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SPATIAL DATA COLLECTION FOR THE PURPOSE OF ARCHEOLOGICAL SURVEY

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Abstract: The article discusses methods of spatial data collection for the purpose of archeological survey. What we intent to get is a collection of spatial data for representation of the current reality from archeological sites. The perfect interaction between GPS and GIS is helpful for this purpose, as it is possible to capture and process spatial data – for later analyzing it – in an easy and effective way. The research was done with the collaboration of the Archeological Institute of Slovak Academy of Science in Nitra, which works with the software environment using the final spatial data format. The dilemma of accuracy versus functionality was solved with respect to the purpose of spatial data collection. The advanced technology – GIS and GPS, as well as their improving interactivity, make the spatial data capture and processing an easy and successful task, with much lower time investment and getting good results.

Keywords: DGPS, data acquisition, GIS/GPS integration, data processing

Introduction

Concerning data acquisition the main consideration is the dilemma between accuracy and functionality (i.e. price and speed). Do we need high accuracy data, with its subsequent time and technology requirements? Or is it preferable to get some stable data, which, even not so accurate, but can work satisfactorily for the discussed application and can be acquired in an easier way? Obviously, for our purpose, which is to acquire data for the archeological purpose, the second option was chosen: we used GPS – *Trimble GeoExplorer* and *Leica GS20* for the data capture and its subsequent management and analysis with a GIS. Used method for spatial data acquisition – Differential GPS improves the results of traditional GPS both in real-time and post-process, with no special additional effort. The chosen spatial information system ESRI's ArcGIS environment was the one Archeological Institute works with. The interactivity with GPS and wide range of supported formats predetermines the chosen environment for the purpose of our research.

The main consideration about data processing is on the coordinate system and the file format in which later work will be done. With regard to the coordinate system, it sounds advisable to work in a local system. In this case, the required system is the S-JTSK, the local system for Czech and Slovak Republics, so data should appear referenced into this system. In relation to the file format, as data is going to be used in ArcGIS, ESRI shapefile is the most appropriate one for the purpose of the next research.

Conceptual framework

Conceptual framework of our research is built on a theory of Global Positioning System and Geographic Information Systems integration. Integration of the two technologies is the effective way to fit to the requirement given by the purpose of our research – capture spatial data for spatial analysis within an archeological application. We provide the very basic overview of GPS, particularly Differential GPS (the method used for spatial data acquisition) together with an overview on basic ESRI's ArcGIS concepts, which influenced setting up the scene for spatial data acquisition, processing and later analysis.

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Global Positioning System

The Global Positioning System (GPS) originated in 1973 by developing of the NAVSTAR project for military purposes. This project was managed by the Joint Program Office of the US Air Force Space System Division, from the Department of Defense of the US Government. The main objective of GPS, as the navigation system, is to compute positions in three dimensions, as well as the time offset. It was conceived as the next step to the TRANSIT military system, operational since 1967, to make possible continuous and real time navigation, anywhere and under any meteorological condition. Nowadays, this is the most popular Global Navigation Satellite System, and its popularity is still growing, not only for professionals, but also in our daily lives, due to its high range of serviceability. Four generations of GPS satellites have flown in the constellation: the Block I, the Block II, the Block IIA, and the Block IIR. The next generation of GPS is the so-called Block IIF, scheduled to launch in 2007, and adds some new capabilities to previous ones.

The scheme of Global Positioning System consists of three segments:

- space segment – consisting of the set of GPS satellites,
- control segment – consisting of a master control (Colorado Springs, USA) and five monitor control stations located around the world,
- user segment (a set of field GPS receivers used for navigation, positioning, time dissemination or other research).

GPS can provide to its users: 24-hour, worldwide service, highly accurate, three-dimensional position information, velocity and timing services, accessibility to an unlimited number of global military, civilian, and commercial users. Among the main purposes we can find for GPS, apart from the 3D navigation, there is surveying, geodetic control, and geological studies, time and frequency dissemination control, atmospheric parameters measurements, etc. The scheme of how GPS works consists of five basic points:

1. The principle of GPS is based on a trilateration from satellites.
2. To trilateration, a GPS receiver measures distance from satellites using the travel time of radio signals emitted by satellites.
3. To measure the travel time, GPS needs very accurate timing.
4. Along with the distance, it is necessary to know exactly where the satellites are in space. High accuracy ephemeris and careful monitoring are the clue.
5. Finally it has to be corrected for any delays the signal experiences as it travels through the atmosphere.

The GPS theory is just the theoretical development of those five basic points. As an introductory fact, we could say that the system provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity and time. For this purpose, the receiver needs to analyze simultaneously four GPS satellite signals, so as to get the distance between the receiver and them, as well as the time offset. When we talk about Differential GPS (DGPS), we are adding a new step – correcting the positions (in real-time by radio signal, or in post-process) from the correction terms from a nearby fixed station with well-known coordinates. This has been the selected method for this project.

To use the satellites as a reference for the range measurements we need to know their instantaneous position with high degree of accuracy. Almanacs transmitted from the satellites contain only approximate orbital data parameters for all space vehicles, sent every 12.5 minutes. This information could be enough for a normal positioning, as GPS satellites' orbits, due to their great height, are very well predictable. However, there are some disturbances produced by gravitational pulls from the moon and sun and by the pressure of solar radiation on the satellites.

Measuring distances

Distances between satellites and receivers are calculated by the time delays, so they are not real distances, but **pseudo-distances**. That is why the key to distance measuring is in a perfect time measurement. In fact, the basis of the distance measurement is the well-known equation - Light Speed × Time. The aforementioned solution for a perfect time measurement calculated by time delays is in the so called Pseudo-Random Code (PRC), which is the code assigned to each satellite, consisting on a complicated sequence of "on" and "off" pulses. It is sometimes named Pseudo-Random Noise (PRN), as it is very similar to random electrical noise.

The GPS satellites transmit signals on two carrier frequencies. The L1 carrier is 1575.42 MHz and carries both the navigation message and a pseudo-random code for timing. L2 carrier is 1227.60 MHz and is used for the more precise military pseudo-random code. To measure distances, two different signals have to get correlated, and for this purpose, both the receiver and satellite clocks have to be perfectly synchronized, in order to start this correlation just when the signal from the satellite reaches the receiver. In this way, it is possible to calculate the time delay between both signals, until their respective codes are correlated.

Once known pseudo-distances distances, the basis of trilateration can give us accurate coordinates of the position. Graphically, it means that we know the distances previously calculated by time delays, and from them, we can calculate other values, getting an spheroid equation for each one. Two spheroids define a circular plane, and three-spheroid intersection defines two points. One of those points has no sense, and can be rejected, but a fourth spheroid, apart from rejecting the non-correct point, makes the calculation even more accurate. So, the real position is nothing but spheroid intersection. That means, the more satellite signals are received, the better and more accurate the result will be.

Three are the main error sources for GPS: Noise, Bias and Blunders. The final GPS error will be a combination of those three errors:

1. **Noise** errors are the combined effect of PRN code noise (around 1 meter) and noise within the receiver noise (around 1 meter). They usually combine with bias errors, resulting in typical ranging errors of around 15 m for each satellite used in the position solution.
2. **Bias** errors are the consequence of the following sources: satellite clock errors uncorrected by control segment, ephemeris data errors, tropospheric delays, unmodeled ionosphere delays, and multipath.
3. **Blunders** are not constant errors, and can vary from a great range of values. They can be consequence of:

- control segment mistakes due to computer or human error can cause errors from one meter to hundreds of kilometers.
- user mistakes, including incorrect geodetic datum selection, can cause errors from one to hundreds of meters.
- receiver errors from software or hardware failures can cause blunder errors of any size.

Apart from those GPS errors, there is another source of error that appears in real time, and can be controlled when capturing data. This is the so-called Geometric Dilution of Precision (***GDOP***), which makes, together with the *visibility*, the last source of error. GDOP depends on the geometrical distribution of the satellites used to calculate a position, and means a coefficient that weakens the accuracy as it grows in value. GDOP has four components: Position Dilution of Precision (PDOP), sometimes the Spherical DOP, Horizontal Dilution of Precision (HDOP), Vertical Dilution of Precision (VDOP), Time Dilution of Precision (TDOP).

While each of these GDOP terms can be individually computed, they are formed from covariance, and so are not independent of each other. A high TDOP (time dilution of precision), for example, will cause receiver clock errors, which will eventually result in increased position errors.

Differential GPS

The idea behind differential GPS (DGPS) is to correct bias errors at one location with measured bias errors at a known position (Dominguez, 2002). A reference receiver, or base station, computes corrections for each satellite signal. So, there are two receivers cooperating: one stationary receiver, another one roving around capturing positions. If the exact position of the stationary receiver is known, it is possible to calculate the satellite signal errors it receives, making it possible to apply those individual pseudo-range corrections to each satellite, which can be resent to the rover receiver, so as to correct its position, getting much higher accuracy on measurements. DGPS removes common-mode errors, those errors common to both the reference and remote receivers (not multipath or receiver noise). Errors are more often common when receivers are close together (less than 100 km).

When navigating with DGPS (Fig. 1), differential corrections may be applied in real-time (by radio link) or in post-process (storing them to be applied later in the office). To remove bias errors, differential corrections should be computed at the reference station and applied at the remote receiver at an update rate that is less than the correlation time of Selective Availability (SA). Differential position accuracies of 1 to 10 meters are possible with DGPS based on C/A code Standard Positioning Service (SPS) signals.

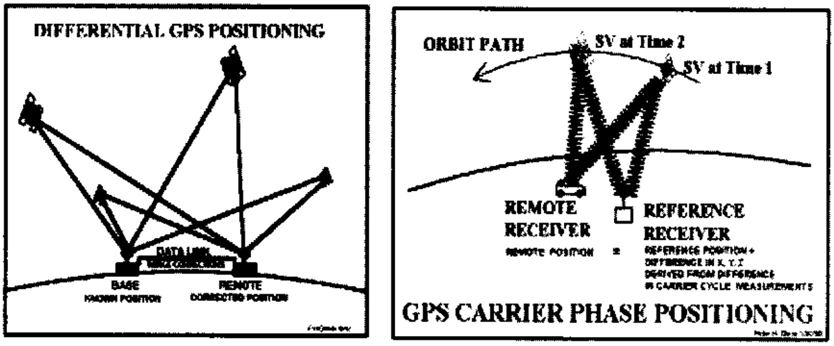

Fig. 1 Differential GPS (Dominguez 2002)

Applications of Spatial Information Systems

The purpose of our project was to acquire spatial data for specific application requirements in order to prepare data for spatial analysis using GIS environment. According to the purpose and the type of spatial analysis, the main applications are as follows (Ritter 2006):

- ***Resource Inventory*** – what objects and object types are available within a given geographic area?
- ***Network Analysis*** – what routes and travel times are available within a given geographic area?
- ***Terrain Analysis*** – examples of information derived from three-dimensional data include degree and direction of slope, analysis of visibility between locations and the generation of maps that show points visible from a given point under specified conditions.
- ***Layer-based Analysis*** – the combined use of the different thematic layers that describe a concrete area, to analyze it as a whole.
- ***Location Analysis*** – getting a list of locations that suit a certain conditions and restrictions, so as to know what is the best location for something, according to the considered criteria.
- ***Spatio-Temporal*** – it is possible even to answer questions about time history of the adjacency of different objects or object types.

The relevance of spatial analysis can be understood from various user-perspectives:

- ***Professionals and Institutions related to geographic sciences*** – cartographers, surveyors, geographers, geologists, archeologists, etc. – those are the main target group of GIS, and they are the ones who must develop this discipline, specially in which concerns to integration with other disciplines like GPS or Remote Sensing.
- ***Other professionals and Institutions*** – the growing demand of sub disciplines like geomarketing for business and commercial affairs, make many other professionals and institutions a suitable target for GIS.
- ***Educational Institutions*** – teachers and students from various study areas can get a great *profit from using GIS as a tool for spatial data processing and analyzing.*
- ***Citizens*** – growing use of GIS for urban planning makes it very important for citizens, enabling the appearance of GIS for public users. Besides, the development of GIS on Personal Digital Assistant (PDA) and portable computer devices can make them very attractive for the majority of our neighbors.

In Archeology terms, GIS can be very useful for:

- **Resource inventory** – to show the different existing features in a certain archeological site,
- **Terrain analysis** – taking into account the locations, geographic characteristics, etc. – it is possible to extract some archeological (prediction, explanation) conclusions
- **Spatio-temporal analysis** – highly important in Archeology, as the purpose of this discipline is to analyze the evolution of our history from current discovery.

Some concepts in ArcGIS

ArcGIS developed by ESRI (*www.esri.com*), has its proper technical terminology to refer to items it uses. There are some ESRI basic must-to-know concepts, as the following:

Layers – define how a set of geographic features will be drawn when they are added to a map.

Coverages – topological format storing geo-objects for complex geoprocessing, building high-quality geographic datasets, and sophisticated spatial analysis. Coverages contain primary (label points, lines and polygons), composite (built from primary feature types), and secondary feature types (tics, links, and annotation).

Shapefiles – stores non-topological geometry and attribute information for the spatial features in a dataset. The geometry for a feature is stored as a shape comprising a set of vector coordinates. Because shapefiles do not have the processing overhead of a topological data structure, they have advantages over other data sources such as faster drawing speed and edit ability. Shapefiles handle single features that overlap or are discontinuous. Shapefiles can support point, line, and area features. Attributes are held in a database format file. Each attribute record has a one-to-one relationship with the associated shape record. An ESRI shapefile consists of a main (direct access, variable-record-length) file, an index file (each record contains the offset of the corresponding main file record from the beginning of the main file), and a database table (contains feature attributes with one record per feature). Attribute records in the database file must be in the same order as records in the main file.

Geodatabase – a common framework shared by all ArcGIS products and applications. It stores each feature as a row in a table. The vector shape of the feature is stored in the table's shape field, with the feature attributes in other fields. Each table stores a feature class. In addition to features, geodatabases can also store raster, data tables, and references to other tables. Geodatabases are repositories that can hold all spatial data in one location. They are similar to adding coverages, shapefiles, and rasters into a Database Management System (DBMS). Advantages of using a geodatabase concept are that features in geodatabases can have built-in behavior; geodatabase features are completely stored in a single database; and large geodatabase feature classes can be stored seamlessly, not tiled. In addition to generic features (points, lines and areas, as well as multipoints, network junctions and network edges) they allow the creation of custom features, which can better represent real-world objects. So, the number of potential feature classes is unlimited. All point, line, and polygon feature class can:be multipartite, have *x,y; x,y,z*; or *x,y,z,m* coordinates, be stored as continuous layers instead of tiled.

Building a Geodatabase requires an abstraction process, to fit the complexity of the real world into a simplified representation that can be interpretable in a computer language. The first step of this process is the conception of the database structure, which is normally represented in thematic layers, according to the area they inform about. For example, a layer can represent roads, rivers, paths, populated places, lakes, etc. Anyway, it is not so simple, as those layers need to adequate to the language the machine can understand. This requires the geographic features to appear as one of the basic shapes, that means, points, lines or polygons. Besides, there are some relations among geographic features that cannot be ignored by the system. The mathematic-logic way to define those geographic relations is called topology.

GIS/GPS Integration

There are three basic ways that GPS technology can interact with or be integrated into GIS. The level of integration associated with these vary from a 'disparate' connection, whereby data is transferred between a GPS system and a GIS system, through to a very *tight* level of integration, whereby GPS technology is totally embedded directly within GIS application software. GIS/GPS integration can be categorized into the following three categories (Harrington 2000):

- ***Data-focused integration*** – the most popular integration method nowadays, and consists on a complete and self-contained GPS system: portable GPS device, which is capable of both capturing and storing data in the field for later transferring, processing and spatial analysis. Nowadays, this is not a one-way model anymore, as it is possible to find GPS devices capable of updating data uploaded from a GIS, ensuring the maintenance of geographic data. So, more than an integration method, this could be called ***interaction***.

- ***Position-focused integration*** – this had been the most common integration method until a few years ago, and consists of a complete GPS system with an independent field device, whose only function is to compute the positions obtained with GPS, which have been previously transmitted to this device in an ASCII-based format e.g.: NMEA-0183 protocol. It is possible to later transfer this data to a GIS.
- ***Technology-focused integration*** – this method implements it in the sense that it is not necessary to have a separate field device to compute positions, as a third party application permits the control of the GPS receiver, and the communication-flow between the GPS receiver and this application is two-way. It is possible, of course, to transfer this data into a GIS, but as in the previous case, this is not the main purpose of this integration method.

The appropriateness of each method is dependent upon the requirements that a user has for field-based operations, the level of dependence the user has on GPS and, to a large extent, the availability of a complete system to meet the specific needs that the user has for a system. For the purpose of our research the 'data-focused integration' was chosen.

Spatial data acquisition for processing in ArcGIS environment

The purpose of the field work is to acquire some data from some archaeological interest areas, The considered areas are located in South-West of Slovakia, particularly in Nitra region. First of the data files we intend to get describes an old fortress, located near the *Topoľčiansky hrad* and the village of *Podhradie* in *Topoľčany* district. Data file received the name of "UHRAD", as it is the name of the hill in which top it is located. The second data file received the name of "ZOBOR", which is the name of the hill where we can find the rests of an old wall, and is in the surroundings of the city of *Nitra*. The third one will be named "KLATOVA", and it is an old pathway and a nearby fortress, located near the village of *Klátova Nová Ves*. In three cases, captured data will be that which describes the shape of the considered archaeological settlement or is presumably interesting for archaeological purposes, and this includes pathways, walls, entrance-doors, channels, crossroads, etc. The concept of the data acquisition and processing is sketched on a Fig. 2.

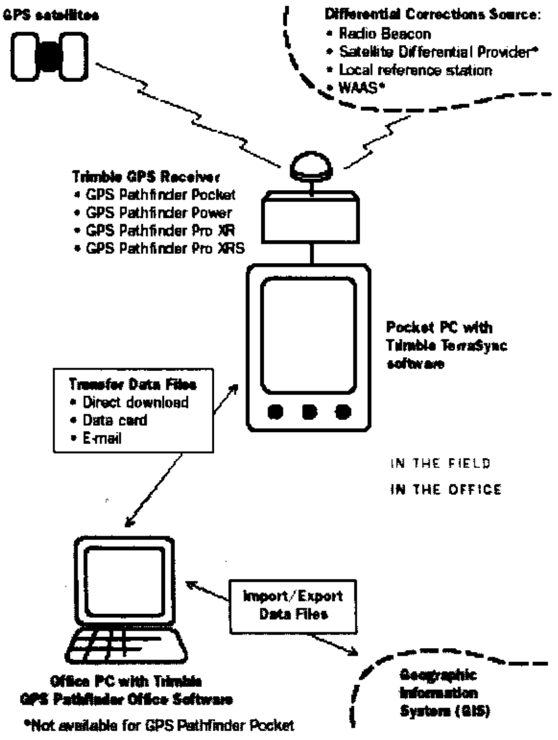

Fig. 2 Scheme of data acquisition and processing

After doing the survey, there is expected to get the aforementioned three data files, showing the reality of those settlements with quite a good accuracy and correctly georeferenced, so as to work on them together with both ancient and current topographical maps of the area.

It is very common in those kind of works related to archaeology, to work in forests or similar places with heavy vegetation. That makes difficult, sometimes, to get a good signal from the satellites, in case it is not blocked. For this reason, it is very important to control the GPS constellation status at any moment, so as to avoid bad quality data, which can spoil the work. The accuracy can be easily improved using *WAAS* (Wide Area Augmentation System) or *EGNOS* (European Geostationary Navigation Overlay System) corrections. This is especially useful in this kind of works, making possible to work with accuracies below 1 m.

Processing of the data for spatial data analysis in ArcGIS 9.0 environment

Once the data capture is finished, the next step is to prepare and process this data in order to later use it in ArcGIS environment. When processing data from GPS to GIS, there are some tasks to do. First of all, data has to be transferred, using the corresponding software in each case. This data has to be, if possible, differentially corrected, so as to remove some errors from different sources, such as small satellite clocks errors, orbit errors, atmospheric noise or multipath errors. When data is transferred and differentially corrected, it is the time to decide on file type. The chosen coordinate system depends on the purpose for which the data has been captured, so it can be a geodetic system, a local system, etc. The file type depends on the GIS it will be further processed in. For ArcGIS, the most appropriate file type is the shapefile, so the purpose of the processing is to get a set of shapefiles, containing all the information captured in field. It is advisable, in any case, to export it in some other formats, just in case there is some trouble with the generated shapefile, especially concerning on coordinates, as it is automatically generated. This trouble is normal when talking about S-JTSK coordinates, as they are negative numbers – due to the orientation of the coordinate axis in a system used by computer, and it is not strange that they are exported with positive values, so the image is translated and rotated upside down. The spatial data was transformed to S-JTSK using a software for coordinate transformation.

It is possible that, when exporting data, some trouble can occur. This is a summary of the two main troubles in this work. As mentioned before, when using *GPS Pathfinder Office* (for processing spatial data acquired by *Trimble GeoExplorer*), it is quite common that the negative coordinates (as they are in S-JTSK) are exported as positive, making the image appear moved and rotated upside down, so it cannot suit any georeferenced map. When using *Leica Geo Office*, we can also have problem when exporting data in a local coordinate system like S-JTSK.

The process we have used for solving those two setbacks has been quite similar; using ASCII exportation in order to, with the help of other softwares (which enforces the perception of interoperability with spatial data), convert data into correct shapefiles. We solved the problem with converting S-JTSK coordinates into negative by using both *Microsoft Excel* spreadsheet and *MapInfo* adjust the data exported in an ASCII format from GPS *Pathfinder Office*.

Working with ArcGIS

By the moment, we have all the needed shapefiles, and prepared to be used in ArcGIS environment. Those files can be opened in *ArcMap*, which is the application for viewing, editing and analyzing geographical data, or by using *ArcCatalog*, the application for organizing geographic data, finding those files in the file explorer, and dragging them to the ArcMap screen. Using ArcCatalog, it is possible to store the common data into a Geodatabase, so as to have it better organized.

When data is displayed in the ArcMap window, we can start operating with that information or doing some analysis. For this purpose, there is another application named *ArcToolbox*, which contains most of the tools for geoprocessing, allowing the creation of new ones by programming some scripts. Those functions permit operating with the data for different purposes, as well as doing a wide range of analysis with it. For archaeological purposes, it sounds very interesting some of those analysis capabilities – it is relatively easy to get some slope or inter-visibility maps, as well as other tasks like working together with ancient maps or getting some 3D visualizations, using *ArcScene*, which is the application for working in three dimensions.

Conclusion

After data acquisition and processing, three different shapefiles have been obtained, as it was intended, receiving "UHRAD", "ZOBOR" and "KLATOVA" names, according to its location. Those shapefiles contain almost all of the archeologically interesting features located in those sites, including old pathways, crossroads, walls, channels, entrance doors, or other current features like geodetic vertex or paths, and for this reason, are very useful for showing the current appearance of those places, that could hardly be represented by other methods, as they are not easily recognized from an aerial photo, and require the in situ surveying to avoid mistakes.

In accuracy terms, we considered two aspects: accuracy and functionality, i.e.: price and speed. As a result, the acquired spatial data suit satisfactorily the requirements for the intended purposes – stable data, which even not highly accurate, but can be used for archeological application purpose (we are discussing spatial accuracy in meters).

As it has been said before, this data can now be the basis for doing many different analysis and visualizations that can be considered as interesting by the Archaeological Institute, due to archaeological purposes. Analysis of inter-visibility between fortresses, slope or aspect studies, 3D visualization and animation of the reality or ancient map georeferencing by linking to field-captured data, are among the most common tasks that, in ArcGIS environment, can be done (and in fact, will be done) with the achieved data. One of the possible applications using spatial data acquired and processed as a result of our research is discussed in the article by (Fencík and Urbina 2006).

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Resumé

Zber priestorových dát pre potreby archoelógie

Príspevok sa zaoberá integráciou Globálneho systému určovania polohy (GPS) a nástrojov Geografických informačných systémov (GIS) s cieľom zefektívniť zber a spracovanie priestorových dát vzhľadom na pomer „presnosť a efektívnosť", resp. „cena a rýchlosť". Príspevok je výsledkom projektu, ktorý bol riešený v spolupráci s Archeologickým ústavom Slovenskej akadémie vied (AU SAV) a spracovaný v bakalárskej práci (Vázquez 2006) na Katedre geodetických základov, Stavebnej fakulty Slovenskej technickej univerzity v Bratislave. GU SAV definoval požiadavky na zber priestorových dát (formát .shp) v prostredí GIS (ArcGIS 9.0 firmy ESRI). Príspevok sa zaoberá definíciou teoretických základov GPS, DGPS aplikácií GIS a integrácie GPS a GIS s prihliadnutím na technologické možnosti a zvolenú aplikáciu. V rámci experimentu bol navrhnutý postup zberu a spracovania dát a priestorových analýz pre potreby archeológie v prostredí GIS. V závere sa analyzujú vzniknuté problémy pri spracovaní meraných dát a ich konverzie do národného súradnicového systému (S-JTSK).Výsledok projektu bol ďalej spracovaný v práci (Velasco 2006), o ktorom referuje príspevok (Fencík a Urbina 2006)

Obr. 1 Diferenciálne GPS (Dominguez 2002)
Obr. 2 Schéma zberu a spracovania dát

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