OPTIMIZATION OF ROUTE IN FIELD AT PRECISE GNSS POSITIONING

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Abstract

The paper deals with solution of searching the optimal route in field in course of precise positioning by GNSS technology. The aim is to carry out observation on all GNSS points, so that the total path length was minimal. The way in field is made up of two types of points: the first points on which we use GNSS measuring methods (GNSS points) and 2. points of auxiliary (crossroads). The task is made more difficult by the fact that GNSS points are measurable with quality only at intervals of good observational conditions. From a theoretical point of view there is a heuristic solution in terms of finding Hamiltonian path in a graph with additional conditions in certain nodes. The application is developed in Borland Delphi. One of the outputs of the optimal solution is a presentation of the drawing of final path in field through online geo-web application in Internet browser. The application has a universal usage in GNSS precise measurements for building of precise control network of structures or in geodynamics.

Keywords: *optimization, GNSS, Hamiltonian path, geo-web map*

INTRODUCTION

The need for precise positioning in the technical practice is an important factor in the implementation of the geometric accuracy of the construction. High accuracy positioning is also needed in assessing the stability of large embankments, dams, landslides, undermined areas and also in local geodynamic networks for long-term stability monitoring of the area potentially usable eg. as a nuclear waste repository, etc. It is of particular importance in railway transport, particularly for high-speed lines designed in various geomorphological conditions. Achieving high (several millimeters) accuracies in determining the position at a distances of 1-50 km is the domain of suitable technology using Global Navigation Satellite Systems (GNSS) based on a permanent network in real time. The effectiveness of the entire field measurement procedure is based on optimizing the observation with measuring receiver at each geodetic point and optimization of finding the time and length shortest path to move the measuring receiver between geodetic points in the area of interest [1].

RELATED WORKS

High accuracy with real-time positioning of moving objects has been considered a standard task of engineering geodesy. An absolute positioning accuracy of 1-3 cm is generally possible worldwide and is further used in many areas of machine guidance (machine control and guidance), and farming (precision farming) as well as for various special applications (e.g. railway trolley, mining, etc.). Publication [2] describes the approach to precise position determination by means of the computation of static raw data with single frequency receivers. Paper [3] deals with the laboratory equipment called the Simulator of Train Position Locator, based on using exactly the same inertial sensors as employed in the real locator. The simulator is able to simulate functions of the real train locator using the input reference trajectory data generated by Real Time Kinematics (RTK) during a test run on the track. The simulator enables testing of the following modes: 1) position determination during train routing on switches, 2) position determination on track sections with limited GNSS satellite "visibility" (tunnels, track cuttings, etc.), and 3) train positioning under different speed profiles. Publication [4] presents a verification methodology and experimental results of the US's GPS and Russia's Global Navigation Satellite System (GLONASS) based train position locator tests at Czech Railways. The verification methodology is derived from the current needs in signaling, and from the parameters of the satellite navigation systems. A key element in the investigation is a switch, on which reliable and continuous position determination of a routing train is most critical. Two-dimensional and one-dimensional routing detection models are analyzed and experimentally investigated on the switch-point. The trials were performed on Pardubice Hradec Kralove - Chocen line with the total track length of 100 km. Effective Real Time Kinematic (RTK) mobile machine control requires a sufficient number of global positioning system (GPS) satellites that are both visible and suitably positioned Reliably obtaining the highest degree of accuracy and precision afforded by RTK technology requires the initial acquiring of a solution (i.e., obtaining an RTK "fix" solution), the maintaining of the RTK fix solution, and if it is lost, rapidly reestablishing the RTK fix solution. Losing the RTK fix solution is a common occurrence when operating near trees, tall landforms, and large structures that can cause significant sky blockage. In [5] a Geographic Information System (GIS) solution for mapping a model of sky-blockages surrounding agricultural fields across entire regions was developed. It employs spatial landform feature layers, such as terrain elevations (levies, ridges, side slopes), forecast satellite availability from Mission Planning software (MPS), and terrain coverage maps.

The primary object of research work [6] is to test and to assess a tightly coupled GNSS and railway track data system for railway applications. One of the key features of this system is its ability to take into account uncertainties in both GPS observables and the spatial railway network data. Since trains travel on pre-defined fixed routes, 3-D positioning becomes a 1-D positioning problem that fixes the position of the train along the track. The spatial railway network database is then used to estimate the other two coordinates. In this way, the accuracy of the railway network database is crucial for the integrated positioning system. Unfortunately, the necessary accuracy of the railway network database is not known. Additionally, the integrity and availability performance of GNSS-based train location system are also essential for the safety-critical railway control systems. The required navigation performances (RNP) for the safety-critical railway applications in terms of accuracy, integrity and availability are investigated. We test different accuracies of the track database for the integrated system. Based on the result, when the GPS is integrated with the track database, the accuracy, integrity and availability are improved. The higher the accuracy of the track database, the better the positioning accuracy is guaranteed. For the integrity and availability performance, the result shows that the medium accuracy of the track database is more cost-effective for the integrated system.

The contribution [7] describes an approach to preprocessing and fusion of additional vehicle onboard sensors – the odometer and accelerometer, all targeted to serve as optional and temporary substitute for GPS-like navigation. The suggested solution explores a rule-based system for mutual substitutions and calibrations of the used sensors depending on actual conditions. The only usage of the GPS here stands in providing regular position calibrations and serves as a reference method for evaluation of the presented results. The presented solutions have been experimentally tested with real-world data as shown in the experimental part of the paper.

Publication [8] describes the Leidos system, that was developed as an operational test-ready navigation system for Positive Train Location (PTL) demonstrating position accuracies that enable cross-track discrimination using low-cost onboard components and no trackside infrastructure. The system combines information from multiple sensors and a track database (when available) in the Leidos Embedded Data-fusion Geospatial Engine (EDGE) sensor fusion algorithms to create optimal state estimates for position, velocity, and attitude. In Phase I of the PTL development effort, Leidos tested a proof-of-concept system using both simulation and real-world track testing at the Transportation Technology Center (TTC) test track in Pueblo, Colorado. The system demonstrated position errors less than 20 cm in the along-track and across-track axes as measured by a fixed-base station Real-Time Kinematic (RTK) GPS reference system. In Phase II, the hardware has been redesigned to support operational railroad installation and testing. The production design has been tested at both the TTC test track as well as on United States Class I railroad operational track territory.

SOLUTION METHOD OF OPTIMAL PATH FINDING

The aim of this paper is to propose an optimization method for measuring by GNSS RTK on railways. The outcome should be itineary of measurement plan, which would include all measured points, while the total length and measurement time should be as short as possible. The task is made more difficult by the fact that at a point the conditions are suitable for measurements only within a certain time interval. From a theoretical point of view it comes to finding the Hamiltonian path in a graph with additional conditions in nodes. The proposed optimization method has two parts:

1. static part when the shortest distance between all nodes on the route is calculated. The basis of this section is known as Floyd algorithm.

2. dynamic part, in which events (i.e. measurements at different points in the system time) are planned. These events are stored in an events list, which is a dynamic structure whose items are ordered by time.

The algorithm is shown in Fig. 1. In the initialization phase are set the global measurement parameters (start and end time, the number of measurements on point, etc., further import list of points, almanacs and distances between points). Then, the shortest distance between all points (Floyd's algorithm) is calculated. Then the events at individual points are planned. If for a given point there are in events list the items with more than the current time, these events are canceled. This can be achieved in the shortest possible measurement time. This process is repeated for each variant. Number of variants is the same as the number of points. In each variant a different starting point is selected. This way simplifies the combinatorial difficulty of the task, because it is known that finding Hamiltonian paths in a graph is NP-completely problem. The resulting variations are saved into matrix of options and optimal variant with the shortest route and the time of measurement is in the first row of the matrix.

The algorithm was created as an application in Borland Delphi. The application includes a module for online geo-web application. This module displays waypoints in various map data in a web browser. Points are marked with symbols with labels containing basic information about the point.

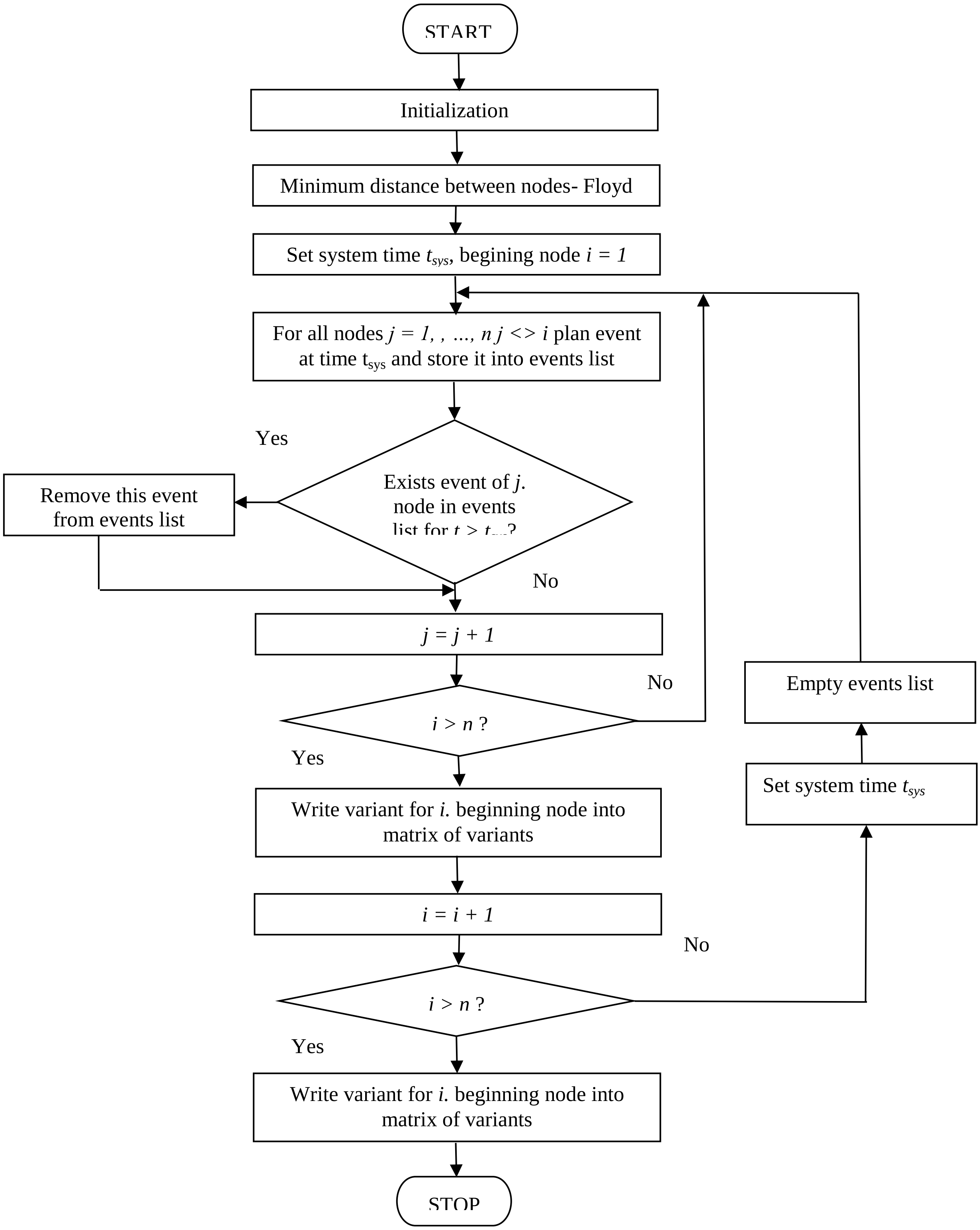

Figure 1. Flow chart of the optimization algorithm

EXPERIMENTAL RESULTS

The proposed optimization method of RTK GNSS measurements was verified on the railway route Hranice – Valašské Meziříčí (Czech Republic). Figures 2, 3 and 4 are outputs from applications, which was created in Borland Delphi. In Fig. 2 is part of the matrix of the shortest distances between all measuring points. The matrix was created using Floyd's algorithm. In the Fig. 3 the variants of itineary with order of measurement points are shown. The optimal variant is in first line in the table. The total route length is 1563 m and the total measurement time is 2 hrs. 10 min. Fig. 4 shows a sample of the online geo-web application. It is a zoom from a Web browser with maps and marks of measured points in the locality. Geo-Web application contains basic controls (changing the map scale, the marks with labels, etc.).

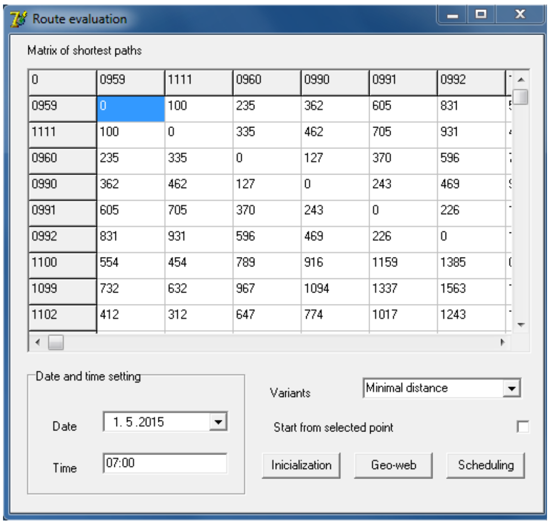

Figure 2. Matrix of shortest path - Floyd algorithm

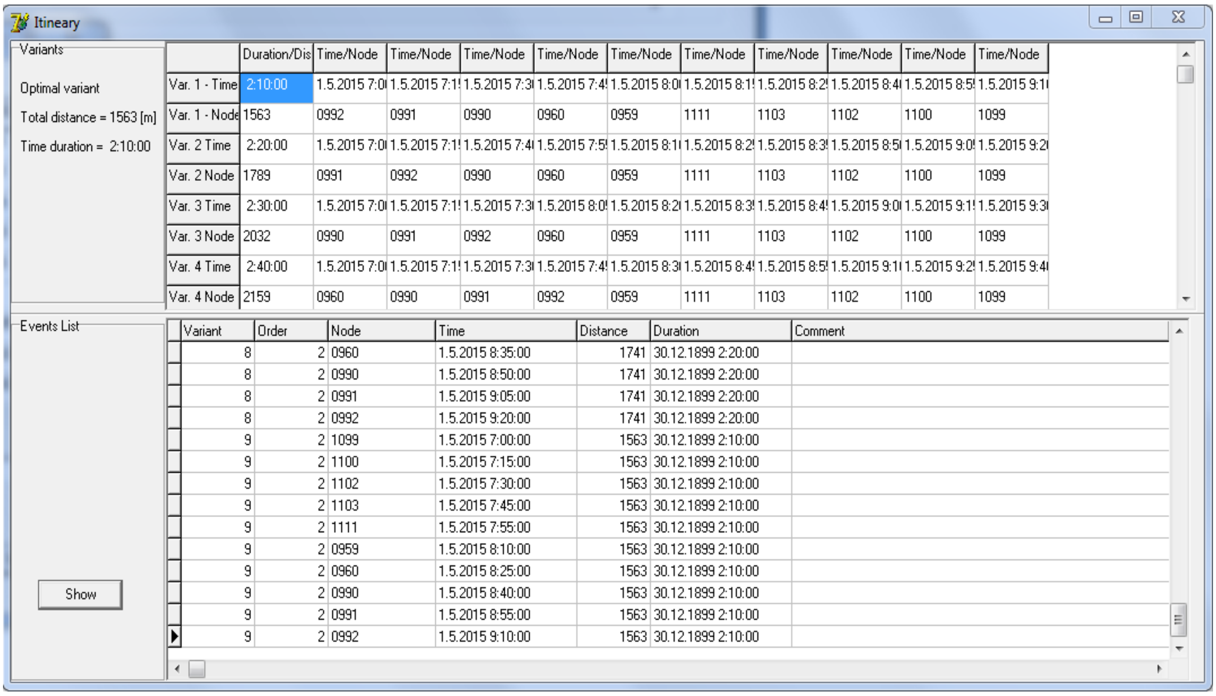

Figure 3. Output of itineary variants

Table 1 presents an overview of the particular variants of Hamiltonian path on section of the railway line Hranice na Morave – Valasske Mezirici. The best variant is ordered first (1).

Table 1. Hamiltonian path variants on section of railway line Hranice na Morave – Valasske Mezirici

Order	Variant of paths										Total distance [km]	Total time [hh:mm]
1	992	991	990	960	959	B	1103	1102	1100	1099	1,563	2:10
2	1099	1100	1102	1103	B	959	960	990	991	992	1,563	2:10
3	1100	1099	1102	1103	B	959	960	990	991	992	1,741	2:20
4	991	992	990	960	959	B	1103	1102	1100	1099	1,789	2:20
5	1102	1100	1099	1103	B	959	960	990	991	992	1,883	2:30
6	990	991	992	960	959	B	1103	1102	1100	1099	2,032	2:30
7	1103	1102	1100	1099	B	959	960	990	991	992	2,075	2:40
8	960	990	991	992	959	B	1103	1102	1100	1099	2,159	2:40
9	B	1103	1102	1100	1099	959	960	990	991	992	2,195	2:45
10	959	B	1103	1102	1100	1099	960	990	991	992	2,295	2:55

Figure 4. Geo-web application (measured points in field)

CONCLUSIONS AND FUTURE WORK

The paper describes the optimization method for measuring by GNSS RTK method on railways. The aim was to propose the measurement itineary with minimum path length and the shortest total time of measurement. The proposed method has two parts: 1. static, which is based on Floyd's algorithm that generates the shortest route between all points and 2. dynamic, which prepares the measurement plan within a shortest time interval as soon as possible. Basis of the dynamic part is the event list. The proposed algorithm was implemented in Borland Delphi. The application includes an embedded module for creating online geo-web applications. The output of this module is a graphic representation of the measured points on a railway line in the web browser, with basic map layers and basic controls. Measured points are illustrated by marks with label, which contains basic information about the point.

In the next part of the project the application will be extended by economic aspects of the measurement process. It is the cost of renting of the equipment, salary for the worker who measures, travel and other expenses. The method is generally useful for measuring on linear constructions and similar structures.

ACKNOWLEDGEMENTS

This paper was elaborated with the support of Brno University of Technology, Specific Research Projects FAST-S-15-2723 and FAST-S-16-3507.

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