The Use of GIS Technology for Planning of GNSS Measurement

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Abstract. Global navigation satellite systems (GNSS), along with geographic information systems (GIS), are currently one of the most growing geo-information technologies. However, there is very little of projects which use of mutual support these technologies. The projects are mainly aimed at solving particular problems (signal propagation in a given area, coverage of GNSS signal, solutions of influence of barriers on the accuracy of measurement, etc.). This paper describes a global view on the interaction GNSS and GIS from standpoint of planning of measurement. The main benefit of GIS technology with support of spatial analyses consists in simulating the real environment and determining of effective deployment of GNSS methods in this locality. GIS thus partially replaces a reconnaissance of the terrain and it allows an increasing the entire measurement process about a hierarchical level above, i.e. into field of planning and management. The essence of method is the division of the area into sub-areas according to the conditions for GNSS measurements, and an optimal surveying method is assigned for each area. The paper describes a mathematical model and technique of implementation of the method into ArcGIS environment. Fuzzy logic is used due to the uncertainty of the conditions for the deployment of GNSS methods. The project also includes an expert system in which existing experience with GNSS measurements are stored. It is assumed that this expert system will be continuously updated and it will contribute to a gradual increase in the quality of the whole planning process. The proposed system is described by a form of block scheme and by a form of the state diagram in UML.

Keywords: GIS, GNSS, management of measuring

1. Introduction

The use of GNSS methods in geodesy for the acquisition of data directly at the terrain with the desired accuracy has particular importance. This is an alternative data collection, which begins strongly compete with conventional terrestrial measurement methods, thanks to a sufficient number of visible satellites on the horizon and a good constellation of satellites throughout the day. Measurement using GNSS technology has some limitations and its use is precluded in some cases. In many cases, it is not entirely clear what accuracy can be achieved using GNSS techniques. This is primarily an application in dense urban areas where GNSS measurements is strongly influenced by local conditions. In this environment, it is necessary to solve the horizon overshadowed by buildings and the influence of the multipath propagation of satellite signal.

It is clear from above facts that the use of GNSS methods in a given location is influenced by many factors and the resultant accuracy of measurement is burdened by a certain degree of uncertainty. Practically, this means that if we decide for measurement by GNSS method without preliminary analysis, there is no guarantee that we will achieve the desired accuracy in given area. In an industrial practice such as building industry, it is expensive and time inefficient to use of GNSS measurements using this method of attempt-mistake. In these cases, it is necessary to schedule the GNSS measurements in advance. The subject of solutions contained in this article is a proposal of the appropriate planning methodology for the application of GNSS measurements with respect to the conditions at given locality.

2. Related works

Existing works, which deal with the given issue, can be divided into the following hierarchically structured categories:

1. simpler tools for planning, which process data based on the almanac and entered values by user (requires a reconnaissance of the terrain):
   a) freely available applications (desktop software, online applications)
   b) a paid software and for registered users
   c) a planning as part of software for GNSS measurements

2. more complex applications, which process planning of measurement using 3D analyses (no terrain reconnaissance)
   a) simulation models without the influence of multipath
   b) ArcGIS tools for planning of GNSS measurement

c) more sophisticated simulation model incorporating the influence of multipath.

The category **1 a)** includes *Planning* software by Trimble Company, *Planning* software by Sokkia Company, *GNSS Satellite Availability Viewer* by Javad Company and *System Effectiveness Model* product by Arinc Company.

On-line applications are *GNSS Planning Online* product by Trimble Company and its version for mobile device called *GNSS Planning*, then *Web Mission Planning* by Ashtech Company and an easy application called *Satellite Prediction Tool* by NavCom Technology Company.

The category **1 b)** includes *Standalone Mission Planning* tool by Topcon Company. *SAPET* software by IDS Australasia and *GNSS RAIM/RNP Prediction Service* product are determined for air and marine industry.

The category **1 c)** contains free available *Waypoint* software, which is for download on website by NovAtel Company. Other software in this category is paid. There is e.g. *Leica Geo Office* software by Leica Company or *GRAL* software by IFEN GmbH Company.

In category **2 a)**, there are several works which solve the given issue. The publication (Gandolfi S. & Via L. L. 2011) deals with the creation of the *Skyplot_Dem* software to determine the visibility of satellites and DOP values. The sample of areal evaluation of the number of visible satellites in this software is in Figure 1. The work (Federici, B. et all. 2010) describes the *GNSS planning* tool, which was created as a module for a freely-accessible Open Source GIS of GRASS software. In the literature (Lee, Y.-W. et all 2008) is designed a prediction model to determine the availability of GPS in urban environments. The article (Kleijer, F. et all 2009) solves the availability of GNSS on case study of Schiphol Airport for planning of navigation of airport vehicles.

The category **2 b)** includes simpler functional tools working with digital elevation model which are created for ArcGIS environment for planning of GNSS measurements. The dissertation (Taha, A. A. M. 2008) deals with the mapping of utilities and a part of this thesis a tool called *Urban Canyon GNSS Simulation* was created. In the paper (Germroth, M., Carstensen , L. 2005) is described *Satellite Viewsheds* tool which has been programmed using VBA. *GNSS Prediction Tool* is the name of the tool to determine the number of visible satellites based on digital surface model in the form of a grid and a Hillshade analysis.

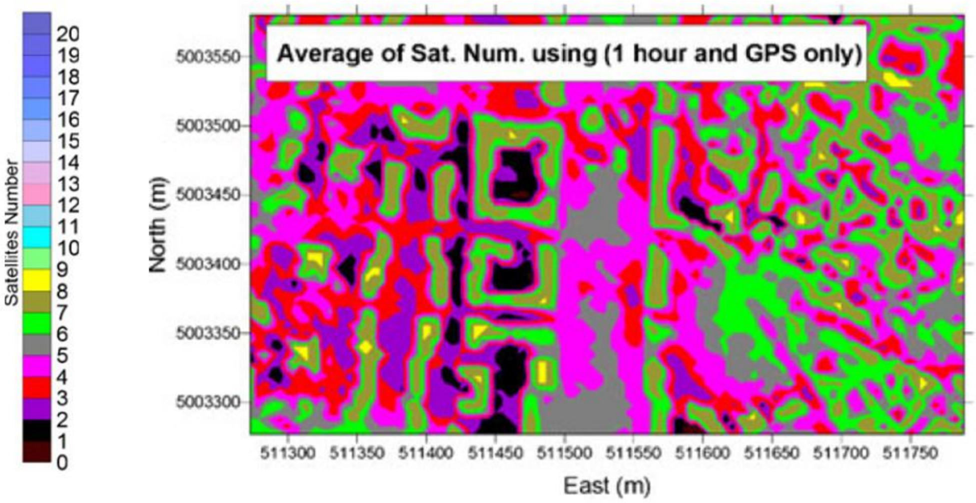

Figure 1. The sample of areal evaluation of the number of visible satellites in *Skyplot_Dem* software (Gandolfi S. & Via L. L. 2011)

In the last category **2 c)**, there are works that already deal with advanced simulation and that also solve the above problems of the influence of multiple reflection. The paper (Lee, Y. et all 2007) describes *Ajax* GIS application, which is used to determine the availability of GNSS in urban environments. The publication (Li, J. et all 2006) addresses how to use the digital surface model created from LiDAR data and 2D building footprints to determine the multiple reflection of GPS signals in dense built-up area. The dissertation (Bradbury, J. 2008) explores the use of models of the urban environment for accurate prediction of the availability of satellites. Articles (Legenne J., Ridder J.-J. 2003) and (Jeannot, M. et all 2005) introduce *Erdospace* tool, which is based on Ray Tracing technique and determines the availability of GNSS. The first article describes the use of this tool in an urban environment, and the other vice versa in a mountain environment. The publication (Lee et all 2008) deals with a determining the multipath using spatially static method called *Satellite participation ratio in outliers versus cluster* (SPROC). The dissertation (Winkler, J. O. 2000) deals with the modeling and simulation of the structure of a GNSS signal and verifies a determining the effect of multipath on two examples of 3D models of cities. Another dissertation (Hannah, B. M. 2001) addresses the general modeling and simulation of multiple reflections of GPS signals. And the publication (Lau, L., Cross, P. 2007) examines the basic principles of technology Ray Tracing for phase measurements.

3. Materials and methods

From the overview of related work follows that the issue of planning of GNSS measurements is the subject of many research projects with varying ranges of the solution. However, none of these works solves the planning of measurement complexly from the level of managerial standpoint. So the proposal of appropriate methodology for this purpose is the goal of our article.

The methodology assumes the use of a number of modules that solve the sub-tasks of planning process. The functions of individual modules are based on one or a combination of several of proven scientific methods.

The fundamental role of planning is a division of locality on the basis of the ***factor algebra*** (decomposition of the set into the equivalent classes) (Lau, L., Cross, P. 2007). In our case, the task can be formulated as follows: There is given a locality (L) where the measurement is considered and a set of surveying methods (M). The goal is a dividing of locality (L) into sub-localities L_i ($i = 1, 2, ..., n$) so that it applies:

$$L_1 \cup L_2 \cup ... \cup L_n = L \tag{1}$$

and simultaneously

$$L_1 \cap L_2 \cap ... \cap L_n = \varnothing . \tag{2}$$

Sub-localities (L_i) can be considered classes of the given locality (L) and the criterion of decomposition is the quality of surveying method $m_j \in M$ ($j = 1, 2, ..., p$) due to the relevant conditions of the given sub-locality:

$$q_j = \sum_{k=1}^{s} \frac{a_{jk} w_{jk}}{s} \tag{3}$$

Where q_j ... quality of j-th surveying method
a_{jk} ... parameter of j-th surveying method
w_{jk} ... weight of parameter of j-th surveying method
s ... number of parameters of j-th surveying method.

The problem lies in the fact that the classification function in equation *(3)* contains generally a number of diverse parameters, which will be needed to transform into a suitable equivalent comparative dimension. The optimal method for this transformation is so called the multi-criteria analysis, more about this method in (Francisco, C. E. S. et all. 2008) or in (Podinovskii, V. V. 2008).

Equation *(3)* defines the cost function which is a need to optimize (in our case, it will be the maximum) due to the given sub-area. The ***optimization*** in GIS is solved for example in (Elariss, H. E., Khaddaj, S. 2012) and (Jung H. et all. 2006). In our case, the linear programming seems as an appropriate method. The result is a dividing of locality (L) into sub-localities (L_i) so that for each $p_i\,(y, x)$ point of sub-locality (Li) applied:

$$\forall p_i\,(y, x) \in L_i\ \exists\, q_j \in M \,/\, q_j = max\,\{q_k \in M, k = 1, 2, ..., s\}. \tag{4}$$

The fuzzy logic with triangular representation will be used due to the uncertainty of parameter values in equation *(3)* and these values will be stored in a geo-database. More about fuzzy logic can be found e.g. in these literatures (Samhan, M. A. 1995) and (Chou, C.-H., Teng, J.-C. 2002). It is assumed in most cases that the values of the parameters will be determined on the basis of the experience of practitioners, or they will be acquired from observation directly in the terrain (the power of signal of the mobile operator with the data of coverage maps, DOP values, etc.). In this case, the rules for interpreting these values will be inserted into the database together with these values. The database thus will achieve character of ***expert system***. The expert system is specifically described in the literature (Liao, S.-H. 2004) and (Ahmadi, F. F., Ebadi, H. 2010).

Furthermore, there are a number of parameters in equation *(3)* which must be determined from the morphology of the terrain in the given locality. This is for example the visibility of satellites, multipath effects, etc. For this purposes, the application of ***spatial analyses*** in ArcGIS environment is assumed. The Line-of-Sight method that is used to identify obstacles of horizon can be as an example of one such spatial analysis. More about this method is e.g. in (Han, J.-Y., Li, P.-H. 2010).

The last group of parameters that affect the quality of the measurements has the time variable values or it is difficult to obtain these parameters directly from the documents. In this case, it is appropriate to establish a mathematical model of the system and then to obtain the parameter values by ***discrete simulation*** or it can be alternatively used of ***data mining*** methods. Simulations in GIS are described e.g. in articles (Viger, R. J. 2008) and (Wang, X. 2005).

4. System design

The aim of the project is a creating of a tool that will be used for planning of advanced GNSS measurements at a preselected locality. The top-down method was chosen for the design of the system. The method is based on decomposition to the functional sub-blocks. Then it is needed to find an optimum realization of function for each block.

The resulting scheme which demonstrates of the proposed system solution for GNSS planning, including its individual process modules, is shown in Figure 2. This tool will be developed for the PC environment and it contains two basic components. The first component is an own kernel that manages individual processes and the second component is GIS.

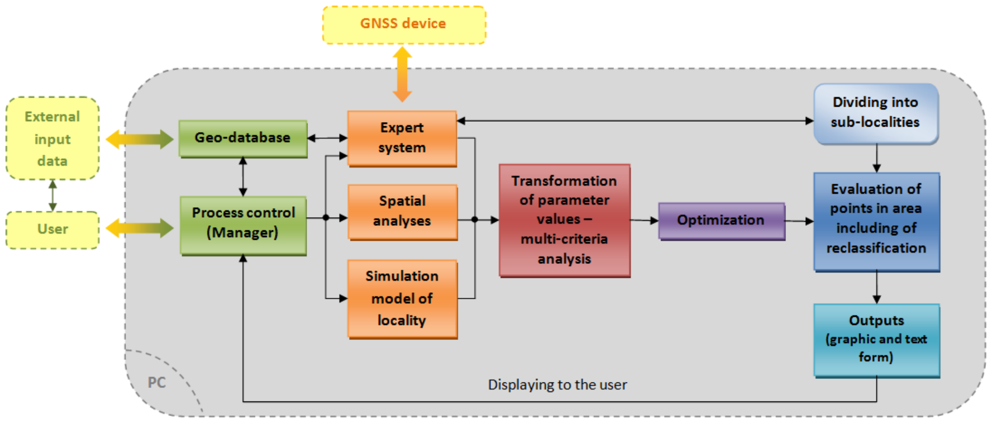

Figure 2. The scheme of proposed solution for a tool for GNSS planning

In the next phase of the proposed solution, it was needed to determine how to properly implement each sub-block of system. In this case, it is considered the maximum use of existing functions in ArcGIS software. If it is not possible to use any of these offered functional tools, it will be needed to program the individual modules using the scripting language Python.

Here is a description of each component of elements and modules of the proposed solution of GNSS Application.

User module

It is expected to use the proposed system for two target group of users:

1. One user group is surveyors which would use the Application for management planning of surveying methods on the given locality. They would save the costs for reconnaissance and hey could directly suggest to the customer a price for specific surveying work that will be done on the locality.
2. Another group of users could be from the area of building industry or agriculture. Nowadays, these areas use a precision GNSS technology to control of earth moving machinery (e.g. a bulldozer or a tractor). Concretely, the RTK method is most used for these works. The users would find out using GNSS Application where some problems might be with navigation of earthmoving machinery using the RTK method.

Control (Manager) module

Manager of process control is the core of GNSS Application and it will be designed for the PC environment. The kernel will choose needed data for planning from a geo-database and this data will be used in later steps. Then it will control the individual processes of planning so the kernel will communicate with ArcGIS through which various analyses will be conducted on the basis of built or of newly programmed scripts. Scheme of the control module is shown in Figure 3 in the form of a state diagram of UML.

Geo-database

Geo-database will contain data that will be needed to evaluate the planning of measurement. This data will be stored in geo-database physically or online connected through web services (e.g. WMS). The individual data layers will be formed from geo-database and they will be an input into GIS. These are layers:

- Meteorological data
- Orthophoto and topographic map
- Digital elevation model
- Land cover
- Signal coverage of mobile networks
- Permanent reference stations.

Simulation model

This module will simulate the real environment of the locality of measurement so that a reconnaissance of the locality before a measurement will not be necessary to carry out. This is a task as the identification of barriers of horizon based on digital elevation model, a calculation coordinates of satellites from almanac, derivation of availability of satellites and DOP values, and determination the availability of signal of the mobile operator.

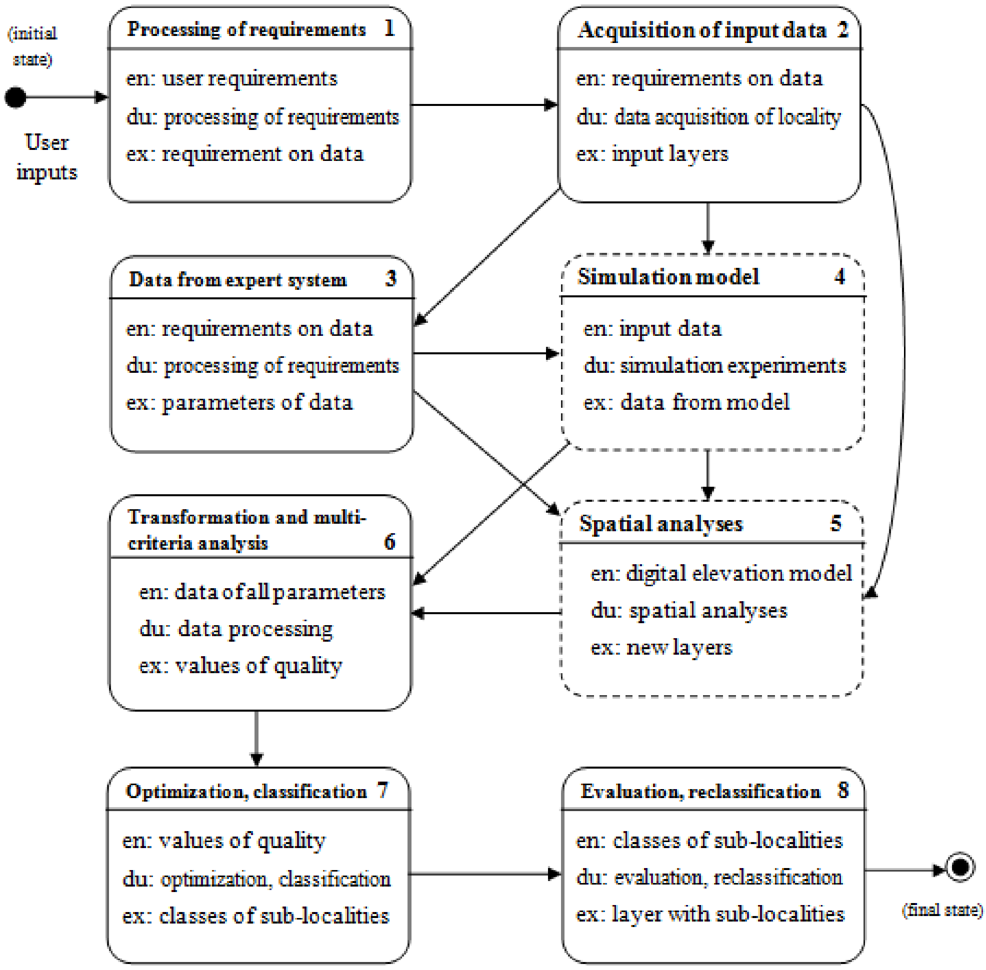

Figure 3. State diagram of the control module

Spatial analyses module

The module will work over the data of digital elevation model and it will be part of ArcGIS. The result of a whole spatial analysis will be the proposal, whether it is preferable to use a receiving of correction from a specific physical reference station of the given network, or to use one of the offered service of network solution for given locality of measurement. Also a proposal of specific mountpoint relates with this task. Some values of the expert system may be necessary for this analysis.

Expert System

The module will contain parameters collected from surveying experience. These are the data which are obtained from the known research results and scientific works, or from the results of own research. These data will include such parameters that will be used to derive risk of multipath or for proposal of the use of specific data services on the given locality. It is assumed that the expert system could be verified after every measurement so that the results of measurement planning would be compared with real measurement data.

Evaluation planning module

The final module will be used for visualizing the results of planning. These results will be in graphical and text form. The basic output of the graphic form will be layer with the plotting of sub-localities within which it is possible/impossible to measure using a selected GNSS method in given locality. The result will be modified according to the input parameters of measurement specified by the user (threshold values). There are other graphical outputs as layers that report on the number of visible satellites, DOP values, risks of multipath, a strength of mobile signal, a status of ionosphere and more.

5. Conclusion

The article describes the system of using GIS technology for advanced planning of GNSS measurements. This planning tool (GNSS Application) is designed for the PC environment. It should serve mainly surveyors; another group of users is expected in building industry or agriculture, which use satellite technology to navigate earthmoving machinery. Application should evaluate the conditions for the given locality of measurement on the basis of the input data and data from the user and it should divide this area into segments in which specific GNSS surveying method will be designed. The static method, RTK, DGNSS and autonomous measurement mode will be used from GNSS methods.

GNSS Application will initially be focused on the environment of rural areas. This application will be used by surveyors for managerial planning and it enables them to quickly and easily determine what percentage of the locality is possible to measure by GNSS technology. If they have this information, they can calculate the customer a cost for specific surveying work. Nowadays, there is no such tool for GNSS planning that could classify a locality on the basis of different surveying methods. With this it also relates the evaluation of the coverage of the mobile operator, which will be specified on the basis of the input data and modeled in the GIS environment. This evaluation of signal is necessary for the RTK and DGNSS methods, and it also has not yet nowhere solved within the planning.

The proposed GNSS Application will be verified using the Topcon GRS-1 device.

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