GPS AND GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT

In the recent years, two developments emerged very fast from the beginnings of their pioneer phases to every day applications: the NAVSTAR Global Positioning System (GPS) as tool for navigation and positioning and Geographic Information Systems (GIS) as computerized databases to update, manage, analyze and present geometric and semantic data. The link of these two systems leads to further synergy effects in the geosciences. Typical examples are real time data base updates in the field, or the optimization of the traffic flow of cars and trucks, to name only two but quite different applications.

The paper first introduces both systems separately and shows the state-of-the-art for each one. As far as GIS is concerned the platforms in use are Personal Computers, graphic workstations and mainframe computers. The progress made in the last years concentrated not onto hardware aspects but software. Today it is generally acknowledged that database standards have to be fulfilled by GIS products.

For GPS receivers a similar progress was reached. Also here scientific interests concentrated more on software developments to detect cycle slips or to determine the carrier phase cycle ambiguities, rather than approving the hardware. Today, the hardware and software components of GPS are now very robust and easy to handle. With differential GPS carrier phase observations, positioning became feasible with cm accuracy. These developments distinguish GPS measurements from classical data acquisition techniques by higher productivity, improved project management and expanded business opportunities.

The second part of the paper deals with complementary features of both systems. By the synergy effect resulting from the link of GPS and GIS new applications will grow dependent on the integration stage of both systems.

1. INTRODUCTION

Positioning and mapping are two major tasks to be fulfilled in many branches not only of the geosciences but also in civil engineering, urban and regional planning, traffic management, sales and many others. Therefore every step towards automation in these two fundamental goals leads to a substantial reduction of man power to be used in further, more intelligent and complex tasks of these disciplines.

Positioning of one or some points belonging to a spatial network without any terrestrial ground control is solved today very efficiently by the NAVSTAR Global Positioning System (GPS). The main benefits of GPS are as follows:

- higher productivity by putting into action smaller crews, higher accuracy, shorter station occupation, and less weather dependence,
- improved project management by more reliable project planning and cost estimating,
- expanded business opportunities by using GPS in inaccessible areas, take on of new kinds of projects, and the combination with Geographic Information Systems.

Therefore, there is no doubt that GPS is the most versatile data acquisition technique we ever used. As known to the GPS community, the two modes' static and kinematic provide for point positioning and to track a line. Consequently, GPS serves as a *'real world digitizer'* . This makes data acquisition and data update so simple and powerful - the link of GPS with GIS is self-evident.

Geographic Information Systems collect all spatial data independent of the digitizer either in the real world or a model (map) of the real world for further data management, data analyses, and data mapping (presentations). As far as digitizing is concerned the GIS accepts all sources of data and all types of digitizer. The digitizer will therefore be: a GPS receiver and a photogrammetric stereoplotter (analytical or digital) delivering three-dimensional coordinates, respectively, and the digitizing table that comes out with two-dimensional coordinates. When using the GPS receiver as digitizing cursor the surface of the earth is serving as digitizing table. It is like the case of a photogrammetric stereoplotter except the ' stereo model ' used is the real world. The mapping task is therefore simply to put the coordinates and its relation between to paper or screen - the presentation software of the GIS solves this task satisfactorily according to different views of the real world objects.

2. GEOGRAPHIC INFORMATION SYSTEMS - STATE-OF-THE-ART

With the introduction of geographic information systems (GIS) (TOMLINSON [1972], TOMLINSON [1984]) in the sixties the first computerized maps of small scale were handled in the Canadian Geographical Information System (CGIS), which was set up for the *"Agricultural Rehabilitation and Development Program"* of Canada. Right after introduction of GIS the pioneer phase started from 1965/1970-1980/1985. The GIS product phase was opened in 1980/1985 and is not yet finished - there is a huge market predicted for such products with an annual increase of 20-30%. Therefore not only workstation GIS products would profit from this remarkable figure but also PC based products share meanwhile the general GIS market. Since 1990 a more realistic proof of GIS is accomplished - it is expected that a broad spectrum of applications will contribute to an increase in product standardization and efficiency. Consequently, a phase of acceptance and application can be stated from 1990.

2.1 Definitions and general remarks

GIS is a computer based technology and is part of and depending on the progress in information technology (IT). The resulting consequences for GIS from the overwhelming speed of progress in IT can be stated by the following conclusions:

- hardware development has its own dynamics and cannot be influenced by the GIS community. Today 32 bit technology is in use - tomorrow 64 bit processors will improve computation speed considerably,
- software and firmware should integrate standards as much as possible: UNIX and Windows NT as operation system, Relational Database Management Systems (RDBMS) for data handling and data queries, TCP/IP as network protocol within UNIX,
- graphical user interfaces substitute (GUI) character user interfaces (CUI), for example OSF/Motif with X Window under UNIX.

As shown by the introductory remarks geographic information systems of today are on the one hand in their product phase, and on the other hand in their acceptance and application phase. Therefore, professional solutions can already be given using GIS products presently on the market. Two definitions of GIS have found broad acceptance not only by the scientific community but also by practitioners that either characterizes GIS according to four pillars. The first definition clearly states the physical components as given by

Definition 2.1: *A geographic information system is a computer based system that consists of hardware, software, data and the user interface.*

It is interesting to see the life cycles of the physical components that are as follows: 3-5 years for hardware, 7-15 years for software, and 30-100 years for data. Besides these figures the costs of investment can be estimated by a relation which will only show the multiple proportions of the different components

Hardware:Software:Data = 1:10:100

The second definition is more specific than the first one, because the tasks a GIS has to fulfill are given explicitly. Therefore it gives much better insights in the functions of GIS what is often wanted to explain why this technology will be used.

Definition 2.2: *A geographic information system is a computer based system for spatial data acquisition and updating, data management and retrieval, data analysis and synthesis, data representation in either graphical and alphanumeric form.*

Further definitions are given in VAN OOSTEROM [1990].

The spatial data types a GIS can handle are of different structures according their geometry and semantic (thematic) behavior. As far as geometry is concerned we differentiate in vector and raster data depending mostly on the scale of representation. For large scale applications the spatial data is of *vectorial type*, which means a polygon is represented by its nodes and edges. If the polygon is closed, the area in between the nodes and edges is called region. To be more specific an open polygon has a starting and end node - between the nodes are points. The relations between the nodes and points, edges and regions form the topological model. Therefore spatial data have two components: geometry (position, size, shape) and topology (relations is-a, is-part-of).

Geometric data have a quantitative nature and are used to represent coordinates, line equations, etc. Basically, there are two different formats: raster and vector format. The two- dimensional vector format has three primitives: nodes and points, respectively, lines and polylines, and polygons. Of course, other primitives are possible such as splines and circles, but this is not the general case for GIS.

Topological data describe the relationships between the geometric data. Several types of relationships exist: connectivity, adjacency, and inclusion. Typical examples of topological queries are: which areas are neighbors of each other (adjacency), which polylines are connected and form a network of roads (connectivity), and which cities lie in a certain country (inclusion). Topological data are not always stored explicitly, because they can be derived from geometric data.

Semantic (thematic) data are alphanumeric data (attributes) related to geographic entities; e.g. the name and number of inhabitants of a city. Semantic data may be any kind of data that can be found in non-graphical databases, e.g. strings, integers, and reals. In summary, the GIS data are depicted in figure 1.

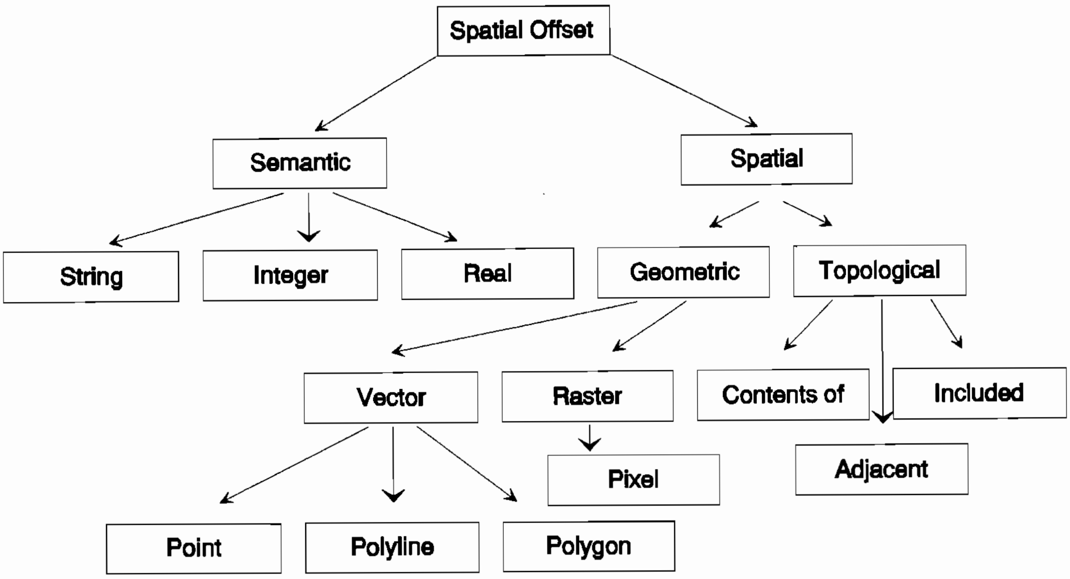


Fig. 1 Link of spatial data types

2.2 GIS-Functions

As indicated by definition 2.2 a GIS is more than a database management system in which different types of data must be incorporated. The general architecture of a GIS is composed of the four components data input and verification, data storage and retrieval, data transformation and manipulation, and data output and presentation. The link of these components characterize the GIS - depending on the efficiency of every component the GIS is more efficient and capable or not.

1. Data input and verification: Geographic information systems accept many possible sources for data input. The classical sources for geometric data are field surveys, photogrammetry, and cartometry. Their accuracy will become less in the same consecutive sequence, also the costs for data capture decrease in the same manner. The data can be entered and verified by using one or more of the available tools: tacheometers, electronic theodolites, GPS receivers, analytical and digital stereo plotters, scanners and digitizers, on-screen digitizing, etc. Format conversion, error detection and editing, topology setup and reconstruction, aggregation and registration are the main substantives used during this GIS section. Alphanumeric data come in via interactive data input or by using any electronic storage and transportation media such as tapes, diskettes, networks. As indicated before the costs of data capture are usually high. The verification of GIS data in the field is not yet solved on-line. But also here, as can be seen in section 3, some progress is to be expected.

2. Data storage and retrieval: The user captures data in the field - every discipline has its own point of view of a spatial object located on top of the earth surface. This results in the external data model which has to be transformed to a more compatible and general one than before. The main aspect is here the definition of a conceptual data model and its mapping in the database management system. Traditional database systems support requirements of multiple users, data retrieval by interactive queries, non-redundancy of data, data security and integrity. Today, most of GIS products integrate for this task relational database technology with its powerful query languages (SQL). Besides non-standard databases for geometric data, there is a trend to store geometric and semantic data in RDBMS. However, the relational database must be extended to support geometric and topological aspects.

3. Data transformation and analysis: The real power of a GIS is given by its analysis capability. This section includes geometric calculations such as buffering, intersections, network analysis. But also further tools from statistics, geostatistics complement the spectrum of data transformation to derive new data and information of the primary data.

4. Data output and presentation: This task is performed not only on the screen but by using several peripheral devices such as plotters and printers. The range is big between low cost and high cost systems although the increase in quality is hardly to detect. Quite a number of different standard software packages are used in this GIS section: GKS, PHIGS, PostScript to name some data output formats that provide for compatible data exchange between different platforms.

3. GPS - STATE OF THE ART

On June 27, 1977 the first NAVSTAR-GPS satellite was launched. After that date further satellites completed the planned configuration of 24 satellites and opened the pioneer phase in real-time, high-precision positioning. The setup of the GPS network of satellites was carried out in three phases: the test phase (1974-1979), the development phase (1979-1985) and the maturation phase (1985-1993) where the satellite constellation has been built up to its full completion (BAUER [1992]). Today with 23 Block II and 3 Block I satellites in orbit the GPS system has been declared fully operational, allowing for weather, time and location independent positioning on the earth surface. Together with the deployment of the global positioning system, research on user hardware and software has pushed the limits of positioning accuracy to a few cm in most applications.

In the context with geographic information system GPS is mainly used for the geo-referencing (geometric relation of objects) of objects which are stored in the GIS. As GIS requires a fast and cost-effective data acquisition, particularly kinematic applications of GPS are of special importance. The state-of-the-art of GPS hard- and software for GIS applications can be characterized by:

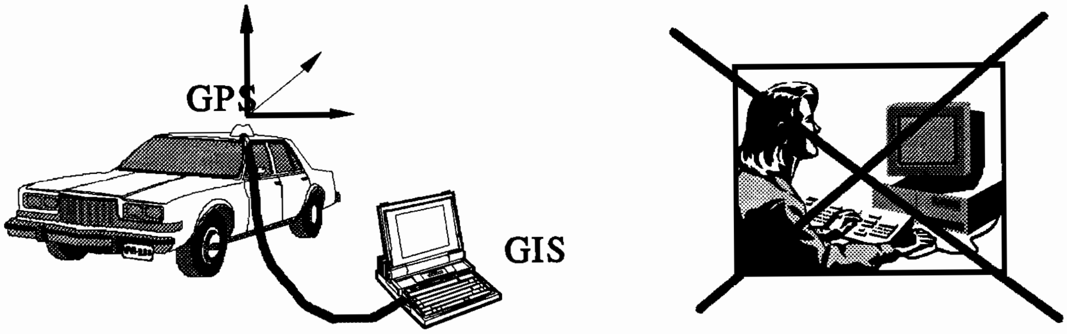
- *GPS-PC cards*: allows a PC to be the host for the GIS and GPS, and therefore simplifies the integration of both systems
- *Handheld GPS Receivers:* makes the GIS data acquisition simple and implies no technical constraints
- *Precise C/A Code Receivers:* highly accurate, cheap positioning capabilities
- *Y-Code Cross Correlation Receivers:* allow for highly precise dual frequency measurements and can provide accurate phase solutions
- *GPS Receivers with dedicated RAM for GIS attribute sampling:* allows for GIS data acquisition with GPS hardware
- *Ambiguity Resolution on the Fly:* software method for precise kinematic, real-time carrier phase solutions (~ 2-3 cm)
- *GPS-GIS integration software:* commercially available GIS software that allows for real-time GPS receiver input
- *Attitude determination with GPS:* allows the full exterior orientation of sensor systems for GIS data acquisition

As a consequence of these technical developments from the GPS sector, georeferencing of GIS objects is simplified by a large amount. As it will be presented in the next chapter GPS allows a highly precise, rapid and cost-effective acquisition of geometric data.

4. APPLICATIONS OF GPS FOR GIS DATA ACQUISITION

The impact of GPS on GIS data acquisition techniques and methods is extensive. As it has been already mentioned one of the most important applications of GPS in the context of geographic information systems is the determination of positions of GIS objects for their referencing with respect to a known coordinate system. In principle there are two approaches that can be used when GPS and GIS are combined for georeferenced data acquisition. The users of GPS and GIS distinguish between *direct-* and *indirect linking* of GPS and GIS (NAVTECH 1990).

GPS and GIS are indirectly linked, if the data acquisition with the GPS receiver and other recording devices is not directly connected to the GIS. Typically a user collects the geometric and semantic data and stores it onto the appropriate devices (e.g. Data Sheets, GPS receiver RAM, voice recording). After the data acquisition in the field, the data is brought back to the office for evaluation. The post-processing of the data usually allows for higher geometrical accuracies, but as a major drawback the completeness and adequacy of the acquired data can only be controlled after the actual data collection. On the opposite direct-linked GPS and GIS give the opportunity to control the entire data flow directly as the data is acquired. The GPS receiver delivers its recorded data to the GIS host computer in real-time, where the GPS position information is immediately transferred to the GIS data format. The user is able to assess the results of the data-



- GIS on board
- attribute sampling directly into GIS
- graphical control of data
- flexible data aquisition
- no work with data conversion

Fig. 2 Direct linking of GPS and GIS

acquisition instantly in the field, with the analysis and visualization functions of the GIS (see Fig. 2). Using these aids, this method allows a very flexible data-acquisition in arbitrary scales and data density. In principle the direct-linking of GPS and GIS may be compared with a 3-D digitizer on the earth's surfaces said before.

In the remainder of this chapter some typical applications of GPS for GIS data acquisition will be presented. Special attention will be paid to two methods for GIS data acquisition which have been developed at the Institute for Photogrammetry of Stuttgart University.

4.1 Applications of GPS in Photogrammetry for GIS Data Acquisition

As photogrammetry is one of the most important methods for the data acquisition for geographic information systems, the key role of GPS for photogrammetry will be discussed separately in this chapter. With the aid of GPS, photogrammetry has evolved to a fast and cost effective tool for data acquisition in mapping, digital terrain models (DTM) and GIS. The promising potential of differential satellite navigation for photogrammetric applications has been discovered early in the development stage of GPS. Nowadays, GPS is an important instrument for many photogrammetrists and it can be used advantageously in several photogrammetric areas.

In principle, there are two major tasks GPS has to solve in photogrammetry. The first one is the survey aircraft navigation. Up to the evolution of GPS the photogrammetrists were navigating visually, which was very difficult in regions with low contrast, or without any significant topographic features. Further there was no control whether the taken images cover the entire area of interest, and whether the images have the required forward- and endlap. Today, the real-time capabilities of GPS make visual navigation unnecessary in most photo flights. A more detailed description of a survey aircraft navigation package can be found for example in BECKER [1993].

More demanding is the second task in which GPS is used. An aim of photogrammetrists has always been to measure directly the parameters of exterior orientation of photogrammetric sensors. To determine these parameters is one of the basic problems of nearly all photogrammetric work. The evaluation of data from photogrammetric sensors require the knowledge of the 6 parameters $X_0, Y_0, Z_0, \omega, \varphi, \kappa$ of exterior orientation. The accuracy which is needed for these parameters varies with respect to the specific application. Depending on the map scale or the type of photogrammetric sensor used, the needed position accuracy for X_0, Y_0, Z_0 can range from 0.05 m up to 10 m and the attitude accuracy for ω, φ, κ may range from 0.1 mrad to 17 mrad. With differential GPS it is now possible to determine the projection center coordinates (X_0, Y_0, Z_0) directly with sufficient accuracy. Recent developments of multi antennae GPS receivers, which allow to measure attitude, will make it possible to determine the rotation angles (ω, φ, κ) at least with 2-5 mrad accuracy. Although this accuracy is not sufficient for most photogrammetric applications, the attitudes can be used as approximate information to simplify the automatization of many processes in the evaluation of photogrammetric images (e.g. digital image processing algorithms).

For obvious reasons the integration of GPS and image data is the principal problem in photogrammetric GPS applications. Several research groups developed approaches to determine the parameters of exterior orientation for aerial images using DGPS observations (CANNON [1991], BAUSTERT/HEIN/ LANDAU [1989], FRIESS [1990]).

The main differences between the approaches of these groups is the way how the carrier phase cycle ambiguities are determined, and how potential errors in the set of cycle ambiguities are treated. Although the statistical and mathematical methods for the ambiguity resolution on the fly are more and more sophisticated, it can not be guaranteed that the correct set of cycle ambiguities can be estimated in 100% of all cases. Therefore an approach to control the error propagation of incorrect cycle ambiguities is needed. The effects of using incorrect cycle ambiguities for positioning applications are reported e.g. in SCHADE [1992]. The way photogrammetrists are dealing with this problem are manifold. Often this problem is just ignored. Hence, the survey flight has to be flown carefully with flat turns, so that at least 4 satellites (with reasonable observation geometry) remain trackable during the entire mission. The drawbacks of this method are apparent: provided only 3 satellites are visible for a short period of time, the entire flight has to be repeated. A further way to reacquire the cycle ambiguities is to use additional sensors like an INS in an integrated sensor system.

The approach, for the determination of cycle ambiguities, which was designed at the Institute for Photogrammetry (e.g. FRIESS [1991], ACKERMANN / SCHADE [1993]) is also based on an additional sensor. This method models the systematic error effects of incorrect cycle ambiguities in a combined adjustment of photogrammetric and GPS data. The combination of GPS and image data makes it possible to control the error propagation of incorrect ambiguities by estimating 6 additional unknowns (XYZ-Offsets and XYZ-Drifts) for each photogrammetric strip. Although many additional unknowns have to be estimated in the combined block adjustment, the photogrammetric block is stabilized via the GPS observations. It is even possible to reduce the number of ground control points to a minimum of 4 points in the block corners, if two additional cross strips are flown. The cross strips have to be flown to avoid singularities in the normal equation matrix for the estimation of the drift parameters. More details on the mathematical background of this integration approach can be found in FRIESS [1990].

The advantages of the presented approach are indisputable. GPS and image data are combined with each other, to find an optimal solution for the orientation (position and attitude) of the aerial camera, at the time of exposure. The benefits of the integration of the two sensor types are extensive:

- The costs for ground control may be minimized
- The maintenance of ground control points (signalization) is minimized
- No care has to be taken in the flight maneuvers, as long as the GPS observations are continuous within the flight strips.
- No initial baseline has to be determined, due to the fact that the ambiguities are estimated on the fly .

To demonstrate the potential of the synergism of DGPS and image data several testflights and pilot projects were carried out. Typical examples for the successful combination are the testflights: Flevoland [1988], Glandorf [1991], Nepal [1992], Cologne[1992]. The results from these test flights are for example reported in ACKERMANN/SCHADE [1993]. There is no doubt that ambiguity resolution on the fly might make the estimation of additional parameters unnecessary. Nevertheless the presented approach still gives a good control whether the correct ambiguities are estimated or not.

In the near future, investigations on the potential of GPS multi-antennae systems will be of special interest for the photogrammetric user. Besides the positioning aspect, the determination of the remaining three parameters of exterior orientation will be a step forward in photogrammetric mapping applications. Potential applications for the full exterior orientation of aerial images with GPS are: orthophoto production, orientation of non-imaging sensors, approximate values for image processing algorithms and a simplification of the aerial triangulation by a reduction of tie points.

A first test with a GPS multi-antennae system has been flown. The results of an accuracy analysis and first applications of a combined position and attitude system with GPS in photogrammetry are presented in SCHADE ET AL. [1993].

4.2 Differential GPS and Laser Profiling for DTM determination

Within geographic information systems digital terrain or CAD models serve as reference surfaces for the 3-D representation of the geometric form and extend of GIS objects. However, the terrestrial acquisition of high quality DTM's has been expensive and time-consuming. With the advent of GPS a new system for the automatic derivation of DTM's was composed and investigated at the Institute for Photogrammetry within the special research group 228 "High Precision Navigation". Within the airborne laser profiling system (ALPS) DGPS, inertial navigation (INS), a video camera and a laser profiler are combined. The strength of the system is to derive digital terrain models in cases, where conventional photogrammetry has problems or totally fails. A sketch of the integrated sensor system can be seen in figure 3. In areas with vegetation cover or with low contrast (e.g. woods, coastal areas, ice-fields, deserts) the laser is capable of penetrating to the earths surface. The laser profiler measures the distance between the aircraft and the earths surface, and with GPS the positions of the aircraft are determined at the time of the laser measurements. The INS is needed to get the orientation (rotation angles) of the aircraft with respect to a known coordinate system. From the measurements of the laser, GPS and INS the coordinates of terrain points can be computed. Each terrain point is determined, from the geometrical point of view, by a vector from the airplane to the laser reflection point. The origin of the vector is measured with GPS, the length and the direction of the vector are determined by the laser and the INS. The integration of the measurement data requires the consideration of various off-sets as well as directional and time references. From the computed terrain points a digital terrain model can be derived with standard interpolation algorithms.

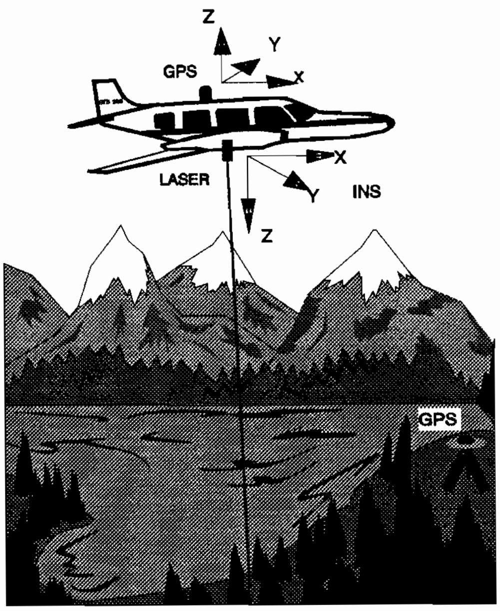


Fig. 3 Principle of the ALPS

The CCD video camera has been added to the system for an automatic, visual control of the error propagation of the entire sensor system. The basic principle for the error control is to find topographic features which can also be uniquely identified in the laser profile. Such a typical feature would be a house or a river. With simple image processing algorithms the offset of the laser profile with respect to the ground truth can be automatically computed. The offset vectors are used as calibration values for the time span until a next topographical control is possible. This way of controlling the error propagation of the sensor system can be compared to the typical error distribution in a surveyors levelling. As this post-mission flight calibration is the only way to control the error behavior of the entire system, some practical limitations do apply. Serious GPS signal interruptions should be avoided as the INS drifts might make it impossible to re-acquire the correct set of GPS carrier phase cycle ambiguities. On the other hand it has to be mentioned that improved theoretical and algorithmic concepts for the ambiguity resolution on the fly and the better satellite constellation can reduce these stringent requirements. The accuracy of the sensor system was determined in several test-flights by independent photogrammetric control measurements. Further the final DTM was compared to the DTM of the federal state survey department which was measured with terrestrial tacheometry. The r.m.s. values of the differences between the control measurements and the ALPS show the high accuracy potential (DTM accuracy 3-5 dm) of airborne laser profiling.

The sensor system which is introduced here, was tested in several empirical test flights in cooperation with the Institute for Flight Guidance in Braunschweig. The results of these test flights confirmed, that the system can operate successfully under typical conditions (ACKERMANN/LINDENBERGER/SCHADE [1992]).

4.3 Other Examples

The applications of combined GPS and GIS data-acquisition are numerous. Only a small extract of all potential applications of GPS for the georeferencing of GIS data can be presented in the scope of this paper. Typical examples would be:

(1) Highway inventory systems: data on the surrounding of roads (traffic signs, houses, trees), its construction state and things like crossings and bridges is required for planning purposes. The data acquisition is done with a vehicle equipped with a GPS receiver for the determination of the road-course and -extend. The attribute data is sampled either with time synchronized voice recording, which has to be post-processed, or the data is entered directly into the GIS when the vehicle is driving along the street.

(2) GPS-GIS for forestry: for planning purposes the type, the size, and the health state of specific trees or tree plantings have to be known. For the geometric data acquisition a backpack GPS receiver is used and the attribute data is stored in the receiver internal RAM.

(3) GPS-GIS for hydrographic surveying: For waterway charting a high precision underwater digital terrain model is required. For the acquisition of the DTM an integrated sensor system has been designed which consists mainly of a GPS receiver and a sonar. The GPS receiver is used for the positioning and the sonar for the depth measurements. Together the two systems deliver the complete geometric relations for the computation of the underwater DTM.

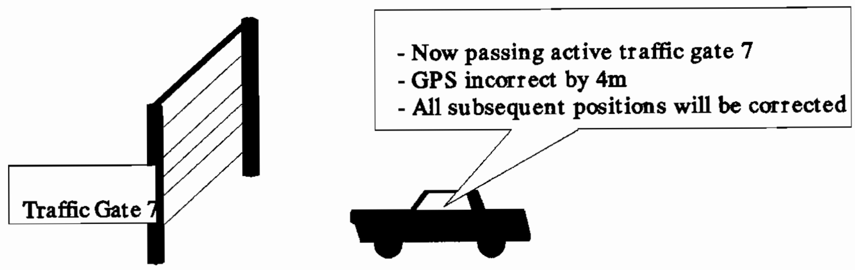
Besides the mentioned applications for integrated GPS-GIS data acquisition many others can be thought of and the authors believe that the huge potential of GPS and GIS for data acquisition will generate an immense number of new applications over the next decade.

5. APPLICATIONS OF INTEGRATED GPS-GIS

Not only data can be acquired with an integrated GPS-GIS system. It is clear that the combination of real-time positioning and existing data sets may be used advantageously in a lot of engineering tasks. The most apparent applications are navigation and vehicle guidance. Obviously, GPS is the primary source for the observation of the vehicle motion. It is more the question which role the GIS plays within the navigation system. Conventionally, the GIS provides the user with information about optimal routing or current traffic information. In principle, the GIS aids the user in making decisions but it does not interact in the position computations. Here, the GIS can be thought of a *non-active sensor* of the navigation system. On the other hand the GIS is carrying, on its data, inherent geometric information which can be used for example for the correction of systematic GPS errors to increase the entire systems accuracy. A typical example would be that systematic GPS errors are so large that the navigation system indicates that a car is off the road. The GIS could, in this case, control and correct the cross-track error of the navigation system. Here, the GIS would interact in the position computations as the systematic GPS errors are corrected, hence, one could speak of GIS as an *active sensor* within the navigation system (see also Fig. 4).

Closely connected to vehicle guidance are fleet management systems which can be used either in land-, marine- or airborne applications. Fleet management systems are mainly useful for dispatching businesses like taxis, fire brigades, police cars, cargo and others. Via a telemetry link the road segment sends its GPS derived position information to the offices where the information is processed by a GIS host and current dispatching, route or traffic information is retransmitted to the cars. The time- and cost-saving effects of GPS and GIS in such applications are obvious.

Not only in classical navigation applications GPS and GIS can be used advantageously, also in emerging sectors like environmental monitoring the synergy effect of both systems has been already discover. A nice example is the tracking of animal movement



- GPS provides the position
- GIS aids the user in making decisions
- GIS may correct the GPS computations with knowledge base

Fig. 4 GIS as an Active Sensor in Navigation Systems

for biological studies, where miniature GPS receivers and data transmitters were attached to Alaskan brown bears. Current position information is transmitted continuously to data processing centers where the data is stored and typical animal movements (e.g. for food collection) can be analyzed.

Further applications of GPS and GIS are known in the sectors of farmland fertilizing where the amount of fertilizer which is emitted is made proportional to the distance which the tractor travelled (e.g. RESCH, LÜTTICKEN, SCHNEIDER [1993]) and military (e.g. contour flights). Nevertheless, the same statement as for the data acquisition does apply: all the presented examples give only a small extract from the numerous applications GPS and GIS can provide.

6. SUMMARY AND CONCLUSIONS

Engineering has been strongly affected by the development of the global positioning system and geographic information systems. GIS provides extensive analysis, visualization and management tools for spatial and semantic data, thus simplifying planning and decision making in sciences and politics. The databases of geographic information systems do need in most cases a spatial relation of the data (georeferencing), so that typical geometric and topological database queries can be dealt with.

On the other hand GPS provides highly accurate, real-time positioning information in a geodetic reference frame on a world wide basis, independent of time and weather.

Unfortunately the inherent information of GPS is purely geometrical. GPS data does not contain any semantic information.

Obviously, a combination of both systems produces a synergy effect where for example:

- the georeferenced data acquisition for GIS can be simplified by using GPS
- or a GPS/GIS combination can solve problems in navigation, traffic- and fleet-management, environmental monitoring or other fields

Within the scope of this paper several existing and potential applications of GPS and GIS have been presented. The advantages of GPS and GIS from an economic aspect are indisputable. The authors beleive that potential of integrated GPS and GIS is so large that automated procedures in GIS data acquisition are leading to a substantial reduction of man power and costs.

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