GPS Satellite Precision Global Surveying

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Abstract

A precision kinetic satellite surveying system is designed and implemented using a Global Positioning System (GPS). A Trimble AgGPS 332 receiver is interfaced to a real-time kinetic (RTK) base station to achieve high precision centimeter scale positioning capability. The receiver system is connected to a laptop personal computer where GPS receiver coordinates are captured and stored with the appropriate ExpertGPS software. The GPS data is layered on top of a GIS map with geospatial features and satellite view photographs of buildings and roads. The Virginia State University campus is used as a testing ground for the precision mapping of GPS satellite kinetic surveying; results are presented to demonstrate the mapping and positioning ability of the hardware and software system, which is capable of global real-time data collection and navigation.

Introduction

GPS is a ubiquitous technology finding new applications due to its amazing capability to locate the receiver's exact position on the earth's surface, based upon triangulation from NAVSTAR satellite signals, as shown in Figure 1.

Figure 1. Global Positioning System satellites (Courtesy: U.S. State Department [1])

Technically, the GPS consists of a constellation of 24 satellites [2, 3] arranged in circular orbits around the Earth at altitudes of 20,200 kms, at orbital planes forming a 55° angle with the equator, such that there are six satellites that can be interrogated at any time from the U.S. land surface.

At any position on the Earth's surface, a minimum of four satellites are needed to obtain the location coordinates as depicted in Figure 2. A primary L1 1575.42 MHz frequency is used and a secondary L2 1227.6 MHz frequency complements it to collect four data points (latitude, longitude, time, and altitude) using triangulation from four satellites [4, 5].

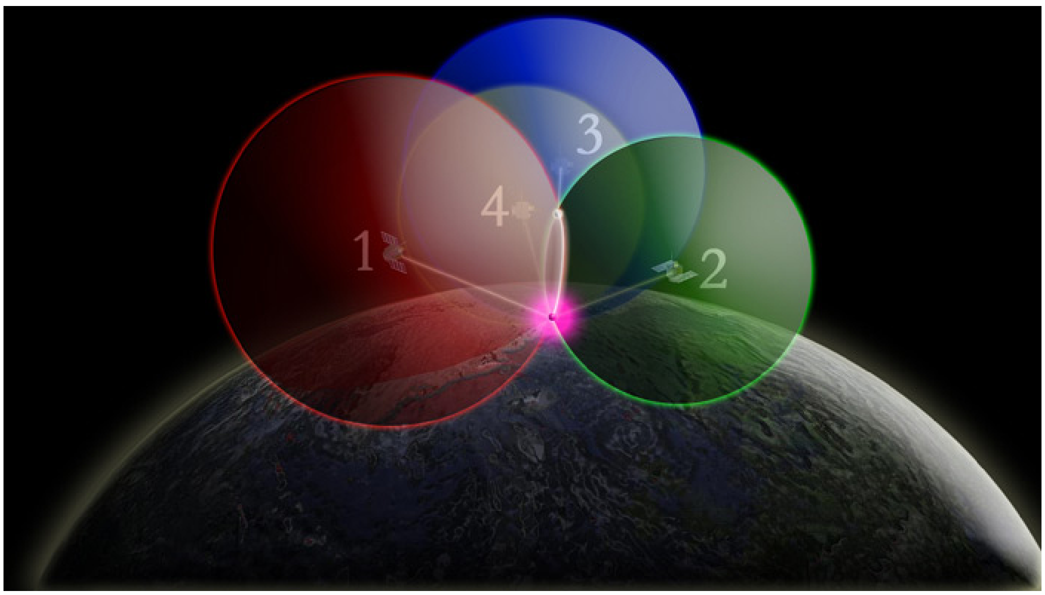

Figure 2. Four satellites used to determine the differential GPS coordinates (Courtesy: NOAA [6])

Once the exact position coordinates are known, this information can be gainfully used in many applications; a common one is the ability to navigate an automobile in real time through a maze of roads and highways [7]. GPS is presently being used extensively by the military and commercial enterprises for land, marine, and naval navigation; mapping; surveying; and many new applications [8].

Using a technique called Differential GPS, which uses a ground base station of a known position and provides a wireless data link to the GPS receiver, accurate and precise determination of the position can be made, as shown in Figure 3 [9].

One such application is precision mapping combined with aerial photographic satellite imaging. Another application is precision surveying of real estate and buildings. These two applications were developed in an electronic engineering technology senior design project at Virginia State University as part of a broader program in the Engineering and Technology

Department's research program in GPS with special applications in remote vehicular control using high precision GPS.

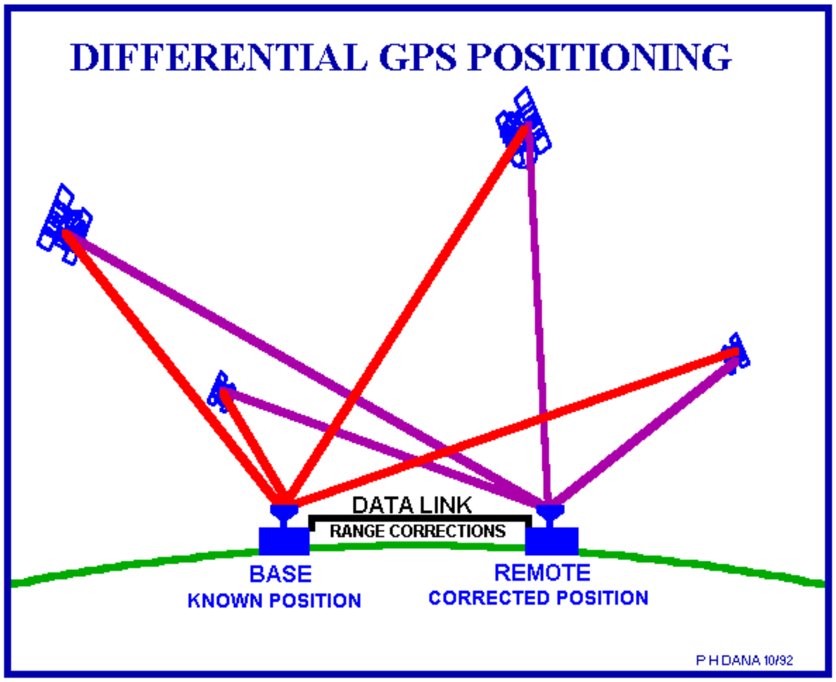

Figure 3. Differential Global Positioning System coordinates for precision mapping (Courtesy: Peter H. Dana, University of Colorado [9])

GPS Hardware

Several suppliers of GPS offer many products, depending upon the application specifications and budget. For this senior design project, the project constraints were defined as follows:

- Must stay within an overall budget of $15,000
- Must connect to a PC
- Must plot GPS data through some program on a map
- Must be accurate to less than 6 inches
- Must be able to withstand harsh environmental conditions

Three commercially available GPS systems were selected, and their specifications were compared versus the project design constraints, as tabulated in Table 1.

Table 1. GPS system constraints

Product	GPS A	GPS B	GPS C	Project Specification	Determination
Cost	$900	$450	$10,000	$ 15, 000	All three meet specification
Accuracy	>3 feet	>4 feet	~1 inch	< 6 inches	Only GPS C meets spec
Handles Harsh Conditions	No	No	Yes	Yes	Only GPS C meets spec
Personal Computer Interface	No	No	Yes	Yes	Only GPS C meets spec

Based upon the design constraint analysis, the GPS System C (Trimble AgGPS 332 GPS system) was selected and procured for this design project. RTK capability was enabled with an accessory base station receiver and antenna to provide the high precision differential GPS capability [10, 11]. A major challenge of the project was to correctly configure the GPS hardware so that the receiver antenna would collect the appropriate satellite data, and the GPS electronics unit could determine the latitude and longitude from the satellite data. The base station had to be installed and configured separately, and a microwave communications link had to be established between the RTK and the GPS mobile unit. This was not easy because the proper settings had to be determined after much trial and error. Once the wireless communication link was correctly established, accurate and precise position determination capability of the differential GOS became available.

GPS Software

Initially, RoadNav software was tried; it was free and easy to use but provided low resolution, and the GPS data could not be easily transferred to other readily available maps. Subsequently, ExpertGPS [12] software was implemented because it provided higher resolution maps, easy PC connectivity, and the GPS data was readily transferable to other programs. Since the ExpertGPS maps were found to be slightly out of date, it was used in conjunction with Google Earth. This combination allowed our GPS points to be on high resolution maps and gave us the capability to verify the collected points.

GPS Hardware and Software Integration

Another major challenge of the project was to integrate the software and hardware; the manufacturer's software was not used because it was not suitable for our application. The GPS coordinates from the receiver unit were transmitted to the laptop using a data acquisition system and stored in a data file. The interface between the hardware and the laptop was not functional in the beginning and had to be precisely configured. The hardware and the software were integrated together using a Toshiba laptop computer, and the completed assembly was made mobile by mounting in a push cart and subsequently in a golf cart, as shown in Figure 4.

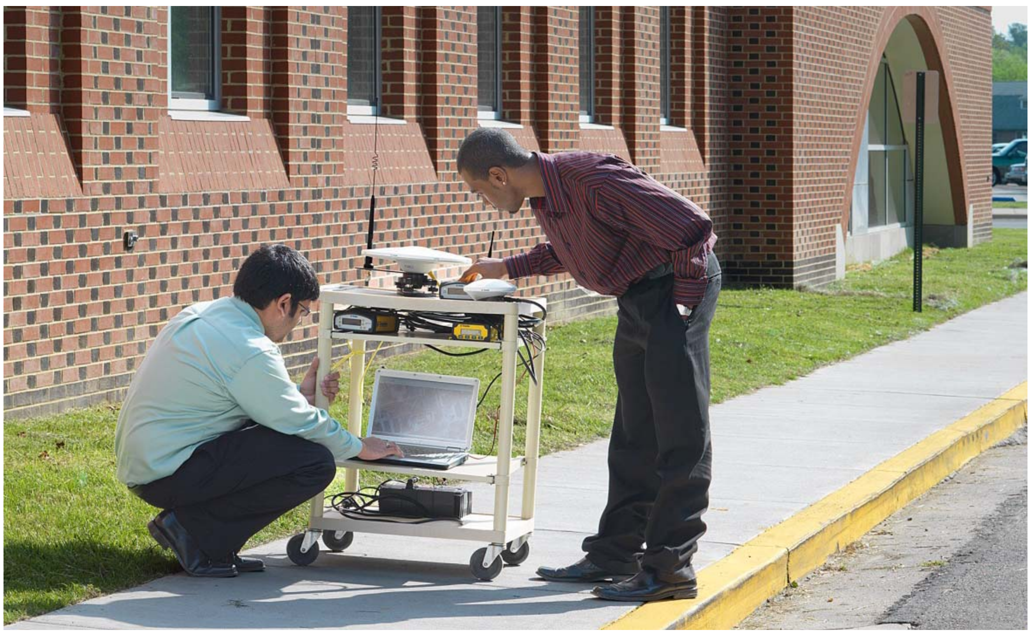

Figure 4. GPS System integrated with a laptop computer

GPS Experimental Results

The golf cart GPS system was driven around the Virginia State University campus to collect GPS data at various known points. Representative GPS data of the salient features of the Virginia State University campus are shown in Table 2; the data were found to be in excellent agreement with the reference values, assuming that the Google Earth coordinates were reliably correct for our purposes.

Table 2. GPS data comparison

Location	**Trimble GPS coordinate**	**Google Earth coordinates**	**Difference**
Engineering Building Latitude	37.23637 North	37.236350 North	0.00002
Engineering Building Longitude	77.41851 West	77.418503 West	0.000007
Hunter McDaniel Latitude	37.23974 North	37.239743 North	–0.000003
Hunter McDaniel Longitude	77.41889 West	77.418899 West	–0.000009
Virginia Hall Latitude	37.23445 North	37.234455 North	–0.000005
Virginia Hall Longitude	77.41894 West	77.418940 West	0
Foster Hall Latitude	37.23791 North	37.237912 North	–0.000002
Foster Hall Longitude	77.41917 West	77.419175 West	–0.000005
Singleton Hall Latitude	37.23823 North	37.238225 North	0.000005
Singleton Hall Longitude	77.41867 West	77.418662 West	0.000008
Owens Hall Latitude	37.23799 North	37.237982 North	0.000008
Owens Hall Longitude	77.41812 West	77.418121 West	–0.000001
Library Latitude	37.23612 North	37.236126 North	–0.000006
Library Longitude	77.41969 West	77.419700West	–0.00001

The GPS data for various locations of the Virginia State University campus are pictorially depicted below on the roadmap in Figure 5.

Figure 5. GPS data for various buildings on the Virginia State University campus

The GPS data points were inserted as an added layer and integrated into Google Earth aerial photographs of the Virginia State University campus, as shown in the following figure.

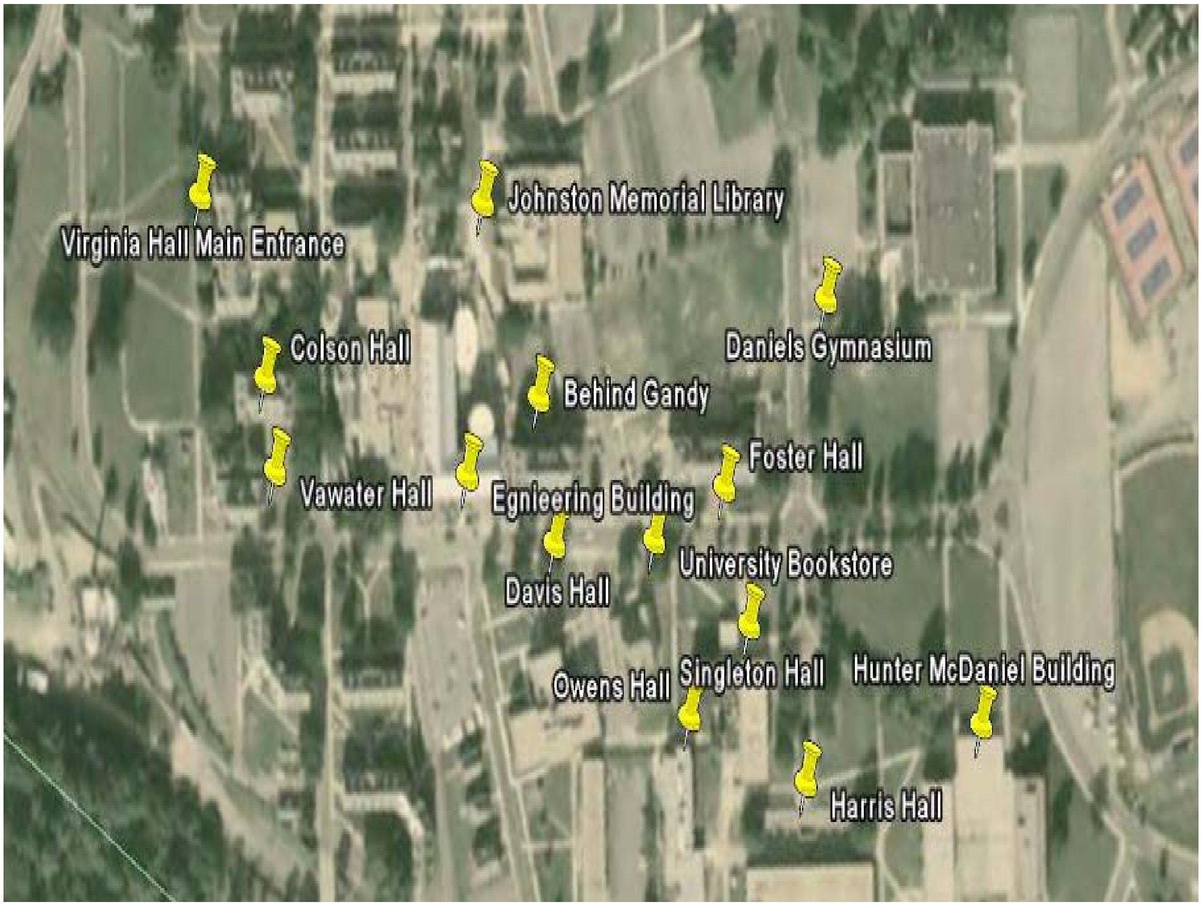

Figure 6. GPS data interfaced to an aerial photograph of the VSU campus

Architectural Mensuration Using GPS Data

The accuracy of the Trimble AgGPS 332 RTK system was verified using the physical survey of the Engineering Building by comparing the GPS data with the architectural design dimensions and with the actual measured values, using a laser measurement tool. Several points at the salient corners of the building were used for mensuration verification, as shown on the architectural drawing of the VSU Engineering Building in Figure 7.

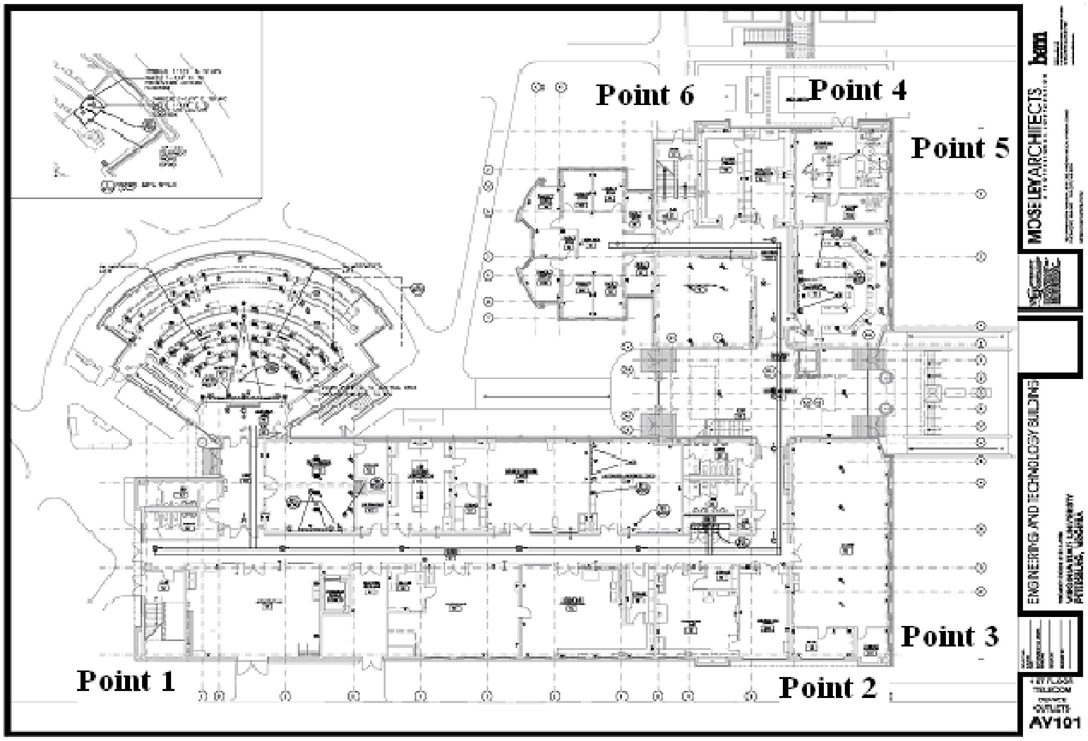

Figure 7. Architectural drawing of the VSU Engineering Building
(Courtesy: Moseley Architects)

The GPS data precision was determined by measuring the latitude and longitude coordinates taken three times for each position, and the measurements were found to be accurate in 1E-6 range; the results are tabulated for the Engineering Building in Table 3.

Using a computer program, the data points were used to calculate the physical measurements of the Engineering Building using the following formula [13]:

R = earth's radius (mean radius = 6,371km)
$\Delta lat = lat2 - lat1$
$\Delta long = long2 - long1$
$a = \sin^2(\Delta lat/2) + \cos(lat1).\cos(lat2).\sin^2(\Delta long/2)$
$c = 2.atan2(\sqrt{a}, \sqrt{(1-a)})$
$d = R.c$
df(inches)=d*39370.07874

Table 3. Physical measurement GPS data

Point	Latitude 1 (North)	Longitude 1 (West)	Latitude 2 (North)	Longitude 2 (West)
Point 1	37.2358845	77.4191790	37.2361373	77.4184428
Point 2	37.2358843	77.4191788	37.2361377	77.4184432
Point 3	37.2358647	77.4191792	37.2361375	77.4184430
Average	37.2358845	77.4191790	37.2361375	77.4184430

Point	Latitude 3 (North)	Longitude 3 (West)	Latitude 4 (North)	Longitude 4 (West)
Point 1	37.2361231	77.4184432	37.2365859	77.4186759
Point 2	37.2361230	77.4184433	37.2365861	77.4186761
Point 3	37.2361233	77.4184435	37.2365860	77.4186760
Average	37.2361232	77.41844333	37.2365860	77.4186760

Point	Latitude 5 (North)	Longitude 5 (West)	Latitude 6 (North)	Longitude 6 (West)
Point 1	37.2366003	77.4186514	37.2365421	77.4188632
Point 2	37.2366001	77.4186512	37.2365419	77.4188630
Point 3	37.2365999	77.418610	37.2365417	77.4188628
Average	37.2366001	77.418512	37.2365419	77.4188630

The calculated distances were compared with the architectural drawing and physical measurements; the results are shown in Table 4. The GPS data calculated dimensions were found to be close to the actual measurement of the building dimensions, with small error values of <0.2%. These results demonstrated that our RTK GPS system with the differential error correction using a wireless connection to a base station was functioning properly.

Table 4. Results of the Trimble GPS data

Location	Front of Building (Inches)	Left Side of Building (Inches)	Mechanical Shed (Inches)
Point 1	**2109.4**	**2720.3**	**708.4**
Point 2	**2110.5**	**2720.9**	**707.5**
Point 3	**2107.8**	**2719.7**	**709.2**
Average Distance	**2109.2**	**2720.3**	**708.4**
Actual Distance	**2108**	**2716**	**708**
Difference	**1.2**	**4.3**	**0.4**
Percent Error	**0.056%**	**0.16%**	**0.056%**

Conclusion

The Trimble AgGPS 332 Global Position System was successfully interfaced to an RTK Base station, integrated with a Toshiba personal computer using ExpertGPS software, and the system was implemented to capture GPS coordinates data for the Virginia State University campus. The accuracy and precision of the GPS system were demonstrated by measuring the VSU Engineering Building's physical dimensions and comparing the results to the architectural drawing dimensions and to the actual physical measurements. The industrial and commercial applications of high precision RTK GPS surveying and mapping were emphasized in a capstone student design project.

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