GLOBAL POSITIONING SYSTEM, REMOTE SENSING, GEOGRAPHIC INFORMATION SYSTEMS, AND PREHISTORIC FOOTPATHS

Michelle M. Butler
Department of Anthropology
University of Colorado, Boulder

RESUMEN

El Proyecto Prehistórico Arenal emplea varios tipos de datos geográficamente referenciados y los integra a un Sistema de Información Geográfica (GIS) como parte de la investigación de veredas antiguas. Entender el proceso de formación y preservación de dichas veredas ayuda a su detección en imágenes generadas por sensores remotos (Sheets & Sever, 1991). La integración de la información de campo y las imágenes en el GIS brinda, a su vez, la posibilidad de analizar y visualizar el movimiento de personas a través del paisaje antiguo. Dicha integración posibilita, además, relacionar imágenes satelitales con rasgos lineales y puntuales, y ubicarlos con la ayuda del Sistema de Posicionamiento Global (GPS). Este artículo trata sobre el uso de esos componentes tecnológicos para el mapeo y análisis espacial de configuraciones arqueológicas dentro del Proyecto Prehistórico Arenal.

ABSTRACT

The Proyecto Prehistorico Arenal is employing several types of geographically referenced data and integrating the data into a Geographic Information System (GIS) as part of its research in ancient eroded footpaths. Understanding the processes of formation and preservation of eroded footpaths enable us to detect them on remotely sensed imagery (Sheets & Sever, 1991). The integration of the field data and remotely sensed imagery into a GIS allows us to both analyze and visualize the movement of ancient peoples across an ancient landscape. The Global Positioning System, the remotely sensed data and GIS technology all allow us to overlay satellite imagery with linear and point features. All of these components are necessary for the mapping and spatial analysis of ancient footpaths, sites and other landmark features. This article discusses the different aspect of the Global Positioning System and the integration of GPS, remote sensing, and GIS as it pertains the Proyecto Prehistorico Arenal.

Michelle M. Butler *michelle.butler@colorado.edu*

INTRODUCTION TO THE GLOBAL POSITIONING SYSTEM

Global Positioning System (GPS) is a satellite-based navigation system initially developed by the U.S. Department of Defense as a military system to fulfill U.S. military needs, but is now commercially available (El-Rabbany, 2002). The Global Positioning System consists of 31 NAVSTAR satellites in geosynchronous orbits, a rover unit, and a base station. At any one time, there are 24 operating satellites with seven back-up satellites. There are four satellites in each of six fixed planes, with an inclination of approximately 55 degrees from the Earth's equator (El-Rabbany, 2002). Each satellite orbits at 11,000 nautical miles above the Earth's surface. Each GPS satellite transmits a signal, two digital codes and a navigation message (El-Rabbany, 2002). The satellites transmit signals, or radio waves, in two types of digital code, carrier phase, transmitted in sinusoidal wave form, and pseudo range, transmitted in square wave form (Fig. 1).

Carrier phase is the most precise type of data, with sub-decimeter accuracy. The industry standard for accuracy is 2-5 meters horizontally and 6-15 meters vertically, depending on the rover unit in use and environmental conditions (Magellan, 1997). The carrier phase requires 15-45 minutes to acquire a position fix due to the need for a large piece of the wave to be recorded. Because of the amount of time needed, carrier phase is only good for collection of stationary points. Pseudo range code, due to the irregularity in its form, requires a much smaller piece of the signal to be collected, so the acquisition of a position fix can take mere seconds. Once the position fix is acquired, points can be collected up to every second. The navigation message contains the coordinates (location) of the satellites as a function of time (El-Rabbany, 2002). The Proyecto Prehistorico Arenal is utilizing Magellan GPS ProMARK X-CM receiver and Magellan Post-Processing Software. The ProMARK X-CM can collect both psuedo range and carrier phase data.

A position fix can be collected in either two or three-dimensional space. Two-dimensional positioning (*x*, *y* coordinates) requires a minimum of three satellites. Three-dimensional positioning (*x*, *y* coordinates and *z* as altitude) requires a minimum of four satellites (Magellan, 1997). Only satellites above the mask angle, the angle above the horizon, of the rover unit will be used. The mask angle can be manually set but should never be less than ten degrees. A mask angle of less than ten degrees may cause the signal to travel through a greater amount of ionosphere and troposphere (see below) and can lead to the introduction of a higher degree of error. Ideally, satellite positions should be widely arrayed to get the most accurate position fix.

Along with the transmission of radio waves, each satellite contains an atomic clock and attaches the time of wave transmission to the radio wave in the signal. The rover unit and base station both record the transmitted satellite signal and each "attaches" the time the signal was received to the file. The use of differential timing, time sent versus time received, is important to accurately calculate the distance and position of both the rover unit and base station on the Earth's surface from the satellite in space. Since the velocity of the radio waves is known and the travel time for the signal from the satellite to the rover is known, distance can be calculated (D = v t). All that is necessary is the position of the satellite, at the moment of signal transmission, within its orbit (Fig. 2).

This spatial information is kept in an almanac file. The Standard Positioning Service (SPS) contains almanac data. The almanac data contains the health and approximate location of every satellite in the system (Magellan, 1997). The GPS receiver collects almanac data from any available satellite, and then uses that data file to locate the satellites that should be visible at the receiver's location (Magellan, 1997). Satellite position as a function of time, is predicted from previous GPS observations at the ground control stations (El-Rabbany, 2002). Overlapping four-hour GPS data spans are used by the operational control system to predict fresh satellite positions. However, this can lead to imperfect modeling, which can cause errors, called ephemeris errors (El-Rabbany, 2002).

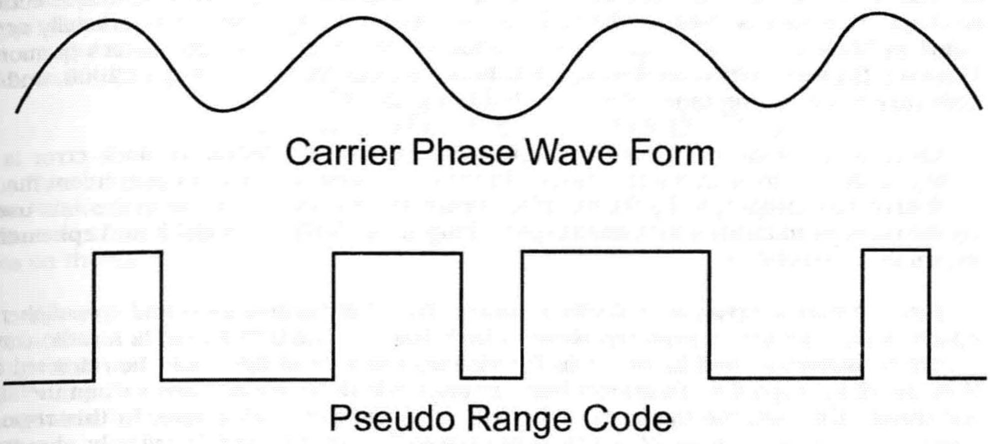

Fig. 1 The regularity of Carrier Phase (CP) versus the irregularity of the Psuedo Range Code (PR). The irregularity of the PR allows much less of the code to be collected before the rover can calculate a position fix.

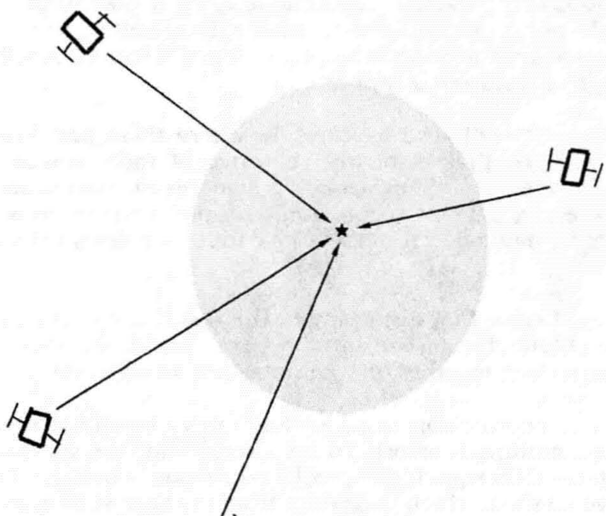

Fig. 2 Representation of the satellite spread in orbit that is necessary for an accurate three-dimensional fix. Only three satellites are required for a two-dimensional fix.

GPS ERRORS

The possibility for errors to be introduced into the position fix during collection is a continuous concern. The introduction of error can be avoided, or corrected for, in some instances. However, some errors are unavoidable.

The most prominent source of error is Selective Availability (SA). Selective Availability, which is used by the U.S. Department of Defense and was officially activated in March of 1990, degrades the signal to an accuracy of 20 meters or more. However, SA was turned off during the Clinton Administration, in May of 2000, and is only turned on during times of war (El-Rabbany, 2002).

Clock and ephemeris errors originate within the GPS satellite. A clock error is a slowly changing error that appears as a bias on the pseudo range measurement made by the receiver (Magellan, 1997). An ephemeris error is a residual error in the data used by the receiver to locate a satellite in space (Magellan, 1997). Both clock and ephemeris errors are correctable.

Environmental error, specifically atmospheric error (ionospheric and tropospheric delay) can cause the transmitted wave to be refracted. The GPS signal is a radio wave and radio waves, as well as waves in the visible spectrum of light, can be refracted as they travel through Earth's atmosphere. Ionospheric Delay causes error when the signal travels through the upper 1000-50 km region of the atmosphere. In this region, there are a large number of "negatively charged" electrons and "positively charged" atoms and molecules that can cause the bending of the signal as well as change the speed of the signal (El-Rabbany, 2002). The quantity of error caused by ionospheric delay depends on time of day and year in which the signal is being recorded (El-Rabbany, 2002). The troposphere is the region from the Earth's surface to approximately 10 km above. Tropospheric Delay is primarily the result of weather conditions (El-Rabbany, 2002). Tropospheric conditions are not easy to predict and collection of GPS data should not occur on severe weather days. Setting the mask angle at no less than ten degrees above the horizon helps to eliminate using a satellite whose signal will be going through excessive atmosphere.

Multipath Error (MPE) occurs primarily where there are buildings, water or any other type of surface that is highly reflective of radio waves. The signal can be "bounced" or reflected off of surfaces and can result inaccurate data collection. To avoid multipath error, data collection would ideally occur in an area without reflective surfaces. However, many newer model rover units are designed with multipath resistant antennae.

Another type of error that can occur is the result of satellite geometry. Good satellite geometry is obtained when the satellites are spread out. When collecting data from satellites that are close together, the data are not as accurate.

Some errors are correctable (*e.g.*, SA and environmental error) and some are non-correctable (*e.g.*, multipath error). To help correct for the various errors that can be introduced into the GPS signal, differential correction is utilized. Differential correction is a comparative method, which uses data from the base station as well as data collected by the rover unit. The base station collects data at regular intervals (regular intervals vary from one base station to another, depending on the operator, over a known geographic location.) The base station collects a position fix at its regular interval and compares the fix collected by the receiver to where the base station knows the position should be. The base station then creates an offset, called the DELTA correction (Magellan, 1997). During differential correction, the computer software matches the points collected by the rover to the base station points based on the time that the signal was received. The computer knows the offset of that base station and applies a reverse offset to change the GPS fix of the rover to the "actual" location. There is an assumption in differential correction that the errors introduced are the same for the base station as they are for the point of collection by the rover unit (Magellan, 1997). For this reason, the base station and rover should be in close proximity (less than 180 Km is a general rule). The base station for this project is located at Volcán Irazu, at an approximate distance of 130 kilometers from the center of Tilarán and collects points at a regular interval of every thirty seconds. Though there are two base stations at Volcán Arenal, they were non-functioning at the time of this fieldwork.

GPS AND REMOTE SENSING DATA IN A GIS

The ability to integrate GPS data and remotely sensed imagery within a GIS provides the Proyecto Prehistorico Arenal with a powerful tool, not only for the display and visualization of complex sets of spatial data, but it also allows us to perform various analyses on the data set (Fig. 3).

Although the computer is an excellent tool to analyze geographic data, it is not a replacement for the human eyes and brain, especially when we look at the relationships that exist between landmarks and paths. However, the combination of person and computer can lead to the solution of research problems that would otherwise be unattainable (Sever & Wagner, 1991).

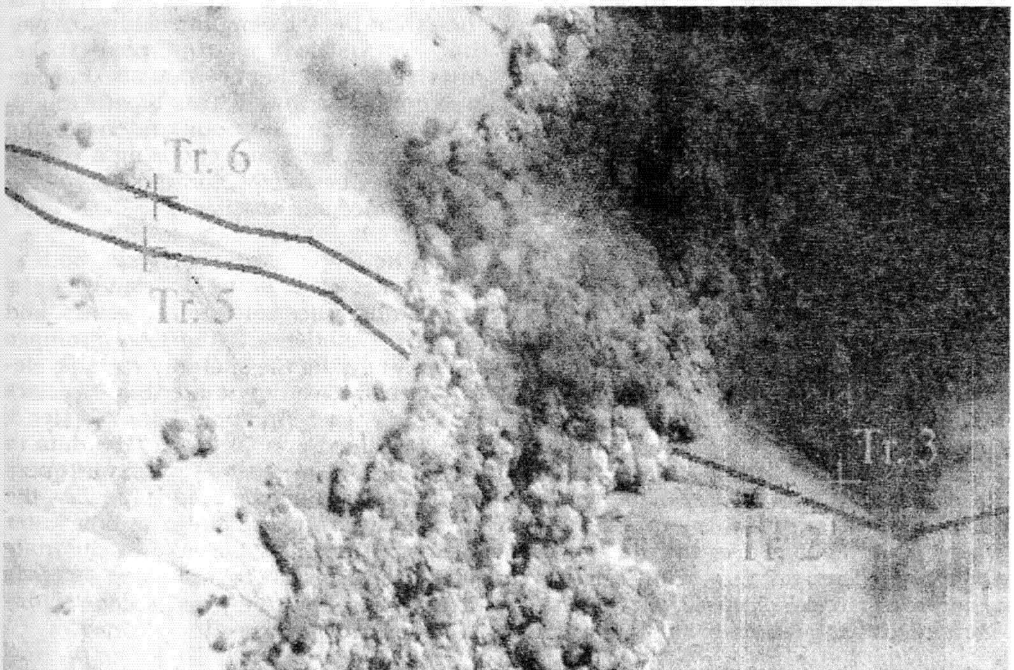

Fig. 3 *IKONOS panchromatic image with GPS vector files overlaid showing paths and trenches.*

However, before any analysis could be conducted, the satellite imagery needed to be georeferenced to allow for accurate point location. GPS control points needed to be collected within the research area. The control point collections were based on locations that were easily resolved on the imagery. The points collected by the receiver were then matched to the points on the image and differentially corrected. The image was then stretched and warped, using complex algorithms provided by the software, to create an accurate image of the "real world".

The project is utilizing high resolution IKONOS imagery and color infrared photography, provided by the National Aeronautics and Space Agency (NASA), ArcView GIS software and Magellan ProMARK X-CM GPS software and equipment. Integrating remote sensing and GIS have been very successful in previous and on-going archaeological projects, such as those at Chaco Canyon (Sever & Wagner, 1991). Making use of the technology that is available can lead to analyses of the research area that previously would have been very difficult or impossible to conduct.

The types of computer analyses that have been proposed include: viewshed, watershed, and slope/aspect. Viewshed analysis is one of the most commonly used analysis tools provided by a GIS (O'Sullivan & Turner, 2001). This analysis has been used in archaeological studies in order to understand ways in which ancient cultures may themselves have understood and used their physical environment, and in turn how this understanding may have influenced the siting and location of monuments and settlements (O'Sullivan & Turner, 2001). The viewshed analysis begins by merging a Digital Elevation Model (DEM) with vector files of landmarks. The actual analysis involves choosing a landmark or position on the ground and having the computer calculate, based on elevations, those areas that are visible from that point (Lake, Woodman & Mithen, 1998). Those areas that are visible from that position also encompass all of the points that have a direct view back to the landmark. This type of analysis can be used as a tool to not only analyze the data and to aid in our understanding of how or why people made the choices they did in the past when choosing a course that later became an erosional footpath, but also as a possible exploratory tool when trying to link landmarks that are typically within sight of one another.

The watershed analysis can be combined with the slope/aspect analysis, both of which require the use of a DEM for the study area. The slope is the difference in elevation between two points, divided by the horizontal difference between the points, and aspect is the orientation of the slope (Dent, 1999). Watershed is the total drainage basin or catchment area flowing into a given outlet. Analyzing the spatially variable elements of a watershed and slope can be a daunting task. Over any land area there are a number of variables, including topography, soil type, and land use (Potter, Yoder & King, 2000). However, these two analyses can be combined in a GIS with GPS data in regards to the location of linear features and the amount of erosion to answer questions concerning where erosional footpaths might be found on the landscape (*i.e.*, the range of slope that creates an erosional footpath). By knowing the direction that water would naturally flow over the surface of the ground, it might be possible to eliminate some linear features that are the result of natural erosion. The overall slope analysis would allow us to isolate those areas on the imagery that have a degree of slope significant enough to allow erosional footpaths to form.

CONCLUSION

With this data set we can also analyze the relationship between landmarks and connecting paths, and eventually predict where more paths might be found. This can be done through a greater understanding of how ancient people moved across the landscape (*e.g.*, following ridges or valleys, linearity favored irrespective of topography, etc.).

We have already begun connecting footpath segments based upon extrapolation between segments that are in line and have the same orientation. The GIS makes this easier by providing an efficient format for displaying all of the data within geographic space and allowing the visualization of the data. It is also an efficient tool for moving through the data and allows us to mark those areas that are likely to contain significant features. The end result is that the combination of GPS data and remotely sensed imagery within a GIS database will allow us to efficiently predict the location of both paths and sites, as well as search for those features in a variety of image types (*e.g.*, scanned color infrared transparencies, IKONOS satellite images, and TIMS imagery). By having accurate GPS data in a GIS, we have developed a tool that can be utilized in all of the stages of this project, from prediction and testing to the final display of our results.

ACKNOWLEDGEMENTS

I would like to thank Dr. Payson Sheets, Dr. Thomas Sever and Daniel Irwin for all their support and critical comments. I would also like to thank Dr. Michael Snarskis for his great introduction to Costa Rican archaeology. Special thanks to W. Derek Hamilton for all his support and for providing the figures for this article.

LITERATURE CITED

DENT, D. 1999. *Cartography: Thematic Map Design*. 5th edition. Wcd/McGraw-Hill, Boston.

EL-RABBANY, A. 2002. *Introduction to GPS: The Global Positioning System*. Archtech Houses Inc., Norwood.

LAKE, M., P. WOODMAN & S. J. MITHEN. 1998. Tailoring GIS software for archaeological applications: An example concerning viewshed analysis. *Journal of Archaeological Science* 25 (1): 27-38.

MAGELLAN SYSTEMS CORPORATION. 1997. *User Guide for the Magellan GPS ProMARK X and the Magellan GPS ProMARK X-CM*. Magellan Systems Corporation, San Dimas.

O'SULLIVAN, D. & A. TURNER. 2001. Visibility graphs and landscape analysis. *International Journal of Geographic Information Science* 8 (3): 221-237.

POTTER, S., D. YODER, & J. KING. 2000. A GIS analysis of the topography, soil type, and land use impacts on the water quality of a small surburban watershed. *Journal of Soil and Water Conservation* 55 (3).

SEVER, T., D. WAGNER. 1991. Analysis of prehistoric roadways in Chaco canyon using remotely sensed digital data. In Trombold, C. (ed.) *Ancient Road Networks and Settlement Hierarchies in the New World*. Cambridge University Press, New York.

SHEETS, P. & T. SEVER. 1991. Prehistoric footpaths in Costa Rica: transportation and communication in a tropical rainforest. In Trombold, C. (ed.) *Ancient Road Networks and Settlement Hierarchies in the New World*. Cambridge University Press, New York.