Journal of Global Positioning Systems (2006)
Vol. 5, No. 1-2:29-34

GPS Reflected Signal Analysis using Software Receiver

Dinesh Manandhar

Centre for Spatial Information Science, The University of Tokyo
Kashiwa-no-ha 5-1-5, Kashiwa shi, Chiba ken, 277-8568, Japan
and GNSS R & D Centre, GNSS Technologies Inc., 6-12-5 Shinjuku, Tokyo 160-0022, Japan

Ryosuke Shibasaki

Centre for Spatial Information Science, The University of Tokyo
Kashiwa-no-ha 5-1-5, Kashiwa shi, Chiba ken, 277-8568, Japan

Hideyuki Torimoto

GNSS R & D Centre, GNSS Technologies Inc., 6-12-5 Shinjuku, Tokyo 160-0022, Japan

Abstract. A reflected GPS signal is normally considered as noise (multipath). However, we believe that a reflected signal contains information about the reflecting object. Though, this information may not be useful for accurate position computation, it may help us to identify the reflecting object itself, which is a type of remote sensing. Besides, by measuring the time delay of the reflected signal, it is possible to estimate the extra path length the reflected signal has to travel. Hence, in general, the analysis of reflected signal can be used for two broad categories of altimetry and remote sensing. However, this type of analysis is rather limited with current commercial GPS receivers. We are in the process of developing a software-based GPS receiver that is capable of reflected signal analysis for remote sensing purpose. The receiver consists of multi-polarization (RHCP and LHCP) array of GPS antennas, front-end device, a PC and necessary software for signal processing. In this paper, we discuss about the system architecture and algorithms, results of reflected signal analysis observed at different places in different conditions and antenna types. Finally, we will discuss the possibility of the system for remote sensing applications using GPS signal.

Key words: GPS, Software Receiver, Multipath, Remote Sensing, Polarization

1 Introduction

GPS signal which is an electromagnetic wave consists of electrical and magnetic fields. The polarization of the signal is defined by the direction of the electrical field vector. If the electrical field vector is perpendicular to the direction of transmission, it is called vertical polarization, and if the vector is parallel to the direction of transmission it is called horizontal polarization. GPS signal is right hand circular polarization (RHCP), which means that the electrical field vector describes a helix of a right hand screw along the direction of transmission.

A circular polarization consists of horizontal and vertical polarization components. When a circularly polarized signal is reflected, the horizontal component always undergoes phase reversal at the reflecting surface regardless of incidence angle. The vertical component undergoes phase reversal at incidence angle less than the Brewster's angle. It does not undergo phase reversal at incidence angle greater than the Brewster's angle. Thus the polarization of the signal may change after reflection depending upon the reflecting material and incidence angle from RHCP to LHCP and vice versa. However, in most of the cases the reflected signals are not perfectly circular, but more elliptical. Hence, the basic observation technique is to use a pair of antennas with reversed polarizations and compare the signal strength between the two antennas.

Unfortunately, commercially available GPS receivers can not perform these tasks and hence we are in the process of developing software-based receiver that is capable of analyzing direct and reflected signal with respect to each other (master-slave mode) or independently. We have conducted experiments in the past using RHCP and LHCP antennas to study the nature of signal from LHCP antenna. The details are given in Manandhar et al. (2004a). Reflected signal analysis capable receiver has been used by Dallas et al. (2000a) and quite promising results have been obtained to estimate soil moisture by Zavorotny et al. (2003), wind velocity by Zavorotny et al. (2000c), wetland mapping and ocean observation by Gatti (1999). GPS signal being in L-band provides good response for remote sensing applications like soil moisture estimation.

2 System Architecture

The receiver consists of a dual-antenna front-end device. It down-converts the signal from 1.57542 GHz to an intermediate frequency at 4.1304 MHz and digitize it at a user-defined values of 1, 2, or 4 bits at a sampling frequency of 16.3676 MHz. This architecture is the same as our prototype receiver in Manandhar and Shibasaki (2005b). The front-end device is a commercially available product. The RF data are logged to PC hard disk and post-processed for signal analysis using user defined parameters. Since the receiver is software-based type, it is possible to re-process the same data with different user defined parameters. Figure 1 shows the hardware architecture of the receiver. Since, LHCP GPS antennas are not used for normal GPS observation, it is hard to find LHCP GPS antenna. We have used low profile antennas with right hand and left hand circular polarization that are designed for the frequency range 1.52 GHz to 1.66 GHz with RHCP and LHCP as shown in figure 2(a). We have also tested with self-constructed helical antennas with right hand and left hand circular polarization as shown in figure 2(a) and 2(b).

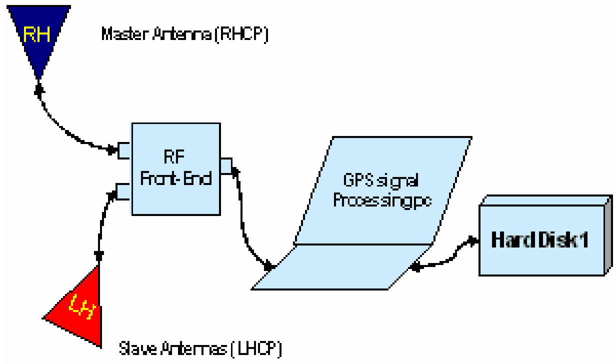

Fig. 1 System Architecture for Study of Reflected signal using RHCP and LHCP antennas

3 Signal Acquisition Procedure

We have acquired GPS signals using two types of ground-based systems as shown in Figure 2. In Figure 2 (a), (b) and (c), RHCP and LHCP antennas are mounted on a tripod. RHCP antenna is zenith oriented and LHCP antenna is nadir oriented or ground oriented at certain angle from the nadir. The purpose for such orientation is to acquire direct signal by the RHCP antenna and reflected signal by LHCP antenna. The reflected GPS signal might be left-hand polarized depending upon the reflecting material and geometry between the satellite and the antenna. A circularly polarized wave has horizontal and vertical components and when we use an antenna of reverse polarization, we will lose half of the energy. Usually, in practice, the polarization may not be perfectly right or left hand circular but an elliptical one. Thus, by using LHCP antenna, we can receive reflected GPS signal with enough signal strength to compute position as shown in Figure 4. This experiment is used to study the behavior of direct and reflected GPS signals with RHCP and LHCP antennas. Figure 4 shows one of the results for C/No with respect to azimuth and elevation for RHCP and LHCP antenna. In some cases for low elevation satellites, we have observed that C/No of LHCP antenna is higher than the C/No of RHCP antenna. This is due to the fact that the signal coming to the antennas are reflected signal that is not right hand circular polarization any more. In another experiment, the antennas, RHCP and LHCP are located on a tower that is 300m tall as shown in Figure 2 (d). The antenna platform can move up and down along the tower which makes the observation possible at different height from the ground. Since the GPS PRN chip is 300m wide, we will be able to see a difference of one chip in pseudorange when the antennas move from the bottom of the tower to the top of the tower or vice-versa. Data from this experiment are used to develop and verify the algorithms for reflected signal analysis.

Fig. 2 Different antenna orientation for ground-based observation. (a) Both RHCP and LHCP oriented vertically up (b) Both RHCP and LHCP oriented towards the building surface (c) RHCP antenna oriented towards zenith (sky) for direct signal and LHCP oriented towards ground for reflected signal (d) 300m tall Boulder Atmospheric Observatory (BAO) Tower at Colorado. Data logged in this tower are used for analysis in this paper

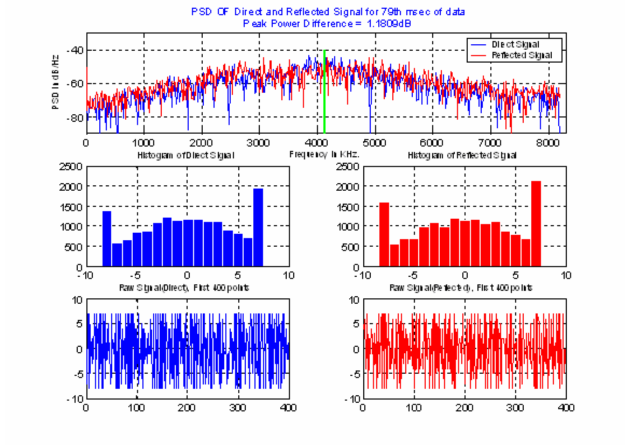

Fig. 3 (Top) Power Spectrum Density of raw GPS signal from RHCP and LHCP antenna, (Middle Left) Histogram of raw GPS signal from RHCP antenna (Middle Right), Histogram of raw GPS signal from LHCP antenna, (Bottom Left) Raw GPS Signal from RHCP antenna, (Bottom Right) Raw GPS Signal from LHCP antenna

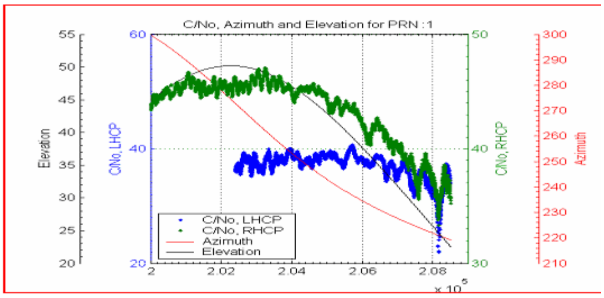

Fig. 4 Carrier-to-Noise value for RHCP and LHCP antenna data with respect to azimuth and elevation

4 Signal Processing

GPS signals consist of carrier waves, PRN codes and navigation data bits. Signals from all the satellites have the same frequency but PRN codes for each satellite are unique. The information from these satellites is recovered by replicating the signal in the receiver and correlating with the incoming signal. This process is achieved in two steps which are called acquisition and tracking. In the acquisition step, we roughly estimate the code phase and Doppler frequency and make a decision that whether a satellite is visible or not. Refer Manandhar et al. (2004b) for details on signal processing. Once, a satellite is successfully acquired from acquisition, we get approximate code phase and Doppler frequency. The tracking loop then continuously decodes the incoming data to extract the navigation codes. Three correlators with a chip spacing of 0.25 are used to compute the signal power at the prompt level. The other two correlators are termed as early and late since they are 0.25 chips ahead and after the prompt correlator. These two correlators will fine tune the code phase. The code phase location of the prompt correlator is used as the reference for processing the LHCP antenna signal. Our assumption is that; had there not been reflected signal in the LHCP antenna, the code phase would have been the same in both the cases, though the amplitude will be different. Thus, instead of seeking the maximum correlation peak, we compute the correlation power at different chip spacing from the position of the prompt correlator. This is achieved by generating the PRN codes with phase offset as provided by the tracking loop for RHCP data. We have used a chip spacing of 0.25 with 30 correlators. Since, the device is software-based, the user can change chip-spacing and number of correlators as required. However, the Doppler frequency is not separately generated for LHCP data, instead we use the same Doppler data that is used for RHCP. This means, we assume that there is no Doppler shift between the two signals. This algorithm concept is similar to the delay mapping receiver (DMR) used by Dallas et al. (2000a). The current receiver has options either to run in Master-Slave mode or in independent mode. Also, we consider the combination of more than two antennas. The software for this part (more than two antennas) is under development. Figure 5 shows the detail algorithm concept. This algorithm provides chip delay and amplitude difference between the two antenna data sets. We can compute multipath or extra path the signal has to travel from chip delay. The difference of amplitude is a function of the nature of the reflecting material and geometry between the satellites and the antennas. Thus, the amplitude difference provides us information about signal reflecting device. A calm water surface will have specular reflection giving higher amplitude value compared to a disturbed water surface due to wind. This will help us to model the differences of amplitudes with respect to wind velocity over the water. Similarly, a wet soil gives higher amplitude values compared to dry soil that enable us to model the soil moisture with respect to the GPS reflected signal strengths. The difference of reflection coefficient of dry soil and wet soil is about 10 times at L-band.

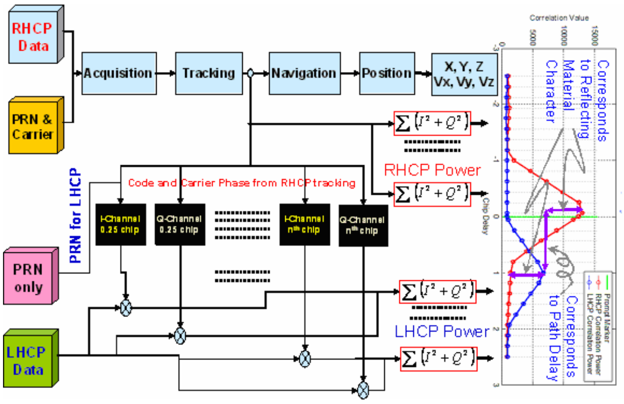

Fig. 5 Algorithm details to process direct and reflect signals from RHCP and LHCP antenna in master-slave mode

5 Results and Discussions

We have conducted some experiments with RHCP and LHCP antenna. RHCP antenna is zenith oriented and LHCP antenna is ground oriented. The experiments are undergoing and we present here some of the preliminary results. Figure 3 shows plots of raw data, power spectrum and histogram of RHCP (red) and LHCP (blue) data. Figure 2 shows different possible antenna orientation for preliminary study of response of signal from LHCP antenna with respect to RHCP antenna. More details can be found in Manandhar et al. (2004a). Figure 6, Figure 7 and Figure 8 show the correlation output at different chip delays with respect to RHCP antenna. This is the main output of the receiver which will be used for analysis of signal reflecting object. When the antennas are at the bottom of the tower, we can see strong signals both at RHCP and LHCP antennas. However, there is not much relative chip delay between the two data sets. This is probably due to the fact that the extra path, the reflected signal has to travel is just a few meters more. The current front-end is designed with 16 Mhz sampling frequency and hence one sampled PRN chip corresponds to roughly 18m. This means that with current hardware it will not be possible to identify a path delay of less than 18m. When the antennas are at the middle of the tower, about 150m above the ground, we can see strong LHCP signal with significant chip delays. The chip delays shown in the x-axis are un-sampled chip delays. One chip delay in the x-axis corresponds to one PRN chip which corresponds to approximately 300m. One un-sampled PRN chip has about 16 sampled PRN chips. When the antennas are at the top of the tower, we can see good LHCP signal at about 1.8 chip delays. This corresponds to a slant range of about 540m. If the LHCP antenna angle from the nadir is 35 degree then the height of the antenna is about 310m. Since, we do not know the exact location of the antenna when it rests at the top of the tower and the antenna orientation angle, it is rather difficult to verify the height estimation. However, it is possible to estimate antenna height by computing additional path delay or chip delay with respect to RHCP antenna data. It is also possible that LHCP signal is stronger than RHCP signal depending upon the antenna orientation and location. In an urban area with heavy multipath, we get this type of observations for satellites that are not at high elevation [6]. The current algorithm is not valid for such cases. It assumes that RHCP antenna data is free from multipath or reflected signals.

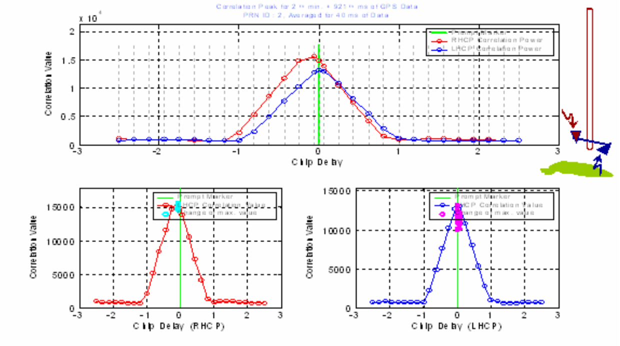

Fig. 6 Chip delay and amplitude difference between RHCP and LHCP antenna data when the antennas are near the bottom of the tower.

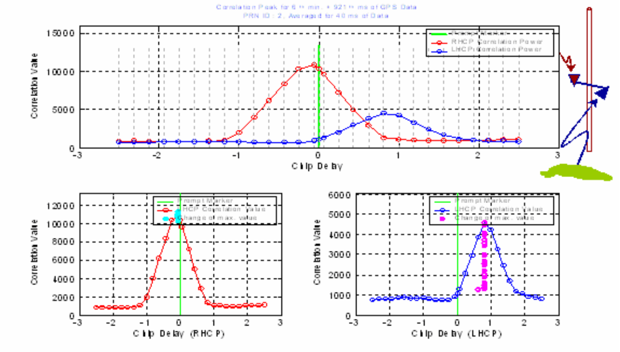

Fig. 7 Chip delay and amplitude difference between RHCP and LHCP antenna data when the antennas are at the middle of the tower

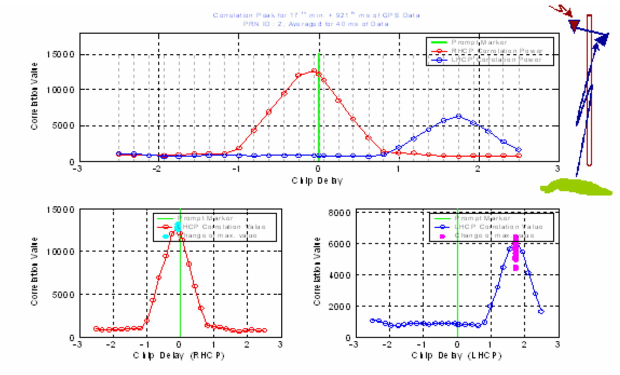

Fig. 8 Chip delay and amplitude difference between RHCP and LHCP antenna data when the antennas are at the top of the tower

6. Remote Sensing Possibility

As we have discussed above, the characteristics of reflected signal depends on the reflecting material. Reflection from calm water surface is much stronger compared to the reflection from disturbed water surface or soil. A GPS signal acts like a passive microwave remote sensing or bi-static radar. Since, GPS signal is in L-band, it is good for soil moisture estimation. There are already on-going research to estimate soil moisture, Zavorotny et al. (2003), wind velocity over ocean, Zavorotny et al. (2000c) and ice sheet monitoring Gatti (1999) etc. However, the developments of models for soil moisture or wind velocity are yet to be verified and proved. All the research did till now have shown very strong possibility of remote sending for certain applications with much better accuracy and resolution. Since, GPS signals are available everywhere every time regardless of weather conditions at free of cost, it may become a very good data source for certain remote sensing applications. Development of perfect receiver (sensor) is still undergoing. There are many issues related with the receiver (sensor) regarding the antenna type, antenna gain, antenna array, polarization, signal processing algorithms, observation techniques and so on. The antenna gain pattern plays an important role as in microwave remote sensing which we are familiar. A narrow antenna beam provides higher ground resolution but covers only a small area. This demands an array of antenna systems of narrow beam widths to cover a large area. Though GPS signal is circular polarization, it may give interesting results and may help to segment different objects if we use horizontal, vertical or the combination of horizontal and vertical polarizations. All these studies are undergoing at various research institutes in the world.

The signal processing techniques are also still under development. There are many different possible ways to process the raw GPS signal. We have presented only one of them in this paper. The biggest issue is how to correlate the signal strength to the reflecting object characteristics. The preferable observation technique is air-borne for higher resolution. But, low altitude space-borne observation is also possible. Surrey satellite is doing research in this field. If space-borne observation technique is successful, then GPS based remote sensing will be the most economic, reliable, all time global coverage in real time solution for some of the remote sensing applications.

Our effort is towards the development of software-based receiver that is capable to analyze reflected signal. This receiver will then be further enhanced for remote sensing purpose at least to classify between the water and non-water body.

7 Conclusions

We have developed a software-based reflected GPS signal analysis receiver. The results show that the algorithms developed are correct and can be used for general analysis of reflected signal. The software also allows the user to change parameters in the algorithm so that the user may perform different types of analysis. The present system architecture assumes that the RHCP antenna will receive only direct signal and LHCP antenna will receive reflected signal or both. We also assumed that the dopplers of the signal in both the antennas are the same. However, this may not be true in practice. Thus, we are considering having quadruple-antenna front-end device. A pair of antenna, each RHCP and LHCP in zenith oriented direction and another pair, each RHCP and LHCP nadir or ground oriented. In this, case we will have better possibility of analyzing both direct and reflected signals coming to the antennas. Finally, we believe that remote sensing using GPS signals are possible and in future we will have Galileo signals as well. This makes theoretically 16-20 channels present at any time around the globe at different frequencies and at different geometry between the satellite and receiver.

8 Acknowledgement

The authors would like to thank Dr. Dennis Akos and Dr. Dallas Masters of the University of Colorado for providing the raw sample data utilized in this effort.

References

Brown A., Mathews B. (2005a) ***Remote Sensing using Bistatic GPS and a Digital Beam Steering Receiver.*** ION Proceedings, GNSS2005

Dallas M., Zavorotny V., Katzberg S., Emery W. (2000a) ***GPS Signal Scattering from Land for Moisture Content Determination.*** IGARSS 2000

Gatti G. (1999) ***Using GNSS signals for ocean observation.*** ESA ETP Technical Notes, 8(8), 1999

Komjathi A., Zavorotny V., Axelrad P., Born G.H., Garrison J.L. (2000b) ***GPS Signal Scattering from Sea Surface: Wind Speed Retrieval Using Experimental Data and Theoretical Model.*** Remote Sensing of Environment, 73:162-174, 2000

Manandhar D., Shibasaki R. (2005b) ***Prototype Software-based GPS Receiver for Reflected Signal Analysis.*** IEEE International Geoscience and Remote Sensing Symposium, IGARSS 2005, 25-29 July, Seoul, Korea, CD-ROM Publication

Manandhar D., Shibasaki R., Normark P.L. (2004a) ***GPS Signal Analysis using LHCP/RHCP Antenna and Software GPS Receiver***. ION Proceedings, GNSS2004 http://www.ion.org/search/search_proceedings.cfm

Manandhar D., Suh Y., Shibasaki R. (2004b) ***GPS Signal Acquisition and Tracking - An Approach towards Development of Software-based GPS Receiver***. Technical Report of IEICE, ITS2004-16, July, 2004

Zavorotny V., Voronovich A. (2000c), ***Scattering of GPS signals from the ocean with wind remote sensing application.*** IEEE Trans Geosci. Remote Sens., 38(2):951-964, 2000

Zavorotny V., Masters D., Gasiewski A., Bartram B., Katzberg S., Axelrad P., Zamora R. (2003) ***Seasonal Polarimetric Measurements of Soil Moisture Using Tower-Based GPS Bistatic Radar***, IGARSS 2003

www.qzss.org

www.sstl.co.uk