# A New Approach to GPS Multipath Visualization

*Lennox Thompson*

Academic Affiliation, Fall 2006: Senior, Coppin State University

RESESS® Summer 2006

Science Research Mentor: Dr.Penina Axelrad
Writing and Communication Mentor: David Aragon
Community Mentor: Kim Cabbagestalk
Peer Mentor: Keith Goodman

**Abstract**

Multipath is a condition where the transmitted radio signal is reflected by physical features or structures, creating multiple reflections of the same signal arriving at the receiver at different times. The result is degradation in signal strength of the transmitted signal from the satellite to the GPS antenna. Multipath occurs when transmitted signals do not go directly to the GPS antenna, but rather arrive from different parts of the environment. These additional reflected signals causes distortion of the direct signal to GPS antennas, but proper positioning can minimize multipath error. Reception of bounced signals at the antenna causes erroneous data from the GPS receiver which results in inaccurate measurement of position. The GPS receiver has trouble distinguishing between reflected signals from direct signals and that is some of the problems multipath produces. To minimize the multipath error, positioning the GPS antenna from a location that is less susceptible to multipath can help the receiver accept amplified signals. Furthermore, a MATLAB simulation was developed previously that predicts multipath based on site analysis data to generate the plot of vectors on a Digital Terrain Model (DTM).This work produces a three dimensional plot of ray paths when signals are being transmitted from a satellite. This ray path visualization enables a user to properly position a GPS antenna to minimize the multipath error.

*This work was performed under the auspices of the Research Experience in Solid Earth Science for Students (RESESS) program. RESESS is managed by UNAVCO, Inc., with funding from the National Science Foundation and UNAVCO. RESESS partners include the Significant Opportunities in Atmospheric Research and Science Program, the United States Geologic Survey, the Incorporated Research Institutions for Seismology, the United States Geological Survey, and Highline Community College.*

## Introduction

## Background

The Global Positioning System (GPS) is a worldwide radio navigation system that was developed by the US Department of Defense. GPS is based on a constellation of 24 satellites orbiting the earth. A person with a receiver using at least 4 satellites can determine their exact position anywhere on the globe. A GPS receiver requires the satellites to be spread around in all directions in order for a person to get an accurate position fix. Terrestrial objects such as mountains and buildings can cause blockage of the transmitted signals. In addition, terrestrial objects or reflectors in close proximity to the receiver can cause interference.

Navigation and positioning are crucial to many human activities such as sailing, surveying, geodetic control, and plate tectonic studies. The availability of accurate GPS technology has contributed to the safety of pilots by pin pointing exactly where to land on an aircraft carrier under zero visibility conditions. GPS is not only used for finding position and navigation, but it can also be used as a clock. The GPS receiver clock is automatically updated based on measurements to atomic clocks carried in each GPS satellite. GPS is used in geoscience applications such as measuring magnetic and

## Motivation (Importance of Multipath Predictions)

This paper describes how antenna and GPS receivers can be affected by multipath. In wireless communications, multipath is the propagation phenomenon that results in radio signals reaching the receiving antenna by two or more paths [Braasch, p 558-559].In an ideal case, the GPS receiver would track only signals arriving directly from the satellite. Multiple paths or multipath occurs due to atmospheric ducting, ionospheric reflection, refraction, and reflection from terrestrial objects such as mountains and buildings. Multipath represents the dominant error source in satellite based precision guidance systems [Braasch, p 558-559]. The transmitted signals from satellites are reflected by just about everything in the local environment in close proximity to the GPS antenna. The result is a barrage of signals arriving at the receiver: first the direct one, then a series of delayed reflected ones. This creates a messy signal. If the bounced signals are strong enough, they can confuse the receiver and cause erroneous measurements.

Sophisticated receivers use a variety of signal processing techniques to make sure that they only consider the earliest arriving signals (which are the direct ones). However, this technology is not perfect and multipath still causes errors. Researchers would like to predict the multipath properties of a GPS antenna and its environment, and to be able to select a position that avoids terrestrial objects that could cause blockage and reflections of the signals.

**Prior Work (Past Efforts to Reduce Multipath)**

The effects of multipath include constructive and destructive interference, and phase shifting of the transmitted signal from satellites orbiting the earth [Braasch, p 559]. Researchers have found that the multipath error usually varies sinusoidally as a function of relative path delay and can contain sharp discontinuities. When the relative amplitude is large, however, the error is not sinusoidal.

Antennas receiving signals from satellites do not receive signals equally from all directions. Since many multipath rays from satellites arrive from angles near the horizon; multipath may be reduced by shaping the pattern to have low gain (concentrated energy) in certain directions. The multipath error equations along with the antenna features give general guidance regarding the siting of an antenna ground reference station. To minimize the effects of multipath "the antenna should be located as far away from other objects as possible and/or should be located in such a way that multipath arrives from directions in which the antenna has low gain"[Braasch, p 559]. Locating antennas away from objects minimizes signal blockage and reduces the strength of multipath signals. But researcher M.S. Braasch states that "mere distance, however does not guarantee multipath immunity." [Braasch, p 559].

Engineers from the Haystack Observatory have designed and constructed a prototype Antenna and Mutlipath Calibration System (AMCS) to obtain in situ corrections. Park, K.-D., P. Elósequi, J. L. Davis, P.O.J. Jarlemark, B.E. Corey, A.E. Niell, J.E. Normandeau, C.E. Meertens, and V.A. Andreatta (2004), "Development of an antenna and multipath calibration system for Global Positioning System sites" Radio Science. The primary components of the AMCS are a steerable parabolic antenna, two GPS receivers, and a computer for controlling and analyzing data. A Labview graphical user interface operates the AMCS either automatically or manually. The interface is responsible for switching between Zero Base Line (ZBL) and AMCS modes, selecting satellites to observe and pointing the antenna in the right direction in order to acquire data. Labview was also used to control the communication between PCs and GPS receivers to download the satellite ephemerides and phase data. The Labview graphical user interface (GUI) is supported by a set of MATLAB routines that handle the more intensive computational tasks, such as the calculation of the topocentric satellite positions and synchronization errors of the GPS antenna. The engineers performed various experiments to assess the ability of the AMCS to calibrate GPS antenna-dependent errors. From the analysis of their experiments, Park,et al. concluded that phase variations due to the antenna pattern and multipath error can vary 5mm of over small changes of even one degree in satellite direction. An error of 5mm is significant for many high precision geophysical applications.

Engineers say the GPS antenna might be affected by short-term (daily) variations in the electromagnetic environment due to varying atmospheric or ground conditions. The difference of azimuth angle can also be a factor of the change of variations of the GPS antenna receiving signals from satellites. In addition, engineers consider that the elevation angle can also have a significant impact in the way GPS antennas receive multipath signals from satellites. They also believe that multipath conditions are worse for environments with more metal reflectors nearby the antenna and that the phase multipath errors and antenna phase variations are generally greater for lower elevation angles. Based on the experiments with AMCS and GPS antennas, researchers from Haystack Observatory concluded that the weather can play a major role in the multipath effect on a GPS receiver. They believe allowing coverage of very small arcs (few degrees) of a GPS satellite will allow a more accurate reception from the satellites to the GPS antennas.

They determined that the phase calibration variations are smaller for greater angles and the phase calibration variations are smaller for a GPS antenna in an environment with certain weather conditions (Ibid., 10). Engineers from Haystack Observatory are certain that the presence of varying amounts of surface water, may affect the attenuation of a signal being transmitted to a GPS antenna. In addition to the varying weather conditions, researchers believe a lower limit of 3-5mm can be incidental for environment effects. The statistics of the multi-day experiments that engineers conducted yielded important information regarding in situ GPS antennas and the performance of the AMCS (Ibid., 10). Engineers from The Haystack Observatory also intend to use the AMCS to study the best approach to the calibration of GPS antennas, and to assess the observed variations of data that they gathered, and to more closely analyze the effects of the environment and weather on GPS antennas.

**Overview**

This paper describes what multipath is and some of the methods researchers use to anticipate the locations multipath rays (from satellites broadcasting radio signals) will hit the receiving antenna. Explanation of why GPS receiver positioning can be a major issue if there is a terrestrial object nearby or a shiny metal reflector at close proximity that causes signals transmitted by satellites from ever reaching the GPS receiver. The formal definition of multipath in terms of radio signals broadcasted from over twenty four satellites orbiting the earth. The work that has been done to reduce multipath error in order to receive only the direct signals and not the bounced or reflected signals. Also the causes of multipath that can affect the satellite based accuracy of sending a direct signal to the GPS receiver.

**My Research**

This summer we were able to implement what researchers have done in the past and tried new methods to trace the multipath rays and calculate exactly where the ray paths will intercept the GPS receiver. We conducted research on the multipath effect of GPS receivers and using MATLAB which is a tool that will allow people to see a graphical image of multipath rays being transmitted from satellites to the receiver. Being able to visualize multipath rays is hard and this summer we were able to use MATLAB as a visual aid to show multipath rays coming from satellites to anticipating where the ray paths are going to make contact with the antenna. This summer we were able to measure multipath rays and the anticipation of where it will hit the antenna in order to properly cite the GPS receiver on the earth's surface. We used MATLAB to show viewers where to properly place the antenna to receive the amplified signals only from the satellites.

**Methods**

A Digital Terrain Model (DTM) enables scientists to analyze the GPS receiver surroundings in order to determine if there are any metal reflectors or other objects that can cause multipath. Satellite imagery is used to create realistic three-dimensional (3-D) views of the landscape and terrain of potential GPS antenna sites. The satellite image plus the DTM produces 3-D imagery that will accurately represent the surface that the GPS antenna is located in order to estimate the best location for antenna siting to reduce multipath.

In addition to using the DTM to illustrate the geometric landscape of the GPS receiver location, MATLAB is a tool that enables a user to visualize multipath on the DTM. MATLAB is a data-manipulation software package that allows data to be analyzed and visualized using existing functions and user-designed programs. It is a tool that has helped simplify the complexities of computing multipath to calculate and predict the specific locations where ray paths are more prone to make contact on the earth's surface.

Calculating ray paths using MATLAB requires creating a function to read data files in addition to filtering the data through the written MATLAB function. The MATLAB tool makes it possible to plot vectors from different angles to simulate what multipath will look like. Ray tracing (with MATLAB) generates a computer model to display the behavior of multipath, showing how multiple ray paths make contact on the earth's surface before reaching the GPS antenna. The visual display can then be used to view exactly how multipath behaves in a specific terrain location.

The 3-D graph shown in Figure 1 provides an example of signals being affected by multipath. The graph is a computer simulation of a three vector space of multipath which shows the direction in which signals approach the GPS antenna. The data contained in the graph consists of site analysis data which was converted into x-y-z coordinates on a 3-D grid in MATLAB.

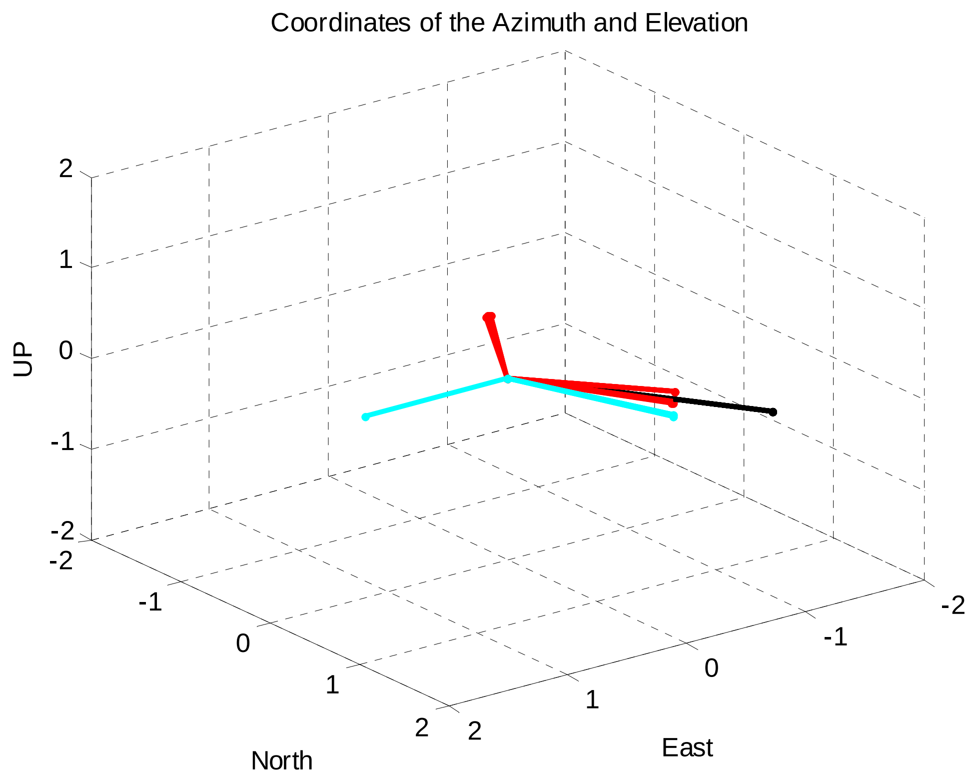


Fig 1: Multipath Visual Display

To compute the x-y-z coordinates the following formulas were applied:

x = radius* cos(El) * sin(Az)

to compute the x component in radians;

y = radius * cos(El)*cos(Az),

also in radians, and

z = radius*sin (El)

to compute the z coordinate in radians.

After calculating the x-y-z coordinates of the satellite's transmitted signals, coordinates were filtered through a previously written MATLAB function which plots 3-D figures of multipath. The 3-D plot symbolizes what the Azimuth (angle between an object and North) and Elevation (angle between an object and the horizon) will be when a signal is being transmitted from a satellite to a GPS antenna.

The red line segment signifies that the number of interactions of the ray paths equated to one interaction before reaching the GPS antenna. An interaction is defined by the number of times a signal bounces on objects at close proximity in the environment of where the antenna is positioned before ever reaching the GPS antenna. The cyan vector line represents two interactions before reaching the GPS antenna. The direct signal shown in Figure 1 is the black solid line, to distinguish it from the other vectorized lines in the computer simulation and to show that the signal transmits directly to the GPS antenna without any bouncing or reflecting off any objects.

Each line segment has a distinct azimuth and elevation, meaning Angle of Arrival (AOA) from satellites when a signal is traveling to a GPS antenna. The signal vectors portrayed in the 3-D model indicate the direction at which the signals are arriving from the satellite transmissions to the GPS antenna. Also, the line width of each signal vector represents the signal strength of the signals being transmitted by the satellite to the GPS antenna.

Finally, based on the calculation of ray paths from satellites; MATLAB will help viewers to see the adjustment of antenna position when ray paths are displayed on the DTM. Also, the computer model will display the results of multipath and how it could distort the direct signal that is being received from the satellite. Within the simulation, moving the antenna to a much less susceptible place to multipath can produce a more accurate satellite signal being received by the GPS antenna.

## Results & Discussion

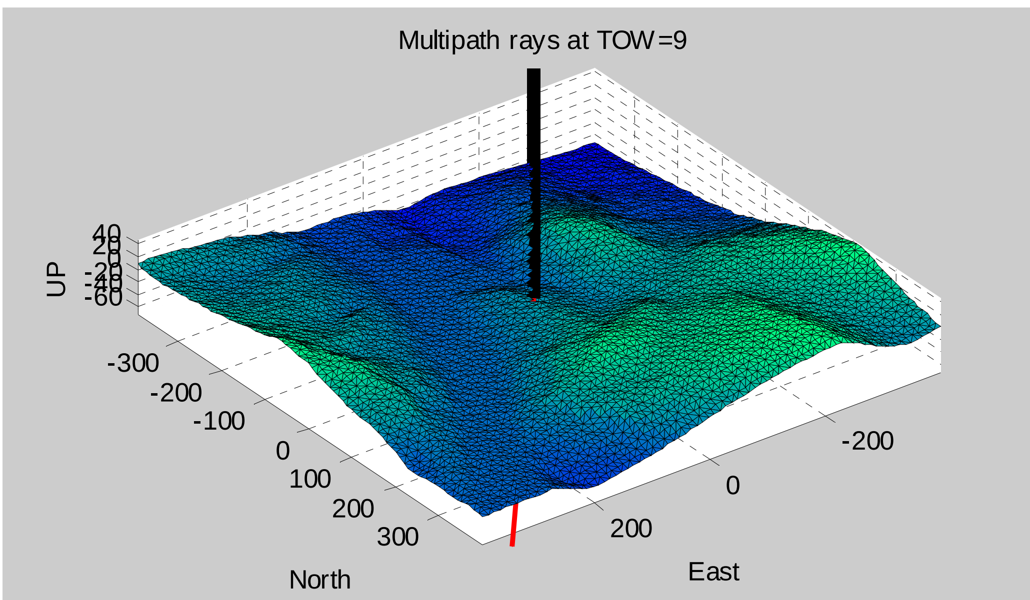


Figure 2: Site analysis grid
This graph display a GPS antenna placed on a Digital Terrain Model of an actual site at Berkeley showing the different angles in which the signal are being reflected before reaching the GPS antenna. The 3D plot symbolizes the direction in which the signals are being transmitted from the satellite.

The Digital Terrain Model shown in fig 2 is a display of the geometries of a Berkeley site that was provided by a graduate student who modeled the environment of the Berkeley site where the GPS antenna was positioned. The black solid line represents the direct signal with zero interactions and the red solid line symbolize reflected with one interaction meaning bouncing off different parts of the earth's surfaces before reaching the antenna. The multiple signal vectors in fig 2 show how multiple signals besides the direct signal is being received from the GPS antenna. Also, in the 3D plot, the vectors have varying line-width which represents the relative amplitude of each signal. Relative amplitude is the signal strength of each signal. The line-thickness is what is represented as the relative amplitude of each signal and how the direct signals and reflected signals have distinct amplitudes.

In addition to the line-width of each signal vector, the red colored vectors in fig 2 represent the number of interactions before reaching the antenna. The cyan color mentioned in the methods sections represents two interactions and the red, one interaction. Notice how the vectors with one interaction arrive from one direction and the one with two interactions from another direction. The direct signal as you can notice comes from a ninety degree angle to the GPS antenna which means that the satellite is directly above of GPS antenna in order for the direct signal to come directly above. The signals with one interaction are being transmitted from Up North direction to the GPS antenna and the signals with two interactions is coming from North East direction to the GPS antenna.

In conclusion, the possible explanation of why the signals are coming from direct angles is because the signals have different relative amplitude and that is what causes signals to reflect from different objects. Also, the environment can be a factor that could increase multipath error. But, the fig 2 is just an example of an antenna positioned at a particular site at Berkeley provided with a model of the environment of the GPS antenna.

Fig 1 is another example of displaying the direction in which the reflected signals and the direct signals are arriving from when the signals are transmitted from a satellite to a GPS antenna. As mentioned earlier, the cyan color represents two interactions meaning the number of times a signal bounces off objects before ever reaching the antenna. The red color represents one interaction and of course the black color has zero interactions because it is being transmitted directly to the GPS antenna without reflecting or diffracting off any objects. As you can notice, the line thickness represents the strength of each transmitted signal. The direct signal which is the black solid line has the strongest relative amplitude of them all. The reason why the direct signal has the most amplified signal is because the signal does not bounce off any surfaces before ever reaching the antenna. When a signal bounces off objects it loses a fraction of its strength because when it bounces off objects the signal disperses in different directions. The difference between the 3D plot in fig 1 versus the 3D plot in fig 2 is that fig 1 3D grid displays multipath occurring at a flat surface with a solid wall. Fig 1 is not based on showing a visual of multipath on a Digital Terrain Model; it only displays the direction in which the signals are reaching the antenna positioned on a flat surface with a wall.

## Conclusion

The overall goal of this multipath research was to model accurately the multipath error at any particular environment and to be able to show a visual of the ray paths in order to properly position the GPS antenna away from the ground surfaces that cause erroneous data from the GPS receiver. The results that were obtained in programming a MATLAB function to convert the satellites azimuth\elevation to the xyz coordinates can help people to display ray paths at any particular environment and also factor in physical properties or structures near the antenna that could cause signals to reflect or diffract. In conclusion, the 3D plot of multipath that was created will help people see a visual of multipath in order to avoid the multipath error.

**References**


1. Park, K.-D., P. Elósequi, J. L. Davis, P.O.J. Jarlemark, B.E. Corey, A.E. Niell, J.E. Normandeau, C.E. Meertens, and V.A. Andreatta (2004), “Development of an antenna and multipath calibration system for Global Positioning System sites” Radio Science

2. Jan P. Weiss, Steve Anderson, Corey Fenwick, Lin Song, Penina Axelrad Colorado Center for Astrodynamics Research, Pete Belay, Ronald L. Brinkley, “Development and Validation of an Aircraft Multipath Model for Land-Based JPALS,” presented in Navigation Annual Meeting 2005,Cambridge,MA,June 27-29

3. Michael S. Braach, “Multipath Effects,” in B.W. Parkinson et al. (ed.), Global Positioning System: Theory and Applications v1 AIAA 1995.