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Use of Global Positioning Systems (GPS) for Topographic Surveys and the Development of Management Units for Precision Farming

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Abstract

The use of Global Positioning System (GPS) technology has become common in situations requiring spatial and topographic information. Many of the receivers currently available offer sub-meter accuracy in two dimensions when correction is applied, whether real-time or post processing. The vertical dimension tends to be less accurate than the horizontal. To determine the relative accuracy of commonly available GPS receivers, four sites east of Saskatoon were surveyed using both conventional survey techniques (Total Station) and GPS (Trimble Pro XRS). The topography of the sites ranged from level (slope class 2) to hummocky (slope class 5). The GPS data were corrected using both real-time differential satellite correction and post processing data provided by local base stations. Digital Elevation Models (DEM) were derived for each of the following: the Total Station elevations, the GPS elevations corrected in real-time, and the post-processed GPS elevations. Comparing the GPS topographic surfaces with the Total Station surface reveals that there are substantial differences in the two, limiting the application of GPS to landform segmentation procedures. The errors present in the GPS surfaces tended to be linear, corresponding with the orientation of the survey transects, rather than random. In landform segmentation, this creates artificial ridges or draws in the landscape. Given these limitations, producers using combination GPS/yield monitor systems will not be able to produce high quality management unit maps, particularly when no differential correction is applied.

Introduction

The Global Positioning System (GPS) is a popular technology used for gathering geographic information for a variety of purposes. The accuracy of the information gathered depends on the quality of both the satellites transmitting the information and on the receiver being used to collect it. GPS is based on satellite trilateration, where the exact coordinates on the surface of the Earth can be calculated by measuring the distance from a group of satellites (minimum of 4 for three dimensional coordinates) to that position. The information is carried from the satellites to the receiver on two carrier waves, L1 (1575.42 MHz) and L2 (1227.60 MHz). These waves carry binary GPS codes. The precise code (P code – available on both L1 and L2) and coarse/acquisition code (C/A code – available only on L1) carry the raw data that is used to derive the required time and distance measurements. The Navigation code (available on both L1 and L2) carries important information for the GPS receivers, like a clock correction, ephemeris, and atmospheric correction. The most precise receivers (survey quality) can collect P and C/A data from both the L1 and L2 wavelengths, however the most commonly available receivers (mapping quality) only collect C/A code from the L1 wavelength (van Sickle, 1996).

Two methods may be used to correct for errors that limit the accuracy of the information collected by the mapping quality receiver: real-time differential correction and post-processing differential correction. Both methods involve a base station or “virtual” base station, and serve to reduce some of those errors that are common to both the base station and rover receivers (i.e., receivers gathering field data), such as clock errors, ionospheric and tropospheric delay, and selective availability (those errors deliberately induced by the U.S. Department of Defense). Real-time correction uses radiobeacons or satellites (“virtual” base stations) that broadcast corrections to the rover receiver as it calculates its position so the stored position has already been corrected. Post-processing instead stores the correction information at a base station of a known location. This file is later combined with the rover file to produce differentially corrected information (Trimble, 1998).

GPS technology is being increasingly applied to scientific research, particularly geomorphic field studies. While it is well-suited to rapid surveying under difficult conditions (Higgitt and Warburton, 1999; Cornelius, et al., 1994), it does seem to be of limited accuracy in determining elevations when a mapping quality receiver is used (Allison, 1996). This study will address whether mapping quality GPS receivers are sufficient for topographic mapping and the development of management unit maps for precision farming by comparing corrected mapping quality GPS data (both real-time and post-processed) with conventional survey data.

Methods and Materials

The data were collected at four sites east of Saskatoon, in the St. Denis area. There was one level site (slope class 2), one undulating sloped site (slope class 3), and two hummocky sites (slope class 5). Each site was approximately 80 acres in area and was surveyed based on a systematic 25 meter grid with additional points included as needed to get a true representation of the landscape; each site included between 400 and 600 points. The horizontal (x, y) coordinates of each point were collected only by GPS with real-time differential correction. The vertical (z) coordinates were taken by both Total Station and GPS methods. The GPS receiver used was the Trimble Pro XRS GPS/MSK/Beacon/Satellite Differential receiver, which is a 12-channel differential GPS (DGPS) receiver with L1 C/A code with carrier-phase filtering and instantaneous full wavelength carrier-phase measurements. Real-time satellite differential corrections were performed using the Landstar satellite system. This receiver offers sub-meter to 5 meter horizontal accuracy with differential correction (Trimble, 1998).

Once collected, the Total Station data were entered into Excel. The GPS data were downloaded into the Trimble Pathfinder program. Post-processing of the real-time data was performed using files from base stations located in Humboldt and Saskatoon. The Pathfinder program combines the files recorded by the base stations with the positions collected by the rover to produce a differentially corrected rover file. Both the raw (real-time corrected) data and the post-processed data were exported in a dBase format in the Universal Transverse Mercator (UTM) coordinate system. The files were then combined to create a single file with the common easting and northing coordinates from the real-time GPS data and the three elevation values for each survey point. The GPS elevations were corrected relative to the lowest point in each site as surveyed by the Total Station. Using the inverse distance, non-radial algorithm in Rockware, a DEM with 10 meter grid spacing was derived for each measurement method. Each of the three DEMs were exported into a landform classification program (Pennock, et al., 1987) that groups the cells into one of seven landform elements based on gradient, plan curvature and profile curvature. These elements were aggregated into landform element complexes based on their global catchment area, a function of drainage. The tabular output of the landform classification program was imported into SPSS for statistical analysis.

Results and Discussion

Just one of the four sites will be examined in detail here, because all four of the sites exhibited similar results. This particular site is hummocky, with a slope class of 5 (10-15% gradient) and elevations ranging from 0 to 13 meters. The DEMs derived using the GPS method were subtracted from Total Station DEM. The differences, on a cell by cell basis, are summarized in the histograms shown in Figures 1 and 2. Ideally, there should be zero difference between the Total Station and GPS surfaces, but this is not the case. Figure 1 shows the difference between the Total Station surface and the real-time corrected GPS measurements, while Figure 2 shows the difference between the Total Station and post-processed GPS measurements. Although the total range of each histogram is close to 5 meters, the real-time data is much more negatively skewed, with a mean difference of –0.70m, whereas the post-processed data is more centered around 0 difference. So, although both GPS methods differ from the Total Station surface, the post-processed data is a better representation for this site. This is consistent with the results of the other slope class 5 site and the slope class 3 site. The differences were not consistent with respect to the direction of the skew, though. For example, the other slope class 5 site had a real-time mean difference of 1.31, while the post-processed mean difference was 0.01.

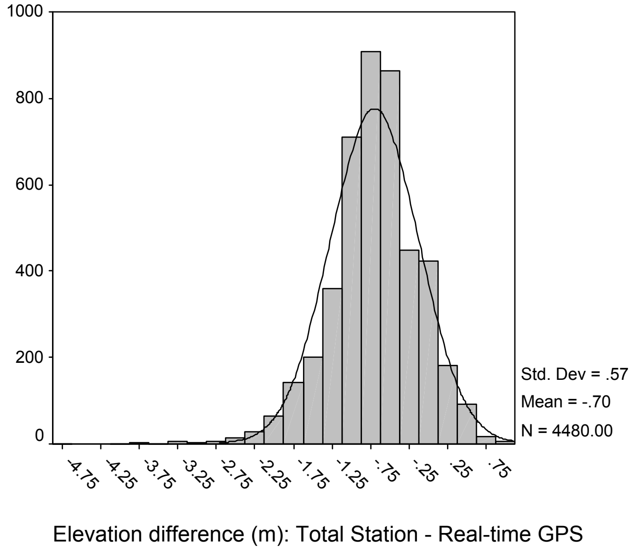

Figure 1: Histogram of the elevation differences, on a cell-by-cell basis, between the Total Station DEM and the real-time GPS DEM.

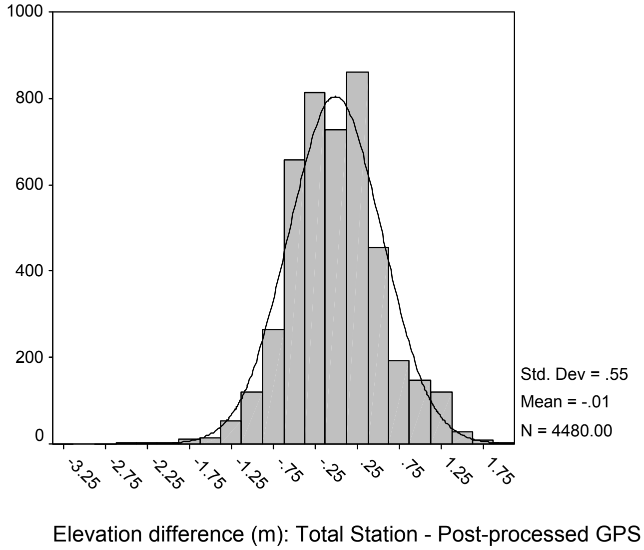

Figure 2: Histogram of the elevation differences, on a cell-by-cell basis, between the Total Station DEM and the post-processed GPS DEM.

The common perception is that the error associated with GPS measurements is randomly generated by the U.S. Department of Defense. The differences shown at this site, however, demonstrate that there is a systematic component to the error. Figure 3 is the surface generated by subtracting the post-processed GPS DEM from the Total Station DEM (i.e., a DEM of the data summarized in Figure 2). Ideally, the surface in Figure 3 would all be level, because the difference in all cells would be equal to zero. Instead, there are distinct ridges present where the GPS elevations were either higher or lower than the Total Station elevations. These ridges are oriented in the same direction as the survey transects. This implies a time-dependence associated with the error, as opposed to a completely random error.

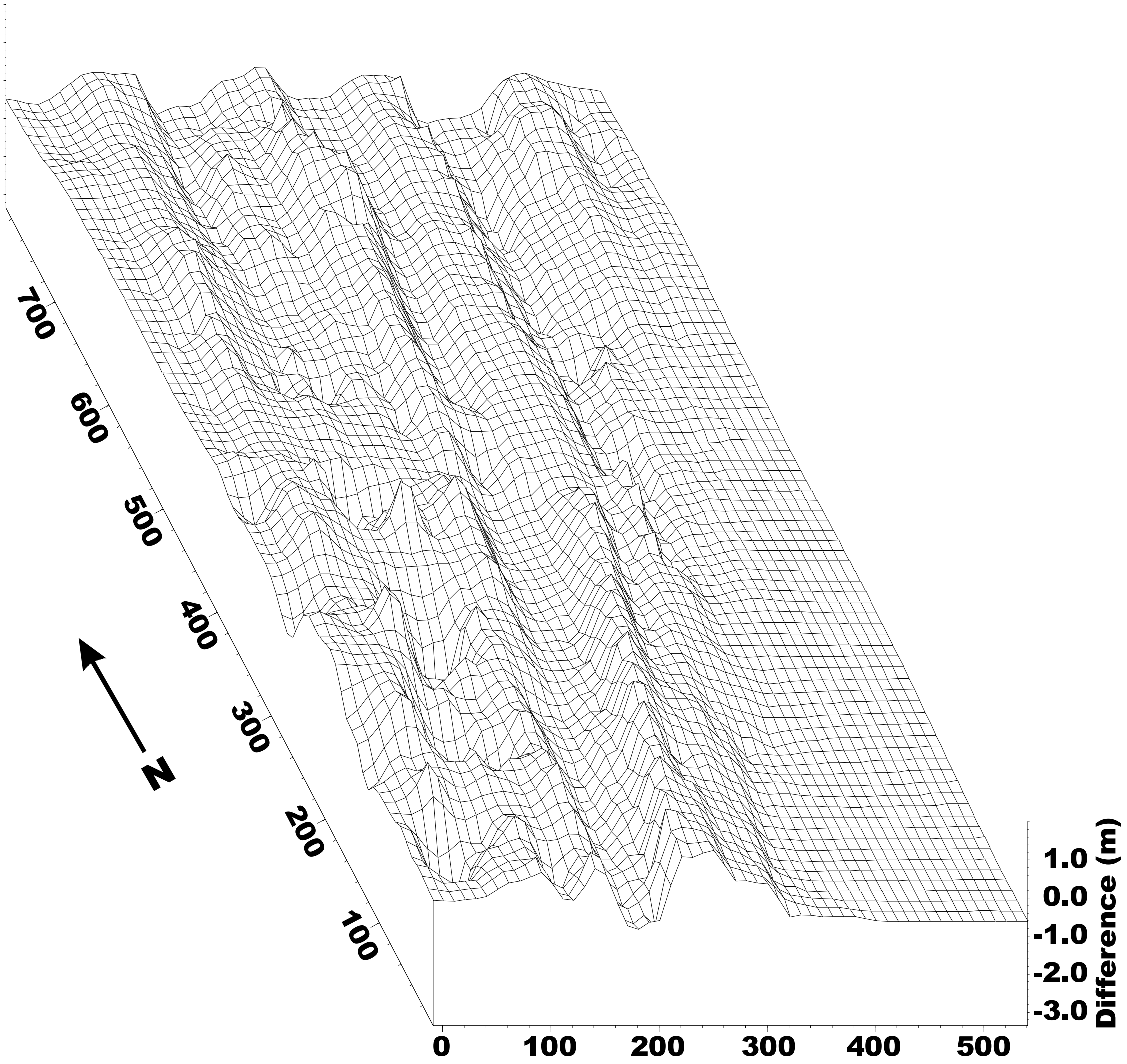

Figure 3: Surface derived by subtracting the post-processed GPS DEM from the Total Station DEM.

The differences illustrated above influence the classification of landform elements. The linear nature of the GPS errors creates hydrological artifacts that do not really exist in the site. Figure 4 is a DEM derived using the Total Station elevations, and it illustrates clearly that there are no distinctly linear ridges or depressions. The difference DEM in Figure 3 shows how the GPS measurements has superimposed these features onto the existing landscape. Consequently, when the landform program classifies each cell based on its gradient, profile curvature, and plan curvature, the GPS grid will misrepresent what is really there. These differences can be seen in Table 1, a cross-tabulation of how the landform element program classified each cell in the Total Station grid, as compared to the post-processed GPS grid. For example, only 68% of the cells classified as level (L) using the Total Station grid were also classified as level in the GPS grid. The other 32% were distributed amongst the other 6 classes. All seven classes exhibit similar disparities. When these seven elements were grouped together into landform element complexes, there was no improvement in the agreement between the two survey methods. The cross-tabulation in Table 2 shows that there is only 70% agreement between level complexes using the two methods. The backslope complexes have even poorer agreement, with only 25% of the backslopes in the Total Station grid being classified as backslopes in the post-processed GPS grid. Due to the differences between the two GPS methods mentioned above, there is also a discrepancy between the classification of landform elements based on the post-processed GPS data versus the real-time GPS data.

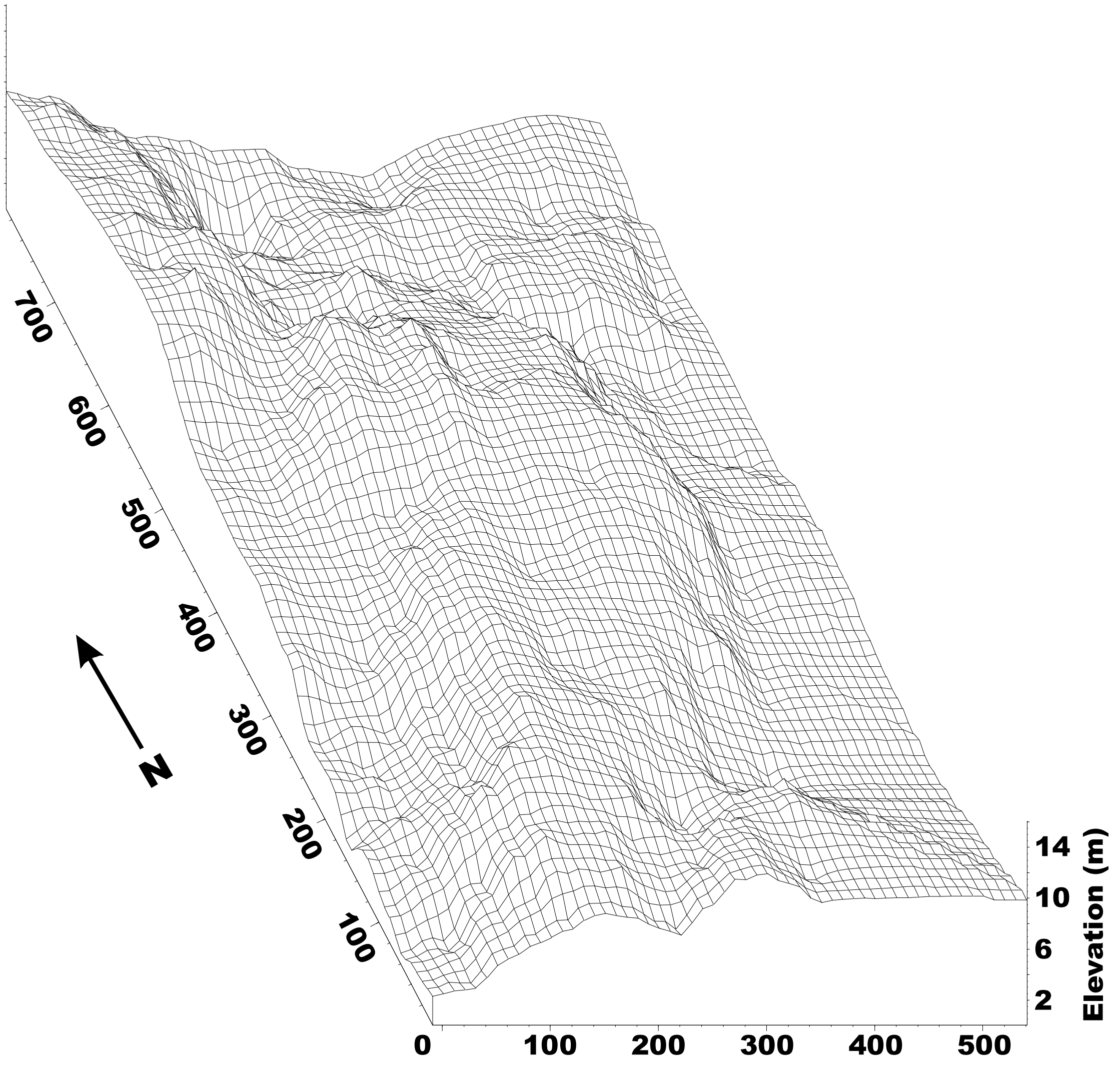

Figure 4: DEM derived in Rockware using Total Station elevation data.

Table 1: Cross-tabulation of Landform elements classified based on Post-processed GPS elevations and Total Station elevations. DS: divergent shoulder, CS: convergent shoulder, DB: divergent backslope, CB: convergent backslope, DF: divergent footslope, CF: convergent footslope, L: level

Count

		Total Station Landform Elements							
		DS	CS	DB	CB	DF	CF	L	Total
GPS Landform Elements	DS	527	77	28	1	10	9	98	750
	CS	69	336	12	15	16	9	103	560
	DB	25	19	81	14	22	4	37	202
	CB	3	32	15	104	18	30	35	237
	DF	8	22	17	17	285	62	90	501
	CF	4	13	3	21	68	490	90	689
	L	79	72	16	20	50	59	976	1272
Total		715	571	172	192	469	663	1429	4211

Table 2: Cross-tabulation of landform element complexes comparing the post-processed GPS grid and Total Station grid. S: shoulder complex, B: backslope complex, F: footslope complex, L: level complex

Count

		Total Station complexes				
		S	B	F	L	Total
GPS complexes	S	1052	35	198	240	1525
	B	53	20	34	41	148
	F	149	22	806	205	1182
	L	149	2	80	1125	1356
Total		1403	79	1118	1611	4211

Conclusion

Although GPS is well-suited to several two-dimensional mapping applications, this study reveals that using mapping quality GPS technology for topographic surveys produces results that are insufficient for landform modeling applications, particularly hydrological applications, due to its tendency to create artificial ridges or draws. While post-processing brought the data accuracy to within ±2 meters for most sites, this is still a 15% error when the total elevation change is 13 meters, and 100% error when the total elevation change is only 2 meters, as is the case in the slope class 2 site. The development of management units for precision farming from GPS data would be of limited success, then, particularly considering that most farm GPS receivers would not be as accurate as the one used in this study. Each point in this study was measured for 30 seconds, averaging six positions together. Most producer systems collect data while in motion, so only a single position is collected for each location. Survey quality GPS systems can provide much greater accuracy (Fix and Burt, 1995), but would be cost-prohibitive for most applications.

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