Leonard R. Kruczynski
Trimble Navigation, Ltd.
645 North Mary Avenue
Sunnyvale, CA 94086

# AN INTRODUCTION TO THE GLOBAL POSITIONING SYSTEM AND ITS USE IN URBAN GIS APPLICATIONS

Abstract:

The NAVSTAR Global Positioning System (GPS) provides accurate position data which can be used to aid the users of Geographic Information Systems (GIS) in several ways. GPS is a satellite-based navigation, positioning, and timing system. From the signals emitted by the GPS satellites, the receivers are able to calculate 3-dimensional position (latitude, longitude, and altitude) and time. GPS, when used autonomously, is accurate to approximately 12 meters CEP[1]. In differential mode GPS accuracy improves to 2-5 meters CEP. For surveying applications, survey-grade receivers are accurate to millimeters.

The GIS applications of GPS include, but are by no means limited to, geo-referencing photogrammetric or digital map data; ground-truthing satellite imagery data; and creating or updating GIS data bases with point, line or polygon digital data. For all these applications and many more, data-logging GPS receiver systems are available which are portable, rugged, and easy to use.

In this paper, we briefly describe some features of the Global Positioning System and report on demonstrations of GPS applications to GIS operations. The utility of GPS for digitizing the location of street lamps and fire hydrants is demonstrated using a GPS set in a vehicle traveling at 25 mph. As an object of interest was passed, a function key was pressed which wrote a marker into a file. The marked geographic locations were then extracted and formatted for importing to a GIS data base.

## INTRODUCTION:

A major problem in managing GIS data bases is trying to correlate data from separate sources. If not done well, the various layers will not register

[1]CEP stands for Circular Error Probable: 50% of the collected points will be inside a circle with radius 12 m and 50% of the collected points will be outside that circle. Autonomous GPS accuracy is subject to degradation by the Dept. of Defense to a level of 40 meters CEP.

properly. This generic problem is alleviated by using a *common grid* such as is available in the Global Positioning System.

GPS uses the World Geodetic System of 1984 (WGS-84), an earth model based on the Geodetic Reference System of 1980 (GRS-80). GRS-80 is also the basis of the North American Datum of 1983. Because the earth model is common worldwide, there are no difficulties caused by varying local parameters. For example, in WGS-84, the center of the earth is defined to be the center of mass of the earth and does not change. In contrast, the NAD-27 defined center of the earth varies depending on location. Worldwide, the WGS-84 model matches the Earth's mean sea level surface to within 30.5 meters RMS, an excellent fit. Data collected using WGS-84 with GPS and data collected from standard surveys tied to WGS-84 benchmarks will properly register with any other WGS-84 positional data.

## THE CURRENT GPS CONSTELLATION:

Presently (May 1990), there are 13 active GPS satellites orbiting the earth. More satellites will be launched to bring the total number of satellites to 24 (21 plus 3 spares). The orbital period for each satellite is approximately 12 hours with an altitude of approximately 12,600 miles (approximately 20,000 km). Each satellite contains very accurate atomic clocks which are synchronized to a common clock by the ground control stations (operated by the U.S. Air Force).

The current constellation provides an average of 11.5 hours of 3-dimensional position fixes per day and an average of 17.5 hours of 2-dimensional fixes per day worldwide. As more satellites are launched by the Department of Defense on planned 60 to 90 day intervals, visibility windows will expand and availability will increase accordingly. The GPS managers expect that by mid-1991, there will be full 2-dimensional availability worldwide and by mid-1993, there will be full 3-dimensional availability worldwide.

The satellites radiate individually coded radio signals which are received by the user's GPS receiver. Along with timing information, each satellite transmits ephemeris information which enables the receiver to compute the satellite's precise position in space. The receiver decodes the timing signals from the satellites in view (4 or more for a three dimensional fix) and, knowing their locations from the ephemeris information, computes a latitude, longitude, and altitude for the user. This position fix process is continuous and is updated once per second.

## OLDER TECHNOLOGIES BEING REPLACED:

The Global Positioning System will eventually replace two current navigation systems. These systems are LORAN and TRANSIT. LORAN is a ground-based navigation system providing continuous position fixes accurate to about 175 meters CEP in coastal waters only (i.e., within range of the LORAN transmitters). TRANSIT is a space-based system which can provide worldwide coverage but only 10 to 30 fixes per day. Sub-meter accuracy is available after 2 days of observation by a stationary user. Both of these technologies only allow 2-dimensional position fixes to be made.

## SELECTIVE AVAILABILITY AND DIFFERENTIAL GPS:

The accuracy of autonomous GPS position fixes depends mostly on the actions of the Defense Department. To deny GPS accuracy to unauthorized or potentially hostile users, the Defense Department has the ability to corrupt the satellite's timing signals and ephemeris data which in turn degrades the accuracy of the receiver's autonomously calculated position fix. This degradation process is called Selective Availability (SA). When SA is activated, position fixes will be within 40 meters CEP. (100 meter 2dRMS, 50 meters 1dRMS and 40 meters CEP are roughly equivalent.)

To obtain a good position fix in the presence of SA, a technique called differential GPS is used. With differential GPS, a reference GPS receiver is set up at a known location and collects data at the same time as nearby (within a few hundred miles) remote receivers collect data at unknown locations. GPS systems can differentially correct position fixes either in real-time (in the field) or as a post-processing operation. The Trimble Navigation GPS PATHFINDER[2] System is an example of a differential system which computes differential corrections as a post-processing operation. With differential GPS, the GPS PATHFINDER System's accuracy will be 2-5 meters CEP.

If higher accuracy is desired, survey-grade GPS receivers are available. The Trimble Navigation 4000 ST FIELD SURVEYOR[3] is accurate to 1 centimeter + 1 millimeter per kilometer of baseline length. Survey-grade receivers only work in differential mode (i.e., at least two must be used).

## GPS AND GIS DATA BASES:

One of the greatest advantages of GPS for GIS applications is that the data is collected quickly and accurately with a common grid. With *data recording* GPS receivers, geographic coordinates, time, and other attribute information are first collected in the field. The data is then downloaded to a computer, reformatted, and exported to a GIS data base *without* manual digitization. Since GPS provides a common reference system, data from GPS sources and sources rectified with GPS will register with each other and with additional GPS data collected in the field.

---

[2]GPS PATHFINDER is a trademark of Trimble Navigation, Ltd.
[3]The 4000 ST Field Surveyor is a trademark of Trimble Navigation, Ltd.

GPS DATA RECORDING:
An example of a data recording GPS receiver which is specifically designed for GIS applications is the Trimble Navigation GPS PATHFINDER System. It is a rugged, portable, battery-powered, data recording system comprised of a lightweight GPS receiver, a Data Recorder, a System Battery, and Software. Included with the software is a suite of post-processing programs some of which are specifically designed for GIS data combination. Two of these programs are: GISGEN which creates GIS files in a number of different GIS formats and AREA which calculates the area of a closed traverse file.

GPS PATHFINDER OPERATION:
While in the field, the user can perform a variety of navigation and geographic data recording functions. For example, to map the boundary of a timber sale area, the user travels to the starting point, turns on the system, and walks, drives, or flies around the boundary. By performing this simple procedure, the user is actually digitizing the boundary. After returning to the office or the laboratory, the user connects the Data Recorder to an IBM PC or compatible and downloads the position data. This data can then be converted to the desired GIS data format (GRASS sites, ARC/Generate, AutoCAD DXF, MOSS Import, EPPL7, ERDAS DIG, or generic ASCII). The post-processing software allows reviewing and plotting on 1:24000 (or any other scale) overlays using a Hewlett Packard[4] Graphics Language compatible pen-plotter.

GPS-GIS DATA COLLECTION EXAMPLES:
The first example of the output of the GPS PATHFINDER System is shown in Figure 1. This figure shows how the system was used to digitize the shoreline of Legg Lake in the San Gabriel Valley of Southern California. The Legg Lake shoreline was walked and digitized in about an hour. Total traverse length is approximately 3 kilometers. The compact GPS antenna was attached to a range pole and the GPS receiver was carried on a hip belt. The data was plotted on an HP 7475B pen-plotter using the GPS PATHFINDER's post-processing software. The scale of the plot is 1:3500. Each point on the plot represents a GPS fix. Notice the plot's tick marks; they allow the plot to be easily geo-referenced.

Another example of the output of the GPS PATHFINDER System is shown in Figure 2. This figure shows how the system was used to digitize selected roads of Redlands, California. The base map is an ETAK roadnet with GPS PATHFINDER data in bold. The compact GPS antenna was attached to a vehicle's roof with a magnetic mount, the driving speed varied from 0 to 60 miles per hour, and the data was collected over a 2 hour period. The GPS data was formatted on an IBM PC and exported to ARC/INFO[5]. In

[4]Hewlett Packard is a registered trademark of the Hewlett Packard Corporation.

[5]ARC/INFO is a registered trademark of Environmental Systems Research Institute, Incorporated.

ARC/INFO, the GPS data and the ETAK base map were combined. Notice the top of the figure. This section reveals how well the GPS PATHFINDER System can *update* an existing GIS data base. Here, the GPS PATHFINDER System obtained accurate data on roads that were built *after* the ETAK roadnet was made. The ability to update accurately is a critical feature of a GIS data generation capability. Over 60% of the USGS 7.5 minute quad sheets, the source data for most digitized maps such as ETAK, are over 10 years old and are based on a 1927 datum.

The third output example of the GPS PATHFINDER System is shown in Figure 3. In this figure a four by six block area of Palo Alto, California was selected for demonstrating the ability of GPS to record the locations of street lamps and fire hydrants on the fly. The GPS Antenna was attached to the left hand side of the roof of the vehicle with a magnetic mount. During the data recording session the driver attempted to drive along the center line of the road. When a street lamp or fire hydrant was passed, a function key was pressed to mark the vehicle's location. The resulting GPS data file was differentially corrected using a base station set up at a known location five miles from the study area in Sunnyvale, California.

The complete digitized path of the vehicle and the marked objects' positions were extracted from the differentially corrected GPS data file and plotted with an ETAK base map of the study area.. This base map was drawn in AutoCAD[6] The roads were driven at a maximum speed of 25 mph, the speed limit of the streets in the study area. Figure 3 shows a high density of digitized points, corresponding to a high density of street lamps in this suburban area. Figure 4 is a zoom view of Figure 3. The location of the vehicle when the function key was pressed is the actual plotted position. Street lamps are marked with open circles or circles with a cross, and the fire hydrants are marked with a square. There was an eight meter registration difference between the GPS data and the road data most probably due to a systematic offset in the road net data. The GPS location was recorded every second. These positions are represented by small dots on each plot. During this study, the locations of two burnt out lamps were recorded and could be extracted and sent on to a facilities management program for scheduling their repair.

## CONCLUSION:

The Global Positioning System can benefit the users of Geographic Information Systems by allowing them to quickly collect accurate geographic coordinates of any feature on the ground for creating, updating, or maintaining their data bases. With the current satellite constellation and the prospect of full 24-hour worldwide 3-dimensional availability in about 2 years, GPS is a viable tool for all who require point, line, or polygon data to create or maintain a GIS data base.

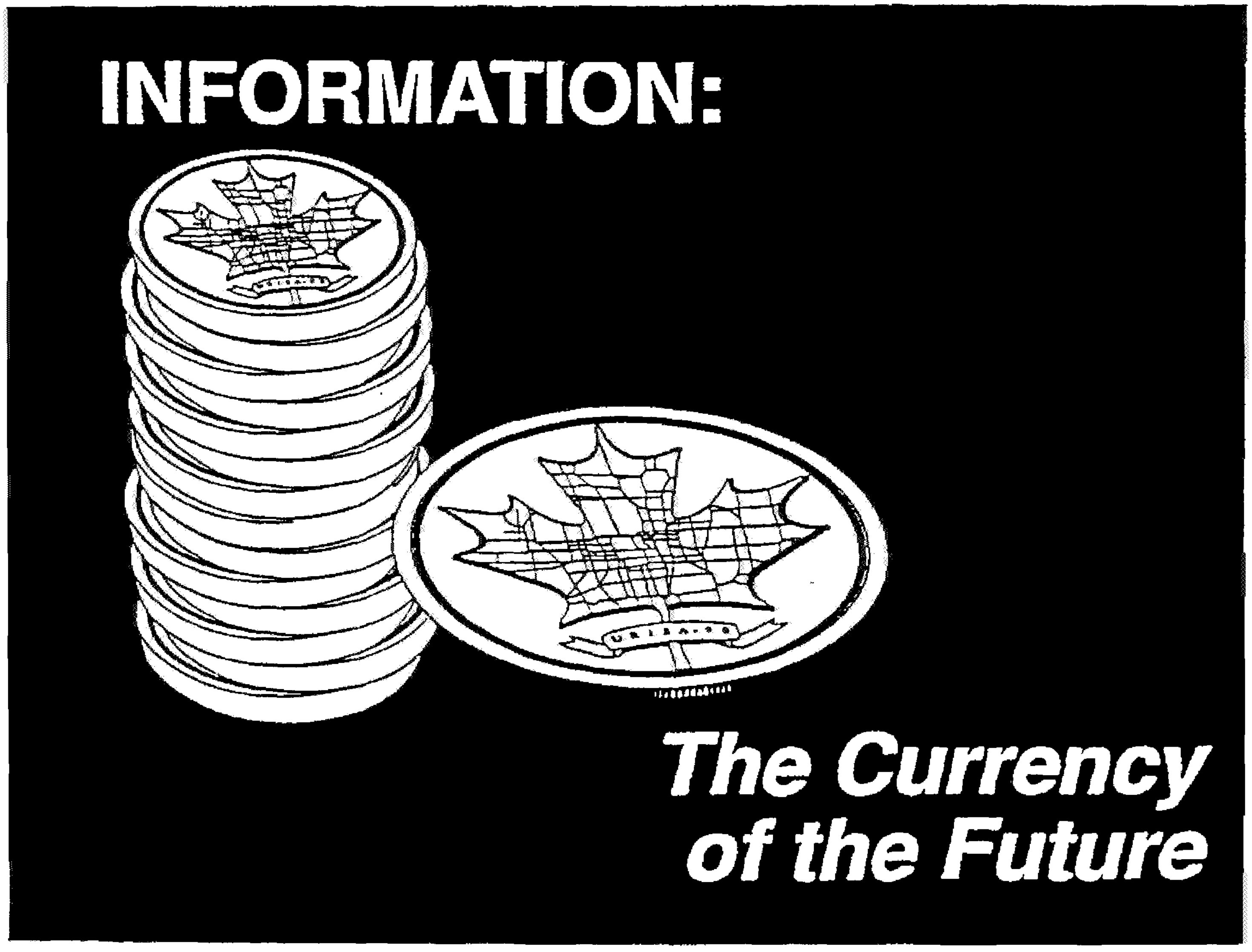
---

[6]AutoCAD is a registered trademark of Autodesk, Inc.

Proceedings of the 1990
Annual Conference of the

# Urban and Regional Information Systems Association

Edmonton, Alberta




VOLUME IV

URBAN AND REGIONAL ANALYSIS • REGIONAL AGENCIES • PUBLIC ADMINISTRATION • PUBLIC INFORMATION • EDUCATION/TECHNOLOG TRANSFER • RESEARCH AGENDA GROUP • STATE/PROVINCE

*URISA '90 graphic courtesy of ESRI, the 1990 Graphic Design Competition Winner*

EXCERPT: PUBLIC SAFETY RELATED PAPERS

# U R I S A   P R O C E E D I N G S

Papers from the annual conference

of the

URBAN AND REGIONAL INFORMATION SYSTEMS ASSOCIATION

August 12 - August 16, 1990

Edmonton, Alberta

Volume IV:

Urban & Regional Analysis • Regional Agencies
Public Administration • Public Information
Education/Technology Transfer • Research Agenda Group
State/Province


Edited by:

Frank Westerlund

Department of Urban Design & Planning
University of Washington
Seattle, Washington

# INTRODUCTION

by Frank V. Westerlund

This volume incorporates papers in three topical areas. The first area, public administration and public information, includes papers dealing with the development, operation, and application of geographic information systems (GIS) and related data collection and management within public agencies at local and state or provincial levels. Included are papers that document the process of system planning, acquisition, and implementation; database design; applications development; and evaluations of system performance, including analyses of system costs and benefits, both tangible and intangible. These papers reflect an increasing sophistication on the part of agency users in their understanding of the role of GIS as a tool within their organizations, and of relationships between technical and management issues.

Other papers in the first section are concerned with applications of information systems to specific areas of public administration. Two papers deal with new responsibilities of local governments in the emerging field of growth management. One describes the design and implementation of information support for a development impact fee program, the other a program for monitoring levels of public service in relation to the process of development review - pertaining to the "concurrency" issue in growth management planning. Another group of papers is concerned with interagency cooperation among local and/or state or provincial governments in such areas as base map maintenance, system operation, data sharing, and public access to information. Two papers provide examples of land information cooperatives or corporations. Other public information issues are dealt with in the last two papers in this section, including arguments for formal recognition of GIS professionals and a thought piece on the implications of multiple participation and public access.

The second topical area is research and applications development related to urban and regional analysis. The first two papers deal with the recurrent issue of accuracy of spatial databases, the meanings of data "accuracy" and "quality", implications of proposed standards, and implementation of quality controls. Another paper discusses GIS research programs in the United Kingdom, as a parallel to the National Center for Geographic Information and Analysis (NCGIA) effort in the United States. Papers on local level urban analysis deal with population estimation, development of demographic databases, and use of real property appraiser files. Local government applications in a developing country are described in a case study of Malaysia. GIS applications related to implementation of land use policies, including growth monitoring and land use change detection are covered in three papers. Other papers document the development of county and regional applications such as multipurpose use of county-wide street address databases and regional flood modelling. A final paper in this section considers the role of a research institute in managing and supplying information to other organizations.

The third topic of this volume, education, is represented by one paper, which describes the extensive teaching and research program in GIS at the University of Melbourne, Australia.

Added to this volume is the URISA Student Award Paper for 1990, by Paul E. Patterson, a graduate student at Georgia Institute of Technology. His paper explores the potentials of transportation demand modelling using geographic information systems and public databases such as TIGER files.

EXCERPT FROM TABLE OF CONTENTS, VOLUME IV

* = Public Safety Related Papers

## RESEARCH/URBAN AND REGIONAL ANALYSIS

## EDUCATION



## URISA STUDENT AWARD PAPER