb-gives-the-human-hand-its-unique

[34] Hart, S., and Staveland, L. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. In P. Hancock and N. Meshkati (Eds.), *Human Mental Workload*. Amsterdam: North Holland Press. Retrieved from http://humansystems.arc.nasa.gov/groups/TLX/downloads/NASA-TLXChapter.pdf

[35] Hilliges, O., Izadi, S., Wilson, A.D., Hodges, S., Garcia-Mendoza, A., and Butz, A. (2009). Interactions in the air: adding further depth to interactive tabletops. *Proceedings of the 22nd annual ACM symposium on User interface software and technology*, 139-148. doi:10.1145/1622176.1622203

[36] Hilliges, O., Kim, D., Izadi, S., Weiss, M. and Wilson, A. (2012). HoloDesk: direct 3d interactions with a situated see-through display. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2421-2430. doi:10.1145/2207676.2208405

[37] Hornecker, E., Marshall, P., Dalton, N., and Rogers, Y. (2008). Collaboration and interference: Awareness with mice or touch input. *Proceedings of the 2008 ACM conference on Computer supported cooperative work*, 167-176. doi:10.1145/1460563.1460589

[38] Hornik, J. (1992). Tactile stimulation and consumer response. *Journal of Consumer Research*, 449-458.

[39] Huber, M., Lenz, C., Rickert, M., Knoll, A., Brandt, T., and Glasauer, S. (2008). Human preferences in industrial human-robot interactions. *International Conference on Intelligent Robots and Systems*, 4749-4754. doi:10.1109/IROS.2010.5651294

[40] Johansson, G. (1873). Visual Perception of Biological Motion and a Model for its Analysis. *Perception and Psychophysics*, 14(2), 201-211.

[41] Joslin, C. , El-Sawah, A., Qing, C., and Georganas, N. (2005). Dynamic Gesture Recognition. *Proceedings of the 2005 Instrumentation and Measurement Technology Conference*, 1706-1711.

[42] Jun, L., Pinelle, D., Gutwin, C., and Subramanian, S. (2008). Improving digital handoff in shared tabletop workspaces. *3rd IEEE International Workshop on Horizontal Interactive Human Computer Systems,* 9-16. doi:10.1109/TABLETOP.2008.4660177

[43] Khoshelham, K. (2011). Accuracy analysis of kinect depth data. International *Society of Photogrammetry and Remote Sensing workshop laser scanning*, 38, 133-138. Retrieved from https://wiki.rit.edu/download/attachments/52806003/ls2011_submission_40.pdf

[44] Koh, E., Won, J., and Bae, C. (2009). On-premise skin color modeling method for vision-based hand tracking. *IEEE 13th International Symposium on Consumer Electronics*, 908-909. doi:10.1109/ISCE.2009.5156946

[45] Lathuiliere, F., and Herve, J.-Y. (2000). Visual tracking of hand posture with occlusion handling. *15th IEEE International Conference Pattern Recognition*, 3, 1129–1133. doi:10.1109/ICPR.2000.903744

[46] Lien, C., and Huang, C. (1998). Model-Based Articulated Hand Motion Tracking for Gesture Recognition. *Image and Vision Computing*, 16, 121-134.

[47] Liu, X., and Fujimura, K. (2004). Hand Gesture Recognition using Depth Data, *Proceedings of 6th IEEE International Conference on Automatic Face and Gesture Recognition*, 529-534. doi:10.1109/AFGR.2004.1301587

[48] Lynch, K. M. (1998). Issues in nonprehensile manipulation. *Robotics the Algorithmic perspective: The Third Workshop on the Algorithmic Foundations of Robotics*, 237-250.

[49] Marquardt, N., Jota, R., Greenberg, S. and Jorge, J. (2011). The continuous interaction space: interaction techniques unifying touch and gesture on and above a digital surface. *Proceedings of the 13th IFIP TC 13 international conference on Human-computer interaction,* 3, 461-476.

[50] Martin, B.A.S. (2012). A Stranger's Touch: Effects of Accidental Interpersonal Touch on Consumer Evaluations and Shopping Time. *Journal of Consumer Research*, 39(1), 174-184.

[51] Mason, A. H., and MacKenzie, C. L. (2000). Collaborative Work Using Give-and-Take Passing Protocols. *Proceedings of the XIVth Congress of the IEA and the 44th Meeting of the HFES*, 519-522.

[52] Mason, A. H., and MacKenzie, C. L. (2005). Grip forces when passing an object to a partner. *Experimental brain research*, 163(2), 173-187. doi: 10.1007/s00221-004-2157-x

[53] McNeill, D. (1992). *Hand and Mind: What gestures reveal about thought.* Chicago, IL: University of Chicago Press.

[54] Micelli, V., Strabala, K. W., and Srinivasa, S. (2011). Perception and control challenges for effective human–robot handoffs. *Robotics: Science and systems workshop on rgb-d cameras*, np.

[55] Morris, M., Ryall, K., Shen, C., Forlines, C., Vernier, F. (2004). Beyond "Social Protocols": Multi-User Coordination Policies for Co-Located Groupware. *Proceedings of the 2004 ACM conference on Computer supported cooperative work*, 262-265. doi:10.1145/1031607.1031648

[56] Muller-Tomfelde, C., and Schremmer, C. (2008). 'Touchers' and 'Mousers': Commonalities and Differences in Co-located Collaboration with Multiple Input Devices. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1149-1152. doi:10.1145/1357054.1357234

[57] Napier, J. R. (1956). The prehensile movements of the human hand. *Journal of bone and Joint surgery*, 38(4), 902-913.

[58] Olson, J. S., Teasley, S., Covi, L., and Olson, G. (2002). The (Currently) Unique Advantages of Collocated Work. In Hinds, L., and Kiesler, S. (Eds), *Distributed Work* (pp. 113-135). Cambridge, Mass: MIT Press.

[59] Pinelle, D., Gutwin, C., and Greenberg, S. (2003). Task Analysis for Groupware Usability in evaluation: Modeling shared-workspace tasks with the mechanics of collaboration. *ACM Transactions on Computer-Human Interaction*, 10(4), 281-311. doi:10.1145/966930.966932

[60] Reetz, A., Gutwin, C., Stach, T., Nacenta, M., and Subramanian, S. (2006). Superflick: a natural and efficient technique for long-distance object placement on digital tables. *Proceedings of Graphics Interface 2006*, 163-170.

[61] Rekimoto, J. (1997). Pick-and-Drop A Direct Manipulation Technique for Multiple Computer Environments. *Proceedings of the 10th annual ACM symposium on User interface software and technology*, 31-39. doi:10.1145/263407.263505

[62] Rekimoto, J. (2002). SmartSkin: an infrastructure for freehand manipulation on interactive surfaces. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 113-120. doi:10.1145/503376.503397

[63] Ringel, M., Ryall, K., Shen, C., Forlines, C., and Vernier, F. (2004). Release, relocate, reorient, resize: fluid techniques for document sharing on multi-user interactive tables. *CHI'04 Extended Abstracts on Human Factors in Computing Systems*, 1441-1444. doi:10.1145/985921.986085

[64] Ryall, K., Forlines, C., Shen, C., and Morris, M. (2004). Exploring the effects of group size and table size on interactions with tabletop shared-display groupware. *Proceedings of the 2004 ACM conference on Computer supported cooperative work*, 284-293. doi: 10.1145/1031607.1031654

[65] Sallnas, E-L, Zhai, S. (2003). Collaboration meets Fitts's law: Passing Virtual Objects with and without Haptic Force Feedback. *IFIP International Conference on Human Computer Interaction*, 97-104. Retrieved from http://urn.kb.se/resolve?urn=urn:nbn:se:kth:diva-13859

[66] Sato, M., Poupyrev, I., and Harrison, C. (2012). Touché: enhancing touch interaction on humans, screens, liquids, and everyday objects. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 483-492. doi:10.1145/2207676.2207743

[67] Savelsbergh G.J., Whiting H.T., and Bootsma, R.J. (1991). Grasping Tau. *Journal of Experimental Psychology: Human Perception and Performance*, 17(2), 315–322.

[68] Scott, S.D., Shellagh, M., Carpendale, T., and Inkpen, K.M. (2004). Territoriality in Collaborative Tabletop Workspaces. *Proceedings of the 2004 ACM conference on Computer supported cooperative work*, 294-303. doi:10.1145/1031607.1031655

[69] Shibata, S., Tanaka, K., and Shimizu, A. (1995). Experimental analysis of handing over. *Proceedings of 4th IEEE International Workshop on Robot and Human Communication*, 53-58. doi:10.1109/ROMAN.1995.531934

[70] Strabala, Kyle Wayne, et al. (2013). Towards Seamless Human-Robot Handovers. *Journal of Human-Robot Interaction*, 2(1), 112-132.

[71] Streitz, N. A., Tandler, P., Müller-Tomfelde, C., & Konomi, S. I. (2001). Roomware: Towards the Next Generation of Human-Computer: Interaction based on an Integrated Design of Real and Virtual Worlds. Human-Computer Interaction in the New Millenium, Addison Wesley, 551-576.

[72] Subramanian, S., Pinelle, D., Korst, J., Buil, V. (2007). Tabletop Collaboration through Tangible Interactions. *16th IEEE International Workshops on Enabling Technologies: Infrastructure for Collaborative Enterprises*, 412-417. doi:10.1109/WETICE.2007.4407200

[73] Sussman, N.M., and Rosenfeld, H.M. (1978). Touch, justification, and sex: Influences on the adversiveness of spatial violations. *The Journal of Social Psychology*, 106, 215–225.

[74] Svensson, M.S., Heath, C., and Luff, P. (2007). Instrumental Action: The timely exchange of implements during surgical operations. *Proceedings of the 10th European Conference on Computer-Supported Cooperative Work,* 41-60. doi:10.1007/978-1-84800-031-5_3

[75] Takala, T. M., Rauhamaa, P., and Takala, T. (2012). Survey of 3DUI applications and development challenges. *IEEE symposium on 3D User Interfaces,* 89-96. doi:10.1109/3DUI.2012.6184190

[76] Tang, J.C. (1991). Findings from observational studies of collaborative work. *International Journal of Man-Machine Studies*, 34(2), 143-160. doi:10.1016/0020-7373(91)90039-A

[77] Tang, M. (2011). *Recognizing hand gestures with microsoft's kinect*. Technical report, Department of Electrical Engineering, Stanford University. Retrieved from http://www.stanford.edu/class/ee368/Project_11/Reports/Tang_Hand_Gesture_Recognition.pdf

[78] Thayer, S. (1986). History and strategies of research on social touch. *Journal of Nonverbal Behavior*, 10(1), 12-28. doi:10.1007/BF00987202

[79] Tran, C. and Trivedi, M.M. (2012). 3-D Posture and Gesture Recognition for Interactivity in Smart Spaces. *IEEE Transactions on Industrial Informatics*, 8(1), 178-187. doi:10.1109/TII.2011.2172450

[80] Tse, E., Histon, J., Scott, S.D., and Greenberg, S. (2004). Avoiding interference: how people use spatial separation and partitioning in SDG workspaces. *In Proceedings of the 2004 ACM conference on Computer supported cooperative work*, 252-261. doi:10.1145/1031607.1031647

[81] Ullmer, B. and Ishii, H.(1999). mediaBlocks: tangible interfaces for online media. *CHI '99 Extended Abstracts on Human Factors in Computing Systems*, 31-32. doi:10.1145/632716.632739

[82] Vogel, D., and Casiez, G. (2012). Hand occlusion on a multi-touch tabletop. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 2307-2316. doi:10.1145/2207676.2208390

[83] Vu, T., Baid, A., Gao, S., Gruteser, M., Howard, R., Lindqvist, J., Spasojevic, P., and Walling, J. (2012). Distinguishing users with capacitive touch communication. *Proceedings of the 18th annual international conference on Mobile computing and networking,* 197-208. doi:10.1145/2348543.2348569

[84] Wagner, A., Curran, P., and O'Brien, R. (1995). Drag me, drop me, treat me like an object. *Proceedings of the SIGCHI conference on Human factors in computing systems*, 525-530. doi: 10.1145/223904.223975

[85] Wigdor, D., Leigh, D., Forlines, C., Shipman, S., Barnwell, J., Balakrishnan, R., and Shen, C. (2006). Under the Table Interaction. *Proceedings of the 19th annual ACM symposium on User interface software and technology*, 259-268. doi:10.1145/1166253.1166294

[86] Wilson, A. and Benko, H. (2010). Combining multiple depth cameras and projectors for interactions on, above and between surfaces. *Proceedings of the 23nd annual ACM symposium on User interface software and technology*, 273-282. doi:10.1145/1866029.1866073

[87] Wobbrock, J.O., Morris, M.R., and Wilson, A.D. (2009). User-Defined Gestures for Surface Computing. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1083-1092. doi:10.1145/1518701.1518866

[88] Wu, M. and Blakrishnan, R. (2003). Multi-finger and Whole Hand Gestural Interaction Techniques for Multi-User Tabletop Displays. *Proceedings of the 16th annual ACM symposium on User interface software and technology*, 193-202. doi:10.1145/964696.964718

[89] Wu, M., Shen, C., Ryall, K., Forlines, C., and Balakrishnan R. (2006). Gesture Registration, Relaxation,and Reuse for Multi-Point Direct-Touch Surfaces. First IEEE International Workshop on Horizontal Interactive Human-Computer Systems, 185-192. doi:10.1109/TABLETOP.2006.19

APPENDIX A

KEY FUNCTIONS IN THE ABOVE-SURFACE FORCE-FIELD SOLUTION

A.1 Program Code for Finding Fingertips

```
/*
findFingertips()
Determines the location of the finger tips given that there may be
several hand objects split by occlusion above the table
Pre: curData (global) - is a copy of the kinectData structure for this
particular frame
     handTipLocations (global) - is a vector of three floating point
numbers, representing a position in three dimensional space
     curHands (global) - is the current instance of the hands as
provided by the KinectArms toolkit
Post: handTipLocations (global) - is updated to include the positions
of the fingertips
Note: This functionality may now be provided in the KinectArms toolkit
 */

void Forcefield3D::findFingertips() {

    const auto& depth = curData->depthImage.data;

  // Mark them as -1,-1,-1 if not found so they will be off screen
  for (auto handTip = handTipLocations.begin();
                handTip != handTipLocations.end(); handTip++) {
    handTip->x = -1.0f;
    handTip->y = -1.0f;
    handTip->z = -1.0f;
  }

  for (auto hand = curHands.cbegin();
                hand != curHands.end(); hand++) {
    // If an arm has two blobs, only the disembodied one should
    // be used for tip since it's likely farthest.
    // To do this, if a tip is already found for this id,
    //   and this hand is not disembodied, then ignore it.
    if (handTipLocations[hand->id].x != -1.0f &&
         // not first handobject found for this id
         handTipLocations[hand->id].y != -1.0f &&
         // not disembodied hand
         hand->armBase.x != -1 && hand->armBase.y != -1)
      continue;

    // Find point farthest from arm base
    float maxDistance = -1.0f;

    // Otherwise find the fingertip location and update
    //     handTipLocations
    for (auto boundaryPoint = hand->boundary.begin();
         boundaryPoint != hand->boundary.end(); boundaryPoint++) {
      const float distance = TableUtil::distance(*boundaryPoint,
           hand->armBase);
      if (distance > maxDistance) {
```

```
          maxDistance = distance;
          const Point3Df _realPoint = projectiveToRealWorld(
            boundaryPoint->x,
            boundaryPoint->y,
            depth[boundaryPoint->y][boundaryPoint->x]);

          const Vec3f realPoint = { _realPoint.x,
                        _realPoint.y,
                        _realPoint.z };
          handTipLocations[hand->id] = realPoint;
        }
      }

    }
}
```

A.2 Program Code for Calculating Proximity

```
/*
calcProximityVectors()
Calculates the proximity vectors and the minimum distance between
fingertips
Pre: proximityVectors (global) - is the set of vectors consisting of 3
floating point vectors and acts as a mapping of each of the fingertip
locations with respect to the other fingertips
     minDistances (global) - is the set of vectors consisting of float
vectors, this is used by the program to determine if a handoff should
occur because two hands are close enough to trigger a handoff
Post: proximityVectors (global) - will be updated to include the new
proximities of the fingertips in relation to other fingertips
     minDistances (global) - will be updated to include the new minimum
distances between each of the pairs of fingertips
 */

void Forcefield3D::calcProximityVectors() {
  const auto& depth = curData->depthImage.data;

  // Reset proximity and minimum distance matricies
  ProximityVectorMat_t proxVec;
  for (int i = 0; i < participants; i++) {
    for (int j = 0; j < participants; j++) {
      proximityVectors[i][j] = Vec3f();
      minDistances[i][j] = std::numeric_limits<float>::infinity();
    }
  }

  for (auto first = curHands.begin();
          first != curHands.end(); first++){
    for (auto second = curHands.begin(); second < first; second++) {
      // If both hands are actually part of the same arm, don't check
    if (first->id == second->id)
          continue;

    // Update distance and proximity vectors based on tips of each hand
    const float distance = TableUtil::distance(
```

```
          handTipLocations[first->id],
          handTipLocations[second->id]);

     minDistances[first->id][second->id] = distance;
     minDistances[second->id][first->id] = distance;

     const Vec3f firstToSecondVec = {
          handTipLocations[second->id].x-handTipLocations[first->id].x,
          handTipLocations[second->id].y-handTipLocations[first->id].y,
          handTipLocations[second->id].z-handTipLocations[first->id].z
          };

     const Vec3f secondToFirstVec = {
          -firstToSecondVec.x,
          -firstToSecondVec.y,
          -firstToSecondVec.z};
     proximityVectors[first->id][second->id] = firstToSecondVec;
     proximityVectors[second->id][first->id] = secondToFirstVec;

     }
  }
}
```

A.3 Program Code for Updating the Above-Surface State

```
/*
update(kinectData, time)
The update function is called once for every frame captured by the
Kinect and determines whether a handoff can occur again using a
hysteresis.
Pre: kinectData - the data structure of the kinect provided by the
KinectArms toolkit
     time - the time of the entire run of the program. The timer begins
at the start of each technique
Post: handoffs (global) – vector structure is updated to note which
users conducted a handoff that is used by the main program to update
the imagery on the table
 */
void Forcefield3D::update(const KinectData& kinectData,
     unsigned long time) {

  curData = &kinectData;
  prevHands = curHands;
  curHands = kinectData.hands;

  // Find hand tips
  findFingertips();

  // Calculate proximity vectors and minimum distances between arms
  calcProximityVectors();

  // Figure out which hands are close enough to handoff
  handoffs = HandoffPairs_t();
  for (int a = 0; a < minDistances.size(); a++) {
    for (int b = 0; b < a; b++) {
```

```
        // Hand off if within proximity and haven't recently handed off
        //without leaving range
        // A constant handoffSupressionTime of 333 milliseconds was used
        // here to ensure changes did not occur within a single frame
        const bool recentHandoff =
            (time - lastHandoffTime[a][b] < handoffSupressionTime) ||
            (time - lastHandoffTime[b][a] < handoffSupressionTime);

        if (minDistances[a][b] <= minHandoffDistance &&
            !surpressHandoff[a][b] && !recentHandoff) {

               handoffs.push_back(HandoffPair_t(a, b));

               // Do not allow handoffs for these two stations again
               // until they move apaprt
               surpressHandoff[a][b] = true;
               surpressHandoff[b][a] = true;

               // Mark time of handoff to prevent same frame changes
               lastHandoffTime[a][b] = time;
               lastHandoffTime[b][a] = time;

        } else if (minDistances[a][b] > minHandoffDistance &&
               minDistances[a][b] < 50000) {

            surpressHandoff[a][b] = false;
            surpressHandoff[b][a] = false;

        }
     }
  }
}
```

APPENDIX B

TECHNIQUE EVALUATION FORMS

B.1 Consent Form

DEPARTMENT OF COMPUTER SCIENCE
UNIVERSITY OF SASKATCHEWAN
INFORMED CONSENT FORM

UNIVERSITY OF SASKATCHEWAN

Research Project: **Improving Digital Object Handoff for Interactive Tables**

Investigators: **Dr. Carl Gutwin**, Department of Computer Science (966-8646)

Steve Sutcliffe, Department of Computer Science (966-2327)

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Please take the time to read this form carefully and to understand any accompanying information.

This study is concerned with improving the exchange of digital objects on tabletop surfaces.

The goal of the research is to determine which methods perform best when exchanging digital objects between several users around a single tabletop surface.

The session will take approximately 90 minutes, during which you will be asked to compete in a friendly game of transferring multiple objects from one side of the table to the other. Your task will be to pick up and pass digital objects to your partner on the other side of the table, or to receive digital objects from your partner and deposit them. You will also be asked to complete a series of questionnaires about your experience.

At the end of the session, you will be given more information about the purpose and goals of the study, and there will be time for you to ask questions about the research.

The data collected from this study will be used in articles for publication in journals and conference proceedings.

As one way of thanking you for your time, we will be pleased to make available to you a summary of the results of this study once they have been compiled (usually within two months). This summary will outline the research and discuss our findings and recommendations. This summary will be available on the HCI lab's website: http://www.hci.usask.ca/

All personal and identifying data will be kept confidential. If explicit consent has been given, textual excerpts, photographs, or video recordings may be used in the dissemination of research results in scholarly journals or at scholarly conferences. Anonymity will be preserved by using pseudonyms in any presentation of textual data in journals or at conferences. The informed consent form and all research data will be kept in a secure location under confidentiality in accordance with University policy for 5 years post publication. Do you have any questions about this aspect of the study?

You are free to withdraw from the study at any time without penalty and without losing any advertised benefits. Withdrawal from the study will not affect your academic status or your access to services at the university. If you withdraw, your data will be deleted from the study and destroyed. Your right to withdraw data from the study will apply until results have been disseminated, data has been pooled, etc. After this, it is possible that some form of research dissemination will have already occurred and it may not be possible to withdraw your data.

Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you have further questions concerning matters related to this research, please contact:

- Dr. Carl Gutwin, Professor, Dept. of Computer Science, (306) 966-8646, gutwin@cs.usask.ca

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a participant. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. If you have further questions about this study or your rights as a participant, please contact:

- Dr. Carl Gutwin, Professor, Dept. of Computer Science, (306) 966-8646, gutwin@cs.usask.ca
- Research Ethics Office, University of Saskatchewan, (306) 966-2975 or toll free at 888-966-2975.

Participant's signature:____

Date:____________________

Investigator's signature:____

Date:____________________

A copy of this consent form has been given to you to keep for your records and reference. This research has the ethical approval of the Research Ethics Office at the University of Saskatchewan.

B.2 Demographics Survey Questionnaire

Demographics Survey

* Required

User ID *

Gender *

- ( ) Male
- ( ) Female

Age *

Height *

Gives us the best estimate of your height & the units of measurement (ie: 5'6")

Handedness *

Are you left or right handed?

- ( ) Right
- ( ) Left

What is the language you speak at home (to parents/kids/etc): *

How many hours a week do you use a computer? *

Which pointing device do you use most frequently? *

We are looking for a device that points on a screen. You should not consider the keyboard as one of these devices.

- Mouse
- Trackpad
- Touchscreen
- Stylus
- Other:

Please rate your experience with digital tabletops: *

- Never heard of it
- Never seen one being used
- Never used one, but seen one used
- Used them once or twice
- Used them on occassion
- Lots of experience using them

Please rate your experience with touch devices (e.g., ipad, smartphone, tablet) *

- Never heard of it
- Never seen one being used
- Never used one, but seen one used
- Used them once or twice
- Used them on occassion
- Lots of experience using them

Submit

B.3 NASA Task Load Index (TLX) Questionnaire

TLX

Please evaluate the task you just completed by selecting the value on the scale from 0 to 10 at the point which matches your experience. NOTE: Performance is measured on a scale where 0 is Good and 10 is Poor

* Required

User ID *

Technique *

Select the technique you just used from the list below

- Slide
- Force-Field (on surface)
- Flick
- Force-Field (above surface)
- Electrotouch

Mental Demand *

How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, forgiving or exacting?

	0	1	2	3	4	5	6	7	8	9	10	
Low												High

Physical Demand *

How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

	0	1	2	3	4	5	6	7	8	9	10	
Low												High

Temporal Demand *

How much time pressure did you feel due to the rate at which the task elements occurred? Was the pace slow and leisurely or rapid and frantic?

	0	1	2	3	4	5	6	7	8	9	10	
Low												High

Performance *

How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

	0	1	2	3	4	5	6	7	8	9	10	
Good	○	○	○	○	○	○	○	○	○	○	○	Poor

Effort *

How hard did you have to work (mentally and physically) to accomplish your level of performance?

	0	1	2	3	4	5	6	7	8	9	10	
Low	○	○	○	○	○	○	○	○	○	○	○	High

Frustration *

How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

	0	1	2	3	4	5	6	7	8	9	10	
Low	○	○	○	○	○	○	○	○	○	○	○	High

Submit

B.4 End of One-Pair Trials Questionnaire

End of Two Person Trials Questionnaire

* Required

User ID *

Please rank the techniques listed below from 1-5 in terms of how easy they were to learn, with 1 for the hardest to learn and 5 for the easiest to learn. *

PLEASE ENSURE YOU USE EACH NUMBER (1-5) ONCE AND ONLY ONCE

	1 - hardest	2	3	4	5 - easiest
Slide					
Force-Field (on surface)					
Flick					
Force-Field (above surface)					
Electrotouch					

Please rank the techniques listed below from 1-5 in terms of how natural they were to use, with 1 for the most unnatural and 5 as the most natural *

PLEASE ENSURE YOU USE EACH NUMBER (1-5) ONCE AND ONLY ONCE

	1 - unnatural	2	3	4	5 - natural
Slide					
Force-Field (on surface)					
Flick					
Force-Field (above surface)					
Electrotouch					

Please rank the techniques listed below from 1-5 in terms of how much you preferred them, with 1 for the least preferred and 5 as the most preferred *

PLEASE ENSURE YOU USE EACH NUMBER (1-5) ONCE AND ONLY ONCE

	1 - least preferred	2	3	4	5 - most preferred
Slide	○	○	○	○	○
Force-Field (on surface)	○	○	○	○	○
Flick	○	○	○	○	○
Force-Field (above surface)	○	○	○	○	○
Electrotouch	○	○	○	○	○

Any further comments?

Feel free to comment on your choices above or anything else you feel we should know.

Submit

B.5 Final Questionnaire

Final Questionnaire

* Required

User ID *

Please rank the techniques listed below from 1-5 in terms of how easy they were to learn, with 1 for the hardest to learn and 5 for the easiest to learn. *

PLEASE ENSURE YOU USE EACH NUMBER (1-5) ONCE AND ONLY ONCE

	1 - hardest	2	3	4	5 - easiest
Slide	○	○	○	○	○
Force-Field (on surface)	○	○	○	○	○
Flick	○	○	○	○	○
Force-Field (above surface)	○	○	○	○	○
Electrotouch	○	○	○	○	○

Please rank the techniques listed below from 1-5 in terms of how natural they were to use, with 1 for the most unnatural and 5 as the most natural *

PLEASE ENSURE YOU USE EACH NUMBER (1-5) ONCE AND ONLY ONCE

	1 - unnatural	2	3	4	5 - natural
Slide	○	○	○	○	○
Force-Field (on surface)	○	○	○	○	○
Flick	○	○	○	○	○
Force-Field (above surface)	○	○	○	○	○
Electrotouch	○	○	○	○	○

Please rank the techniques listed below from 1-5 in terms of how much you preferred them, with 1 for the least preferred and 5 as the most preferred *
PLEASE ENSURE YOU USE EACH NUMBER (1-5) ONCE AND ONLY ONCE

	1 - least preferred	2	3	4	5 - most preferred
Slide	○	○	○	○	○
Force-Field (on surface)	○	○	○	○	○
Flick	○	○	○	○	○
Force-Field (above surface)	○	○	○	○	○
Electrotouch	○	○	○	○	○

Please rank the techniques listed below from 1-5 in terms of how well they worked with TWO people, where 1 worked the worst and 5 worked the best *
PLEASE ENSURE YOU USE EACH NUMBER (1-5) ONCE AND ONLY ONCE

	1 - worst	2	3	4	5 - best
Slide	○	○	○	○	○
Force-Field (on surface)	○	○	○	○	○
Flick	○	○	○	○	○
Force-Field (above surface)	○	○	○	○	○
Electrotouch	○	○	○	○	○

Please rank the techniques listed below from 1-5 in terms of how well they worked with FOUR people, where 1 worked the worst and 5 worked the best *
PLEASE ENSURE YOU USE EACH NUMBER (1-5) ONCE AND ONLY ONCE

	1 - worst	2	3	4	5 - best
Slide	○	○	○	○	○
Force-Field (on surface)	○	○	○	○	○
Flick	○	○	○	○	○
Force-Field (above surface)	○	○	○	○	○
Electrotouch	○	○	○	○	○

Any further comments?

This is the last question of the last survey, so feel free to comment on your choices above or anything else you feel we should know.

Submit

APPENDIX C

DIGITAL OBJECT REPRESENTATION STUDY

C.1 Consent Form

DEPARTMENT OF COMPUTER SCIENCE
UNIVERSITY OF SASKATCHEWAN
INFORMED CONSENT FORM

Research Project: **Visually Representing Digital Object Possession when the Digital Object Exists off of the Surface of the Tabletop**

Investigators: **Dr. Carl Gutwin**, Department of Computer Science (966-8646)

Steve Sutcliffe, Department of Computer Science (966-2327)

This consent form, a copy of which has been given to you, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, please ask. Please take the time to read this form carefully and to understand any accompanying information.

This study is concerned with improving the exchange of digital objects on tabletop surfaces.

The goal of the research is to determine which methods of representing a digital object above the surface of a table perform the best.

The session will take approximately 30 minutes, during which time you will be asked to determine repeatedly whether the digital object shown belongs to one of the other players or is resting on the surface of the table and available to be 'picked up'. You will also be asked to complete a series of questionnaires about your experience with a few follow-up questions.

At the end of the session, you will be given more information about the purpose and goals of the study, and there will be time for you to ask questions about the research.

The data collected from this study will be used in articles for publication in journals and conference proceedings.

As one way of thanking you for your time, we will be pleased to make available to you a summary of the results of this study once they have been compiled (usually within two months). This summary will outline the research and discuss our findings and recommendations. This summary will be available on the HCI lab's website: http://www.hci.usask.ca/

All personal and identifying data will be kept confidential. If explicit consent has been given, textual excerpts, photographs, or video recordings may be used in the dissemination of research results in scholarly journals or at scholarly conferences. Anonymity will be preserved by using pseudonyms in any presentation of textual data in journals or at conferences. The informed consent form and all research data will be kept in a secure location under confidentiality in accordance with University policy for 5 years post publication. Do you have any questions about this aspect of the study?

You are free to withdraw from the study at any time without penalty and without losing any advertised benefits. Withdrawal from the study will not affect your academic status or your access to services at the university. If you withdraw, your data will be deleted from the study and destroyed. Your right to withdraw data from the study will apply until results have been disseminated, data has been pooled, etc. After this, it is possible that some form of research dissemination will have already occurred and it may not be possible to withdraw your data.

Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. If you have further questions concerning matters related to this research, please contact:

- Dr. Carl Gutwin, Professor, Dept. of Computer Science, (306) 966-8646, gutwin@cs.usask.ca

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a participant. In no way does this waive your legal rights nor release the investigators, sponsors, or involved institutions from their legal and professional responsibilities. If you have further questions about this study or your rights as a participant, please contact:

- Dr. Carl Gutwin, Professor, Dept. of Computer Science, (306) 966-8646, gutwin@cs.usask.ca
- Research Ethics Office, University of Saskatchewan, (306) 966-2975 or toll free at 888-966-2975.

Participant's signature:____

Date:____________________

Investigator's signature:____

Date:____________________

A copy of this consent form has been given to you to keep for your records and reference. This research has the ethical approval of the Research Ethics Office at the University of Saskatchewan.

C.2 Demographics Survey

Demographics Questionnaire – Digital Object Representation

Date:______________________ **UserID:**_________

Gender: Male Female

1. **Age**: _______

2. **Handedness**: Left Right

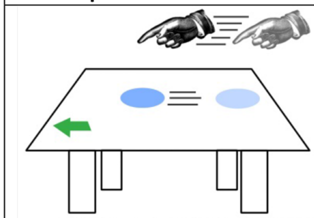
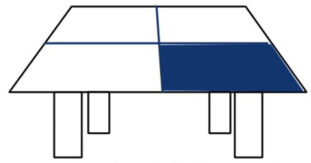
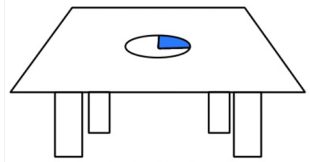
3. **Which pointing device do you use most frequently**?
□Mouse □Trackpad □Touchscreen □Stylus □Other: ________________

4. **Please rate your experience with digital tabletops**:
□Never heard of it □Never seen one being used □Never used one but seen one used
□Used them once or twice □Used them on occasion □Lots of experience using them

5. **Please rate your experience with touch devices (e.g., ipad, smartphone, tablet)**:
□Never heard of it □Never seen one being used □Never used one but seen one used
□Used them once or twice □Used them on occasion □Lots of experience using them

C.3 End of Task Survey

PLEASE ENSURE YOU USE EACH NUMBER ONCE AND ONLY ONCE

Technique 1	**Technique 2**	**Technique 3**
 As hand moves above the table object on the table moves with the hand, object is lighter than original, when hand is off of the table an arrow appears	 Quadarant of the table highlights depending on who has the object	 Image is represented in middle of table as an outline, with one section highlighted indicating who has the object

Please rank the techniques listed below from 1-3 in terms of how easy it was to understand ***who had the digital object***, with 1 for hardest to understand and 3 as the easiest to understand

	Hardest to Understand		Easiest to Understand
Technique	1	2	3
1			
2			
3			

Please rank the techniques listed below from 1-3 in terms of how easy it was to understand ***whether the object was 'on' or 'off' the table***, with 1 for hardest to understand and 3 as the easiest to understand

	Hardest to Understand		Easiest to Understand
Technique	1	2	3
1			
2			
3			

Please rank the techniques listed below from 1-3 in terms of ***how much you preferred them***, with 1 for least preferred and 3 as the most preferred

	Least Preferred		Most Preferred
Technique	1	2	3
1			
2			
3			

C.4 Interviews

Interview 1

Do you have any comments about the techniques?

P1: Your tests with the low resolution made it difficult to tell if the object was translucent or not cause the color didn't really change.

How difficult was it to rank the techniques?

P1:it was pretty obvious

Any other comments, problems with the keyboard input?

P1:No, the keys were great

Interview 2

Do you have any comments about the techniques?

P2: It seems there is a little bit of disconnect between the study task and what the test is for. It's as if you are walking in the middle of the task and it's frozen and you are trying to understand what is going on. Whereas in the actual task you are more interested in doing the task and there is a complete history. So I pick up an object and hand it to someone and you want both people to understand what is going on in the complete transition of the task rather… and so… um… I start to question how much relevance to have just a snapshot. I guess you can imagine a situation where someone is handing you an object but you are looking away when they give that to you. I don't know how common that is. I see there is a little bit of disconnect between the study task and what you are studying. I don't know if that is the problem but that's something to consider.

What about the techniques themselves?

P2: So given the task I think I was responding to the sheer size of the notification, so in pretty much all of the tasks I give very similar orders, because T2 is the quarter of the screen, and you always know that one, [it] is very easy. This one [T3] is next easiest, but it's a very different representation, so you don't have to look at it and figure out if it is solid or transparent, so you just look at it and say oh that is completely different. This one [T1] it feels like you have to spend an extra fraction of a second deciding which representation it is. So it may be something in the real task you have less to decide when there is someone's hand there & the object is moving, so maybe that task [T1] would be easier if someone was actually controlling it. At a rule it seemed hardest because it was the same ball [represented as being picked up & the one on the table]. And I think I said I liked this one better [T3], because the ball wasn't there when it was picked up.

In T2 the other object appeared in the shaded square sometimes

P2: Yeah and it seemed that it was getting in the way of the other object sometimes. T3 seemed more out of the way so it seemed more useful. I rated these ones [T1 & T2] lower than the other task [T3] but it wasn't much lower.

Any other thoughts?

P2: For the experiment you are wanting people to do this as fast as possible, the tasks seemed pretty easy, I assume you are recording errors as well?

Yes

P2: I don't feel like I made any errors, so you may find that people are topping out quite a lot, which might not get you the nice distributions. I don't know how you could make it harder, but maybe you could add some visual cues to make people feel like should be going faster, like perhaps adding a visual timer for the participants to see.

It's a bit of a different task because I want to study one person at a time, but the problem we are trying to solve is that in our study we ran this summer, people had to quickly determine whether they had the object or not, because they were completing the task of handoff so quickly. Some people got confused as to whether they held the object or the object was still on the table, since we just used a semi-transparent object in the corner of the screen. So we are trying to create the same situation without all the other people. So it makes it a little difficult for technique 1 since it relies heavily on movement.

P2: So maybe your issue is more providing a good description of your motivation in your paper. So it is actually a problem, it doesn't feel like it should be a problem if you don't know the background.

Interview 3

Do you have any comments about the techniques?

P3: It was different when I was observing versus actually using it [T3]. It was weird because I had the experience of picking up the thing and it was like the change is over here and I look over here and wonder why is it over there, oh yeah because I have it. It was almost like a disconnect where it almost felt for a second like it had been taken away from me. It is interesting since as an observer I can tell what is going on the best that way, because I don't have to look at all the other garbage happening, the little circle in the center tells me all what is going on. But as a person using what I care about, I kind of like the one that is hovering [T1] because I get the sense that I have it, and when I have it off of the screen its kind of pointing where it is. And when I was using it I was looking for where the green object was and the green arrow tells me who has it. That tells me all the information I need when I need to know, I can go look for the information, and all the information is present. It's easy for me to sort out the information that I don't normally care about. [T3] As an information center, it felt clunkier when using it than when I was watching it, when I was watching it it was nice, like a scoreboard in a game or something like that.

What about the techniques themselves?

P3: Technique 2 is fine, all the information is there, and I can interpret it, but it's a little loud if anything, but its fine, it works, it works just as well if not better than T3, but it might be too much noise I think. T1 you still get all the information like this [T2] but you get other information like when it is moving.

P3:It was almost harder in some of those example slides to tell who possessed it because the arm wasn't there, if there is an un-highlighted circle there I can assume that guy has it. I suppose you can't reach too far because of the [Kinect] boarders. It might be kind of difficult to look at it and say I can guess that he has it for a fact. But in the real world when you are actually using it the arm would tell me, its another piece of indicative information that explains that.

You found it difficult to rank them according to your survey?

P3:Yeah, it was interesting just having the experience of watching the demo, I liked that one [t3] the best, but when I was actually using it I liked T1 the best.

Interview 4

Do you have any comments about the techniques?

P4:no [no comments]

How hard was it to rank the techniques?

P4:yeah it was very close

What about your thoughts on the first technique? Where the hand helped you know where the object was?

P4:The only thing I found hard was the transparent and the non-transparent, when it's on the table its solid, and when it's not on the table its transparent, sometimes it's not that easy to distinguish.

What about using this stuff in the real world? Would you prefer one of these techniques over the other if you were using it in the real world?

P4:I think those two [T1 & T3], because on the table there will be other things too, and T2 will take up too much space, but those two [T1 & T3] will be easy to distinguish

Interview 5

Do you have any comments about the techniques?

P5: The only thing that had any difference than the other ones was the one with the object was transparent or not, everything else was easy to tell. And I felt like in terms of speed and performance, very little of it [the experiment] was actually seeing what you were testing and more of it was just finding the right button to push. It's not that I was hunting for the button to push, but it was processing in my mind what button to push, even though in my mind I knew exactly what person had the object. I don't know if that will be a factor for you.

Would it have been faster if you could vocalize it?

P5: It would have been faster if you could have used a joystick and point it in one of the four directions

What about using these techniques in the real world? If you were using it live rather than task based?

P5: It depends on the situation. In the survey I liked the T2 the most, that wouldn't be as good if there were more objects and stuff

Even if you could see objects behind it?

P5: It would still be fine I guess, but the one in the middle [T3] takes up less space and less visual clutter but it also requires dedicated space. Yeah I'm fine with either [T3 or T2], if I saw the actually situation I might change my opinion. Oh yeah, and in regard to the previous question, the first technique you can't do it as you would normally do it in the real world [no arm above the surface to give you context].

Interview 6

Do you have any comments about the techniques?

P6: The following around one might be easier when I'm actually holding it and moving it around but it was definitely the hardest to just look at still images and connect the dot thing, like oh yeah that definitely belonged to that person. Whereas with the quadrants you knew it was definitely with that person. I liked the quadrants, it was big and obvious you had the object, but when you had the purple object light up the background, but the green object was still on the table, then it was hard to see your object, so you know you had the wrong object, but you kind of loose track of your own object when you mix it up I guess. And then, just remembering how we did the handoff tests when we were playing, I liked the center one [T3] cause I remember when we were doing that we would stand up like this and my focus was on the center and it would be the easiest to tell [who had it]. The center one was my favourite because I knew what we had done in the previous studies and I knew my focus would be at that point [the center]. The quadrant one was easy too, if your focus was in the center then it was just as easy as the entire thing lighting up so it was easy to keep track of your object.

How easy was it to rank these techniques?

P6: I had a pretty good idea of which ones I thought were better in my mind.

Interview 7

Do you have any comments about the techniques?

P7: Just what I was thinking about the whole… I wasn't actually performing handoff, so that might lead me to change my preferences and worked well and what didn't. The feedback of the first technique with the floating circle, I know where it is, not just who has it. I don't know if I would actually use [video feedback in T1] in an actual handoff or not. Preferences is a hard one to answer.

You had trouble translating what you saw today into a live scenario?

P7: Yeah, where the techniques would actually be used.

So even though you got to experiment in the beginning that wasn't enough for you?

P7: Yeah, that was just getting to know the techniques. The Second technique gives you a nice strong signal that when you picked it up you got it. Also with T1, it wasn't there until I picked it up, again, it was a nice strong visual feedback. The feedback with the hovering circle [in T1] was a little bit less, if you missed the change in the color scheme, between not-transparent and transparent, you might miss it. Of course it moves, jitters, so that helps you know what the thing is [and who it belongs to].

Was it difficult to rank the techniques then?

P7: Yeah I found ranking them difficult, the ones where you had to determine who had the object and whether the object was on the table or not were easy to rank. But I ranked the hover circle technique [T1] the lowest in both of those but I don't know if that is actually fair, when I guess you would consider how it actually performed.

Interview 8

Do you have any comments about the techniques?

P8: Well, I think the first one [T1] is the hardest, and I don't like it the most because they can look very much alike [the two states] whether it is on or off [the surface] it's not obvious because you are just shading it a little bit. There is no huge visual differences. But, I say that only because I'm not interacting with it. I did try it, but I think if I'm interacting with it it will be a lot different because when I see it moving, then I know my perception of it. So the still image is a lot different, because it has a lot to do with motion, and that's also one main difference between this and the other two techiques. The first one, motion matters, the second and third one doesn't matter. It doesn't show anything, so a still image would be good enough. The second one has a huge difference, very visible, the third one is also visible but not as big of a difference. For the third one I needed to pay attention to the center part, but for the second one I can pretty much pay attention to anywhere and I would be able to know which one belongs to a person or is on or off the table. Whether things are on or off the table would be huge, because I've got lines across the whole table [T2], so its affecting the whole table, not just the quadrant, because you have the other two lines [the grid], so I can actually tell very easily if one object is off of the table. But then, what I'm actually saying is only based on this particular setting, this setup that you use, that you are testing me on, this [T2] would be less obvious when there are actually more than one object when you picked it up. Because, this line, the visual thing, would be always on if there is at least one object off of the table, so this can become the background if there is always one object, and this can also affect the background and affect other stuff. So the effect would be less if there was more than one object off of the table. But it will still be good because it would still be obvious whether at least one object is on or off of the table.

P8:I would also want to see more kind of conditions, it's just because the first technique involves movements, and it would actually be very different, if you were doing it as you were moving it around and passing an object, and showing like a 2 second clip, then it would be obvious for the first one, and it could be the best because things were moving and it kept your attention. I don't know I would need to try it out [in the task] to see. But for this task I think the first one [T1] is actually harder because the shape is the same and there is no differences.