Global Positioning System Signal Acquisition Using USRP

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Abstract— Throughout history, humans were always traveling around the globe looking for a better location to move to. This raised some challenges such as travel path and the accuracy of the traveler's geographical location. It also pushed for new a invention of a navigation system which will lead the travelers to the correct path and that's where the Global Positioning System (GPS) came to life. This paper will discuss the communication aspect between the receiver and transmitter in detail and it will show a simulation of the GPS communication system between the satellites and USRP which will be used as a receiver.

Key words— USRP, GPS

I. OBJECTIVE

The objective of this paper is briefly discuss the digital communication aspect of Global Positioning System and to discuss the engineering architecture and building structure of the GPS receiver which will be implanted using Universal Software Radio Peripheral (USRP). This implementation will involve software design, building, and testing of using Labview by National Instruments and a hardware front end interface consists of USRP device and a windows platform operating system computer. The USRP will be used to realize the software defined GPS receiver.

II. INTRODUCTION

Global Positioning System (GPS) is a system owned and operated by the United States government designed to provide users with positioning, navigation, and timing (PNT) [1]. This system was initially developed in 1973 to provide more accurate geological location for the moving troops. The GPS then then became available to the public but with limitation until the year of 2000 when the US government unleashed its full use potential to the public.

In order to fully understand how GPS works, a general idea of the entire global positioning system must be explained. The system consists of the user segment (receiver), the control segment, and the space devices segment (transmitters) [2].

A. Space Segment

The space segment consists of a minimum of 24 orbiting satellites circling the globe 12,000 miles above us and at least three backup satellites which will be used when repair is performed on one of the main satellites. This constellation of orbiting satellites became fully in service in 1994 [2]. The position of the satellites ensures that the user will be able to view a minimum of four satellites which are required to provide an accurate physical location of the receiver. Figure 1 provides an oversight of the location of the orbiting GPS satellites.

The calculation of the receiver location based on the information supplied by the satellites are done using a technique called "Trilateration" which uses the knowledge of the distance of the receiver from a minimum of three satellites to calculate the accurate location of the receiver on earth. This method is shown in 2D in Figure 2 where it shows how the location of the three satellites will intersect in a single point which will be the location of the receiver. A fourth satellite might be used to improve the accuracy of the location, but normally three satellites are enough to provide a geographical location of the receiver.

GPS satellites operate on unique frequencies centered at two L-band of the electromagnetic spectrum: the civilian L1 band which operates at frequency of 1575.42 MHz and the military reserved L2 band which operates at a frequency of 1227.60 MHz [3].

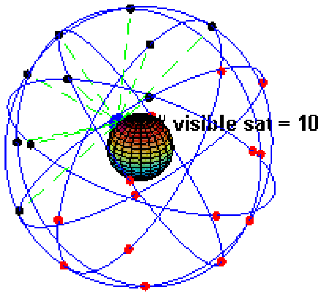


Figure 1: Orbiting Satellites

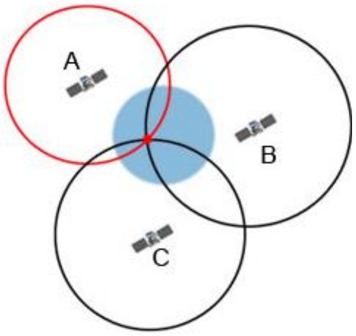


Figure 2: Trilateration Method

Each GPS satellite has a unique coarse/acquisition (C/A) code consisting of 1.023 million chips / second. The transmitted signal from the satellite which contains the message and the C/A code are modulated using binary phase shift keying (BPSK) for the L2 band. The Message contains the navigational information is transmitted at a rate of 50 bps. The message conations a total of 1500 bits frame for which it is divided into 5 sections of 300 bits each. The first subframe contains the satellite clock and health data. The second and third subframes contain satellite ephemeris data which will be used to calculate the satellite position, and the fourth and fifth conations the almanac data [3].

In the case of the L1 bands, the carrier is modulated with private code referred to as (P) code. And just like L1 case, the (P) code and the navigational message will be modulated using BPSK. Both C/A and P codes are generated as a Pseudo Random Noise (PRN) and the bandwidth of the of the spread spectrum signal for L2 bands is 2.046 MHz and for L1 bands is 20.46 MHz [2].

GPS systems utilize Code Division Multiple Access (CDMA) which allows the communicator to access the entire spectrum at all times. The goal behind using this utilization is to decrease the transmitted spectral density somewhere below the thermal noise level on an unfriendly receiver [4]. Therefore each GPS satellite transmits the signal with enough power to ensure minimum signal power of -160 dBW or equivalent to -130 dBm at earth.

B. Control Segment

The GPS control segment composed of global network designed to monitor satellites performance, monitor satellites transmission, send commands and data to the orbiting satellites, and to perform general performance analysis.

This segment involves [2]:

1. Master Control station (MCS): is the main controlling block in the GPS system where the MCS generates and uploads the navigational messages and ensures the accuracy and health of the orbiting satellites constellation.
2. Alternate MCS.
3. 16 monitoring sites: Its main job is to track the GPS satellites and monitor their path as they pass overhead and provide their observation back to the MCS.
4. 12 commands and control antennas: It consists of 12 S-band communication link’s antennas used to transmit navigational messages and data upload. It is used also to send processor programming firmware and to collect telemetry.

C. User Segment

GPS technology became an essential asset in today’s modern world. It affected human life in a positive way where it is used for several purposes such as: agriculture, aviation, environment, marine, rail roads, space, roads and highways, recreation, timing, surveying and mapping, and public safety and disaster relief.

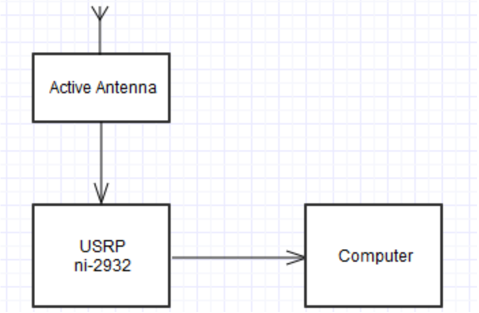


Figure 3: GPS Receiver Implementation Block Diagram

Table 1: Hardware components of the GPS receiver

Part	Description
Antenna	VERT 900
USRP	NI USRP 2932 with GPS discipline and 400 MHz to 4.4 GHz operational range
PC	Windows 7 platform DELL XPS laptop with 1G Ethernet port
Electric Inverter	CyberPower CP1000AVRL

III. CONFIGURATION

After the discussion of the general building structure of the Global Positioning System, a complete structure of the receiver end of the GPS will be discussed in the following section. Figure 3 shows the general hardware block diagram of the designed receiver where the ni-USRP will replace the conventional GPS receiver and it will be used to capture and record the navigational messages sent by the GPS satellites.

A. Hardware front-end

In order to implement this system, several hardware components were used inside the testing lab. A list of these hardware are shown in table 1.

The antenna used to capture the L1 Band signal which operates at 1575.42 MHz was VER900. This antenna has 824 to 960 MHz, 1710 to 1990 MHz Quad-band Cellular/PCS and ISM Band Omni-directional vertical antenna, at 3dBi Gain [5].

A Windows 7 platform laptop PC was used in order to build the system block diagram using Labview which will be used to operate the USRP. This PC must support Ethernet communication with a rate of one Gigabit per second. This computer was built with an Intel Core i7 Processor and has 8G of ram which allows implementing our simulation at fast speed.

Due to the difficulty of capturing signal inside the closed environmental lab, a battery storage inverter was used to power the USRP during the testing stage outside the university campus.

B. USRP

USRP is a transceiver device primarily used to demonstrate communication system principles to students.

This device was made by National Instruments and it has great capabilities. It operates at wide range of frequencies (400 MHz to 4.4 GHz) covering cellular, Wi-Fi, GNSS, and L band radars. It is prebuilt with integrated GPS that improves clock precision and slows global device and synchronization and position [6].

C. Software Implementation

As discussed earlier, the computer used to operate the USRP had Windows 7 platform installed. USRP requires special software to be installed on the operating PC such as “Labview” or “GNU Radio” which operates on Linux based platform. In this project, Labview installation was performed by the university’s IT department which provided the team access to the software from outside the lab environment. Labview is powerful software which may be used to construct a complete communication system and it provides the user with a wide range of possibilities to improve their design.

Matlab was also used in this project to process the captured signal. The main functionality of Matlab was to call the Google map function and plot the Latitude and Longitude points captured by Labview then plot the recorded path on the map.

IV. METHODOLOGY

As previously stated, the GPS satellites signals are transmitted on two different bands, L1 and L2 as in Equation 3 and Equation 4. These two band frequencies were derived from the fundamental frequency of 10.23 MHz

$$Band\ L1 = 154 * 10.23 = 1575.42\ MHz \qquad (1)$$

$$Band\ L2 = 120 * 10.23 = 1227.60\ MHz \qquad (2)$$

More details of the GPS signal characteristics are displayed in table 2.

The GPS signal codes and carrier frequencies would be generated using equation 4 and equation 5 and a block diagram which will represent this frequency is shown in Figure 4

$$Frequency\ 1 = L1\ carrier + P * code + \frac{C}{A} code + Navigation\ Message \qquad (3)$$

Table 2: GPS Signal Characteristics [1]

	C/A	P	Navigate Date
Chipping Rate	1.023 Mbps	10.23 Mbps	50 bps
Length per Chip	293 m	29.3 m	5950 km
Code Type	Gold	PRN	NA
Carried On	L1	L2	L1,L2
Repetition	Easy to Acquire	Precise Positioning, Jam Resistant	Time, Ephemeris
Feature	1 ms	1 week	NA

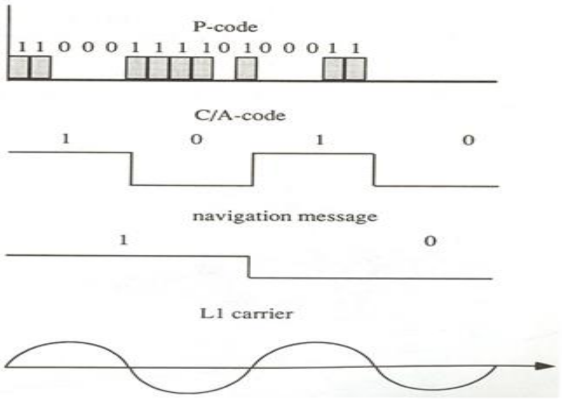


Figure 4: Schematic of GPS codes and carrier phase [8]

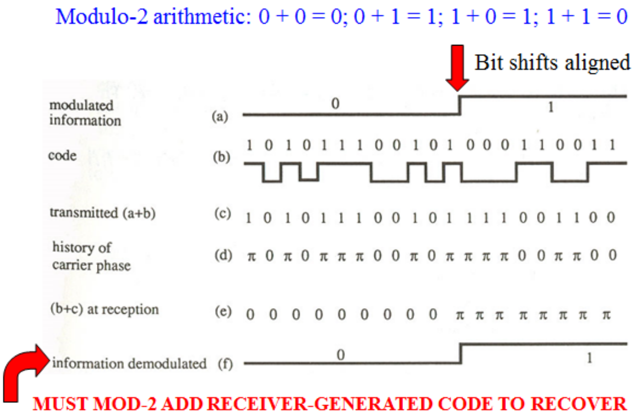


Figure 5: GPS code Recovery technique [8]

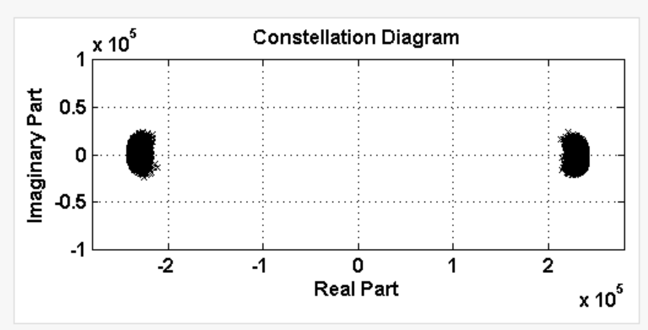


Figure 6: Constellation Diagram of Received Data

$$Frequency\ 2 = L2\ carrier + P * code + Navigation\ Message \qquad (4)$$

Transmission of the GPS signal is done using BPSK modulation scheme. The recovery of the transmitted signal must be done using the same technique where this recovery approach is shown in Figure 5 and the constellation diagram of the obtained signal is shown in Figure 6.

In some cases, the superposition of the two codes is required, but this is not unique due to the fact that the bit transition occurs at the same epoch because both codes are multiples of the fundamental frequency as we stated earlier; additional constraints were imposed to arrive to a solution which is the Quadri-Phase Shift Keying (QPSK) which will put the two codes at $\left(\frac{\pi}{2}\right)$ apart. The generated phase and Quadrature expression of this model is given in equation 5 [3].

$$y(t) = I.\cos(wt) - Q.\sin(wt) \qquad (5)$$

$$where$$
$$w = 2\pi f$$
$$I\ is\ the\ in-phase\ componenets$$
$$Q\ is\ the\ quadrature\ components$$

From Equation 5, it is noticeable that the spectral components of I are $\left(\frac{\pi}{2}\right)$ out of phase with those in Q. This will allow the two signals to be separated at the receiver's end.

V. RESULT AND DISCUSSION

The general methodology of GPS signal capturing was previously discussed in this paper. The hardware used to obtain the receiver longitude/latitude coordinates was introduced and discussed in detail. The assembly of the hardware was done outside campus where a clear path to the satellites was reachable.

The GPS receiver setup started by connecting the USRP to the computer using Ethernet cable, then connecting VERT900 Antenna to the designated GPS SMA connector on the USRP device rear panel. After completely setting up the hardware of the receiver, the designed Laview software was opened and the proper parameters were set to obtain the Power Spectrum Density (PSD) of the carrier frequency. Figure 7 shows an illustration of the obtained PSD for L2 band signal. Figure 7 shows a center frequency which was intentionally set at 1.576 GHz in order to the viewer to see the captured signal frequency which is shown at 1575.42 MHz. Looking in more details into Figure 7 shows a bandwidth centered at the L2 carrier frequency specified earlier with a bandwidth $B \approx 2000\,Hz$. A plot of this specific bandwidth was not producible due to the limitation of Labview plot zooming capability.

After locking to the correct frequency, another VI in the Labview software was used to capture the acquired signal from the GPS. This signal contains the data information from all the locked satellites which will contain the longitude and latitude location, time stamp, and other information such as the number of satellites locked during the data acquisition process. A more detail of the message sent by the satellites is shown in Figure 9A and Figure 9B.

The result from this message will be modified inside the main VI which will calculate the longitude and latitude of the location of the USRP. The coordinates obtained will then be saved inside CSV file. The VI allows the user to append to the file which will enable the user to capture multiplication and then plot the path taken using Google map.

After successfully capturing the coordinates of the GPS for a single location, an attempt to capture the signal using a moving vehicle was the next goal of the team members. To accomplish this result, a backup battery inverter was used to provide power to the USRP device while driving inside the car. The USRP was able to obtain the GPS satellite data and record it inside the CSV files. The CSV files will then be opened with Matlab which will run the designed code to obtain Google map and plot the path taken by the vehicle on the actual map. A plot of the coordinates recorded on Google map was done and Figure 10 shows the starting point which is drawn in red and the ending point which is drawn in blue. This path taken by the car is shown in green color.

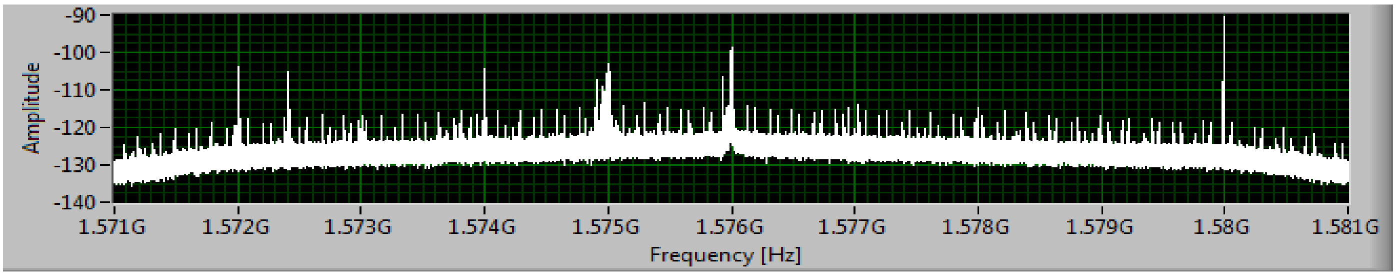


Figure 7: Power Spectrum Density for L2 band Signal

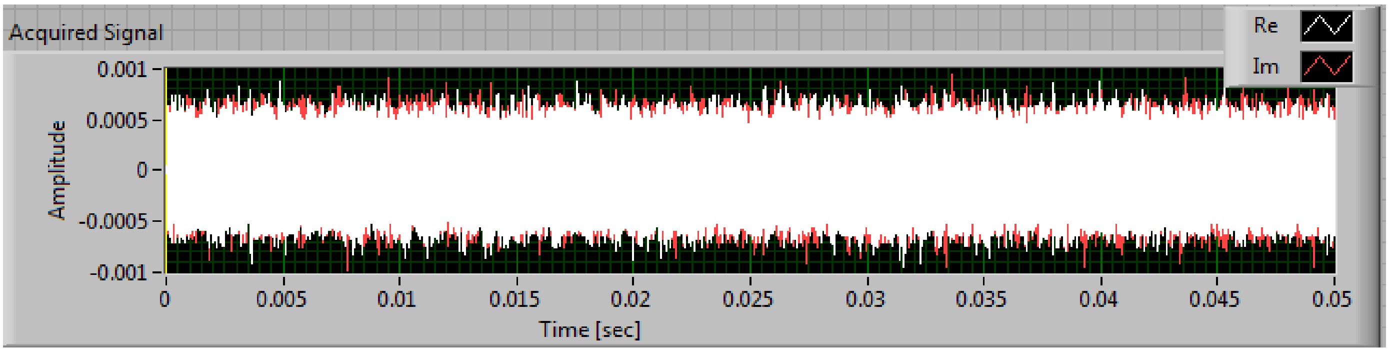
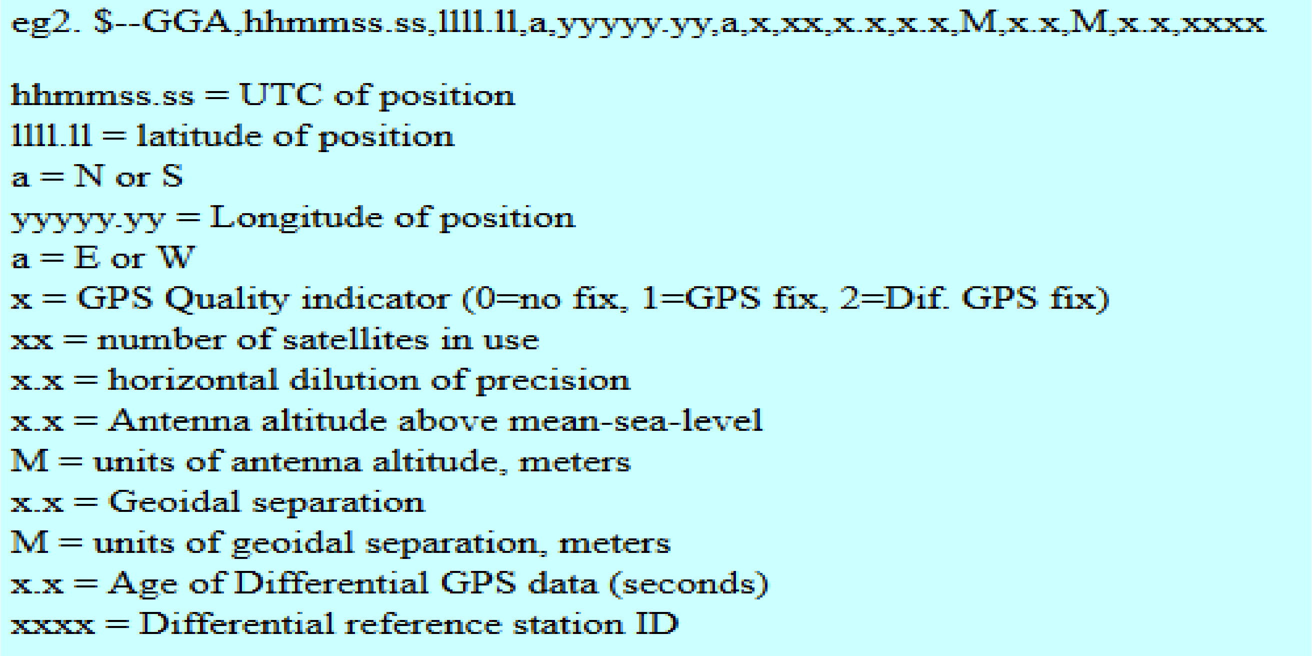


Figure 8: GPS Acquired Signal



eg2. $--GGA,hhmmss.ss,llll.ll,a,yyyyy.yy,a,x,xx,x.x,x.x,M,x.x,M,x.x,xxxx

hhmmss.ss = UTC of position
llll.ll = latitude of position
a = N or S
yyyyy.yy = Longitude of position
a = E or W
x = GPS Quality indicator (0=no fix, 1=GPS fix, 2=Dif. GPS fix)
xx = number of satellites in use
x.x = horizontal dilution of precision
x.x = Antenna altitude above mean-sea-level
M = units of antenna altitude, meters
x.x = Geoidal separation
M = units of geoidal separation, meters
x.x = Age of Differential GPS data (seconds)
xxxx = Differential reference station ID

Figure 9: GPGGA Message [10]

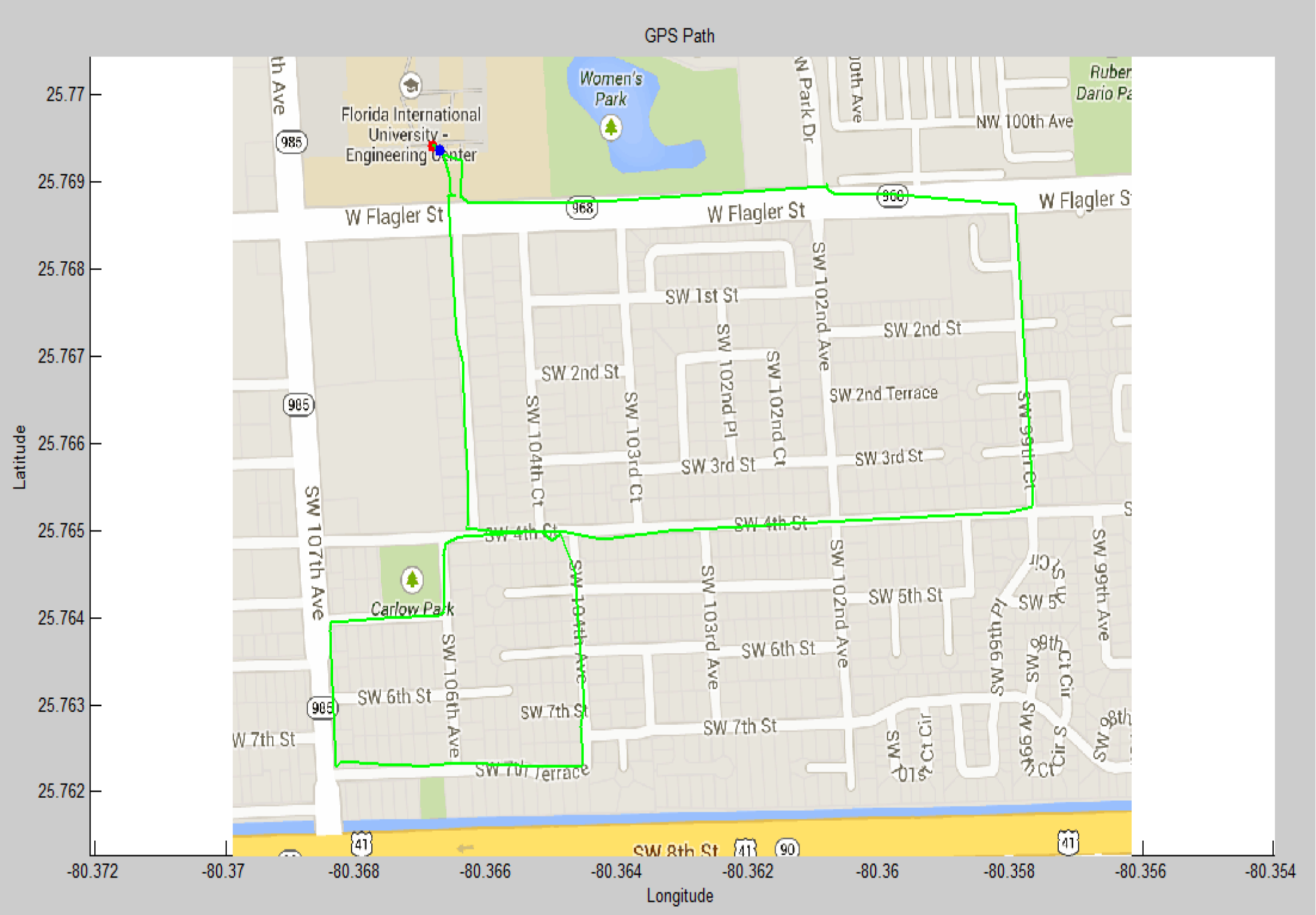


Figure 10: Matlab Taken Path Plot using Google Map

The system designed system performance was in general acceptable. Several changes to the system will affect the system performance positively. Here is a lists of these changes:

A. Use of appropriate antenna

The antenna used in this design was designed to capture GPS signal. But since the operational range of the VERT900 is very close to the 1575.42 MHz frequency of the GPS, then it was able to acquire the signal with minimal power loss.

B. USRP clock

The USPR 2932 has an internally built clock which was used in the acquisition of the satellite signal. The problem encountered during the testing stages was the time taken by the USRP to lock a position. This is a great tool for demonstration, but it is not reliable for daily operation where the USRP used to take anywhere from 5-50 seconds to lock.

VI. CONCLUSION

With precise accuracy and using the right devices, GPS can pinpoint a person's global position on earth. During this project, a general idea of the GPS simulation was introduced and discussed. The use of USRP and labview was a great help in the demonstration and understanding of GPS signal capturing and decoding. GPS receivers are becoming very important devices in today’s world. The accuracy and reliability of these devices are becoming in a great interest to many engineers and research facilities.

VII. REFERENCES

[1] Farrell, Jay, and Matthew Barth. *The Global Positioning System and Inertial Navigation*. New York: McGraw-Hill, 1999. Print.

[2] "The Global Positioning System." *GPS.gov: GPS Overview*. N.p., 11 Feb. 2014. Web. 19 Apr. 2014. <http://www.gps.gov/systems/gps/>.

[3] Thompson, Elizabeth A., Nathan Clem, Isaac Renninger, and Timothy Loos. "Software-defined GPS Receiver on USRP-platform." *Software-defined GPS Receiver on USRP-platform*. Elsvier, 25 Jan. 2012. Web. 20 Apr. 2014. <http://www.sciencedirect.com/science/article/pii/S1084804512000343>.

[4] Kaplan, Elliott D., and C. Hegarty. *Understanding GPS: Principles and Applications*. Boston: Artech House, 2006. Print.

[5] "Ettus Research." - *Product Detail*. N.p., n.d. Web. 20 Apr. 2014. <https://www.ettus.com/product/details/VERT900>.

[6] "NI USRP-2932." - *National Instruments*. N.p., n.d. Web. 20 Apr. 2014. <http://sine.ni.com/nips/cds/print/p/lang/en/nid/211246>.

[7] Rizzos, Chris. "Sect_4.1.3." *Sect_4.1.3*. Rizos, SNAP-UNSW, 1999. Web. 20 Apr. 2014. <http://www.gmat.unsw.edu.au/snap/gps/gps_survey/chap4/413.htm>.

[8] Larson, Kristine. "ASEN 4519 Homepage." *ASEN 4519 Homepage*. N.p., n.d. Web. 20 Apr. 2014. <http://www.colorado.edu/engineering/ASEN/asen4519/asen4519.html>.

[9] "Quantized." *Quantized*. N.p., 07 Nov. 2011. Web. 22 Apr. 2014. <http://www.acasper.org/2011/11/07/gps-signal-analysis/>.

[10] "GPS - NMEA Sentence Information." *GPS - NMEA Sentence Information*. N.p., n.d. Web. 23 Apr. 2014. <http://aprs.gids.nl/nmea/>.