ZESZYTY NAUKOWE AKADEMII MARYNARKI WOJENNEJ
ROK LIII NR 3 (190) 2012

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THE INTEGRATED TRAM TRACKING SYSTEM BASED ON GPS

ABSTRACT

A new application using The Global Navigation Satellite System is the main objective of a project developed at the Department of Advanced Geodesy of CTU in Prague. Essential functionality is determining the location of a moving object on a predefined track. New and unique features deal with simultaneously processing GPS measurement data with other information, such as information about trajectory and object velocity. This method reduces the minimum number of satellites necessary to locate a moving object to only two satellites. The fully developed system may be useful for active management and tracking of public city transportation or monitoring of freight movement, e.g. hazardous materials.

Keywords:
GNSS, digital map, Kalman filter, city public transport.

TRACKING IN CITY PUBLIC TRANSPORTATION

The Global Navigation Satellite System (GNSS) is increasingly useful for positioning moving objects. It streamlines many intelligent transportation systems [8]. An important application of these systems is tracking city public transport vehicles. It encompasses the tracking of buses, trains, and trams. The movement patterns of these vehicles vary. Open space during the ride is a common character for the movement of buses and trains. On the other hand, the movement of trams is commonly in difficult spaces from a GNSS positioning standpoint, e.g. narrow streets bordered by high buildings in the center of old towns. The GNSS signal can be lost in these spaces or the number of reachable GNSS satellites is decreased. If the number of reachable satellites decreases below four, an ordinary GNSS receiver is not able to calculate its position. Because of this insufficiency, the GNSS has not yet been applicable for tracking trams [4] although tram positioning, as well as train positioning, has one advantage compared to regular vehicles. Both tram and train movement is limited by the tracks. Tram tracking can be interpreted as tracking of changing position on a predefined track. The location of the track is important information which may be utilized to locate a tram despite the GNSS receiver only reaching a limited number of satellites.

TRACKING TRAM PUBLIC CITY TRANSPORT

In the Czech Republic there are only a few cities where trams are used: Prague, Brno, Plzen, Ostrava, Olomouc, Liberec and Most-Litvinov. These cities track their trams using a 'infra-beacon radio-signal' system except the city of Olomouc. This city has used a GPS tram tracking system since 2006. The system was provided by the company ELTODO which owns all rights [6].

All new types of tram vehicles in the Prague public transportation system are equipped with GPS receivers [9] although the Prague Transportation Company does not presently consider GPS tracking for the tram network [4]. The main reason is unreliability of the GPS in problematic urban space, e.g. narrow streets bordered by high buildings in Prague's Old Town center.

GPS OR INFRA-BEACON

Comparison of the GPS and the infra-beacon radio-signal system can be made in terms of some criteria: the costs of the systems, flexibility, and reliability. GPS has already been established. The GPS satellite system can be used for free. It is necessary to equip all vehicles with GPS receivers and ensure service for receivers. The infra-beacon radio-signal system is more financially demanding because the infra beacons must be placed along all vehicle routes. All vehicles must be equipped with a device that communicates with the infra-beacons. Both parts (the infra-beacons as well as the device for communication) need service. The GPS tracking system is flexible. The main risk is: shutdown of the GPS for public use by the U.S. government, the owners of the GPS satellite system. The infra-beacon system is by comparison inflexible. Every change of routes or creation of new routes also generates requirements for new infra-beacons. The GPS system seems to be presently unacceptable for tram tracking because of satellite signal loss in problematic spaces, whereas the infra-beacon is reliable where installed [4].

If the problem with satellite signal loss in problematic spaces were to be solved, GPS tram tracking system might become more acceptable. This paper presents a method to reduce this deficiency by decreasing the minimum number of satellites necessary for GPS tracking.

THE PREDEFINED TRACK

An essential requirement to decrease the number of necessary satellites for moving object localization is processing GPS measurements simultaneously with information that conditions the movement to a known (predefined) track [1]. If the predefined track is mathematically described in the coordinate system WGS-84 [7], only two satellites are required to determine the object position [1]. It corresponds with two unknown parameters that have to be solved: the receiver clock bias and the track chainage.

Initial work in developing software that simultaneously uses GPS measurements and the constraint of a geographic track has been performed [2]. The algorithm used in this software is able to determine tram position on the basis of GPS information from only two satellite signals. This reduction in the number of necessary satellites for accurate location specification will enhance further utilization of GPS for tram tracking. Initial testing of the system at an in-line skating track called ‘Ladronka’ in Prague was successful [1]. This test was performed under perfectly known conditions, e.g. accurate specification of the track. The data in that test can therefore be considered as ideal. The current objective is to further develop the system and enable it for real operation on an operational tram track. A tram track in the Prague public transport system is used for testing.

METHODOLOGY

THEORETICAL ASPECTS OF TESTING

A practical example of a moving object on a predefined track is the movement of rail vehicles. The movement of these vehicles is strictly defined. A tram in the Prague public transportation system was used for demonstration and testing in live operation. Receivers Leica (GX 1230 GG), Topcon (Hyper+) and U-blox with 5 Hz data frequency were used for testing. The following data form the basis for testing: GPS measurements were saved in a standard Rinex file and a digital map with the tram trajectory was acquired. Those data are processed subsequently by GPS post--processing software. The moving tram location coordinates at every measurement time-point is the result of this data processing.

The digital map provided by GIS Department of the Prague Public Transport Company contains a vector model of tram-lines and it is stored in dgn format (Bentley MicroStation). The vector model contains layers of rails, tramlines axes and detailed survey points with elevations. The vector model is only a 2D design, an elevation of a detailed survey point has not character of an attribute but only a text field related to the detailed survey point.

The testing area is located in Prague, in a municipal part called 'Nusle'. The testing tram ride leads from the tram yard to the neighborhood central square and back to the tram yard. The testing area includes various types of space: open space, narrow streets bordered by high buildings, tunnel underpass. Varying numbers of available satellites during the ride are expected.

THE JUNCTION PROBLEM

It is important to have in mind that positioning on a predefined track is a strong constraining condition. It is possible to find a solution on every curve representative the track that is introduced into processing of GPS measurements. If it is possible to find the solution on every curve it is also possible to find a solution on more curves at the same time. In reality it is natural that the object is moving only on one curve at a time. However, it is common that a single railroad track branches into several tracks.

A complete track is saved in software as a set of track segments. Every segment holds information about successive track segments. The current track segment being traversed by the object (here the tram) is always selected from this set. If the object reaches the segment end point, the next track segment is selected. The next segment is selected according to the rule that successive track segments have one joint point. In case that more than one successive track segments are available (due to a junction), it is necessary to consider all these track segments. It is evident that the object is moving on one of them, but which one? This situation can be called the junction problem. The problem is solved by means of criteria. All possible track segments are saved in a set. At every new timepoint, software calculates the object's position on every track segments from the set. Then a collection of criteria decides if a track segment is marked as unsatisfactory. Track segments marked as unsatisfactory are not sorted out immediately, only its counter for unsatisfactory solutions is increased. Then measurements from new timepoints are processed. A track segment is finally rejected out when the counter reaches previously defined maximal value.

This principle does not choose correct track segments in one moment but rather observes the progress of solutions on every track segment. Simultaneously it is indicated for each time period that the object is moving on several track segments. The junction problem is solved when the set contains only one track segment.

MATHEMATICAL ASPECTS

The GPS measurements can be processed by several methods. The developing software enables to process the GPS measurement by least square method or by Kalman filtering. In the both cases, two unknown parameters are solved: track chainage *ds* and the receiver clock bias δR. The least square method processes every timepoint independently. The position from previous timepoint is used only as a first step of the iteration; it has no deeper significance [2]. The Kalman filter enables the position to be predicted and then specified on the basis of actual measurements [3]. A model of linear motion is considered. A state vector contains distance *ds,* velocity *v*, and clock bias δ:

$$\begin{pmatrix} ds(n) \\ v(n) \\ \delta(n) \end{pmatrix} = \begin{pmatrix} 1 & \Delta t & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} ds(n-1) \\ v(n-1) \\ \delta(n-1) \end{pmatrix} + \begin{pmatrix} 0.5\Delta t^2 & 0 \\ \Delta t & 0 \\ 0 & 1 \end{pmatrix} \begin{pmatrix} a \\ d\delta \end{pmatrix}. \quad (1)$$

The symbol *a* represents random acceleration with a normal distribution ($E\{a\}=0$, $\sigma^2=E\{a^2\}$), $d\delta$ symbolizes random noise for clock bias.

RESULTS

TRACK CHAINAGE AND VELOCITY

The result presentation is focused on comparison the least square method and the Kalman filter. In fig. 1 the results of: DPGS with condition to locate object on the track — processing of C/A code by least square method, DPGS with condition to locate object on the track — processing of C/A code by kalman filter are represented.

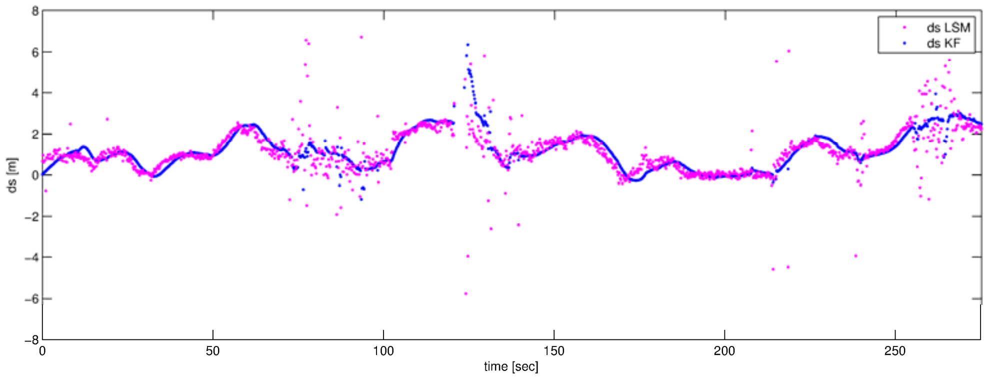

Fig. 1. Result track chainage *ds* — different processing of GPS measurement

Source: own study.

In fig. 2 the object velocity is represented. In the case of least square method, the current velocity (ds/dt) is calculated. Kalman filter assigns the velocity by equation [1].

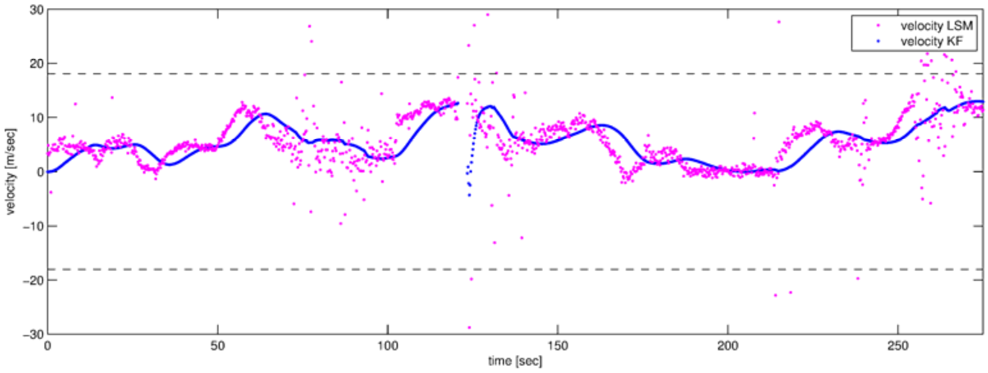

Fig. 2. Velocity — different processing of GPS measurement

Source: own study.

It is evident that processing of GPS measurement with condition to locate a object on the track using the least square method [1] does not consider all available information about the movement (e.g. character of velocity). The measured movement in terms of velocity is not continuous. The values are too dispersed. Negative velocity is detected incorrectly. If the tram moves, negative velocity is almost impossible because the tram vehicle can rarely back (e.g. in a yard). Technically maximal velocity for a training tram vehicle is 65 km/h [5], higher values are impossible.

A better result for velocity is achieved by applying a mathematical filtering method the Kalman filter. The negative velocity was eliminated, and velocity also meets technical parameters for continuity.

THE JUNCTION PROBLEM

The object moves on its track. If the object reaches a junction where the track branches into several tracks it is necessary to calculate the position on every branch [2]. Individual solutions are compared on the basis of a collection of criteria. The collection of criteria contains simple criteria and composite criteria. Simple criteria directly reject track segments with too high errors from LSM. Composite criteria compare solutions between themselves on the basis of the mean squared error (MSE). See differences in progress of MSE on every trail. In this case the junction problem is solved when the right-hand trail is rejected (fig. 3).

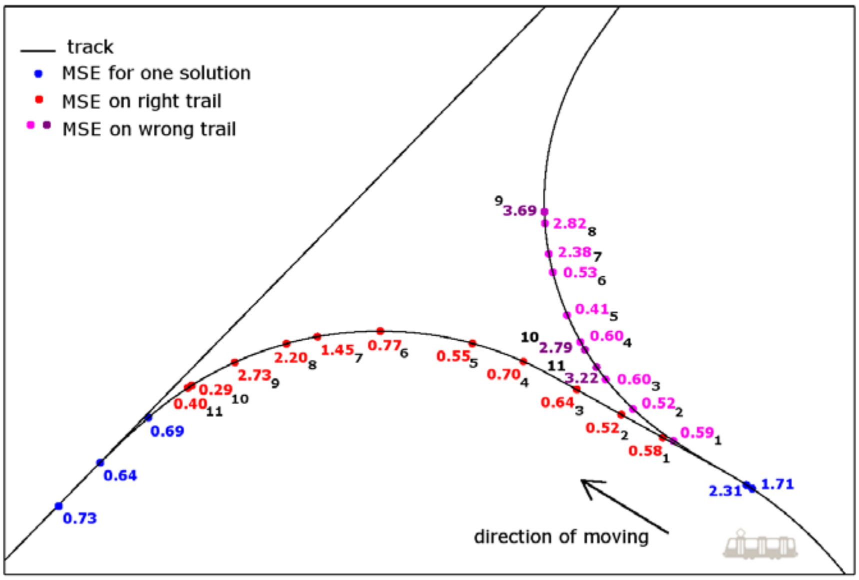

Fig. 3. MSE progress on track

Source: own study.

CONCLUSION

A tram tracking method based on GNSS was introduced. The objective was to overcome a presumption that GNSS is not acceptable for tram tracking in Prague and other cities with challenging urban space in terms of receiving multiple satellite signals. The main argument against GNSS for tracking trams is the lack of reliability by the GNSS signal in such problematic space, e.g. narrow streets bordered by high buildings. If information about a tram's trajectory is used with GNSS measurement processing the minimum number of required satellites is decreased. Thus GNSS becomes more reliable.

The mathematical principles of GPS measurement processing have to be based on Kalman filtering. This processing method enables the use of dynamic characteristics. Dynamic filtering provides resulting position and object velocity that comply with continuous motion that corresponds with real tram motion.

Some system improvement based on GPS could be achieved by using another measuring technique, e.g. a gyroscope, an accelerometer, or an odometer [8]. Integrating GPS with other measuring sensors allows more system reliability in the case of signal interruption. This additional information could also improve the decision criteria for selecting track segments at junctions.

One important point has to be omitted up to now: the comparison with reality. There is no information about real tram position in every timepoint. It is the motivation for following research; to demonstrate the precision of the system and to conflict the result position with the real position.

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ZINTEGROWANY SYSTEM ŚLEDZENIA TRAMWAJU OPARTY NA GPS

STRESZCZENIE

Głównym celem projektu realizowanego w Katedrze Zawansowanej Geodezji w Pradze jest nowe zastosowanie The Global Navigational Satellite System. Jego istotną funkcjonalnością jest określanie lokalizacji obiektu poruszającego się po zadanej trasie. Nowe i unikalne cechy odnoszą się do jednoczesnego przetwarzania danych pomiarowych z GPS z innymi informacjami, takimi jak informacje o trajektorii i prędkości obiektu. Metoda ta zmniejsza minimalną liczbę satelitów potrzebnych do zlokalizowania obiektu do jedynie dwóch. W pełni opracowany system może być użyteczny dla aktywnego zarządzania publicznym transportem miejskim lub monitorowania ruchu frachtu, na przykład niebezpiecznych materiałów.

Słowa kluczowe:

GNSS, mapa cyfrowa, filtr Kalmana, miejski transport publiczny.