DETERMINING THE MUTUAL LOCATION OF MOBILE OBJECTS USING THE ASG–EUPOS SYSTEM

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1. INTRODUCTION

The utilization of satellite global navigation systems for the purpose of examining the kinematics of mobile objects is in a sphere of intense research by many world scientific centres. Very often these studies take advantage of local or national systems providing accuracy support in determining position. The building and commissioning of the ASG–EUPOS active network, encompassing the entire country, took place in mid–2008. For users, this opened up the possibility of more efficient use of GNSS technology in both static and kinematic measurements. Currently, it is possible to use five services, including three operating in real time (NAWGEO, KODGIS, NAWGIS). Depending on the service utilized as well as the mobile receiver used, the average error in determining position ranges from a level of 0.03 m for the NAWGEO service to 1 m for the NAWGIS service.
The authors of this paper undertook an effort to utilize the NAWGEO service to determine the mutual locations of mobile objects. The Kalman filter was used in preparing the accumulated data.

2. KALMAN FILTER

Systems monitoring the variability of dynamic objects, or rather what in kinematic digital signal processing theory are known as *observers*, are often widely used in geodesy and navigation. Systems for monitoring engineering objects (applying both satellite and terrestrial technology) and satellite navigation systems can presently gather data with a frequency of a few dozen hertz. An ever–growing quantity of data as well as the demand to analyze the accessible data immediately (in real time) forces the use of recurrent algorithms. The primary position among the most frequently used observers is taken by the recursive least square algorithm (RLS), the recursive least square algorithm with a “forget” coefficient, where the oldest measurement data are forgotten (WRLS), and what is used most often today, the Kalman filter (KF).
The Kalman algorithm is one of the most popular methods for dynamic filtration. An important advantage of this method is the ability to estimate values that are not accessible for measurement, on the basis of other measured variables and equations linking the two groups of values. What stems from this is that it is necessary to describe the process and the measurement system using a mathematical model (only one measuring model is known in estimates using the least square method, where the process does not change in time).

It is a known fact that the Kalman filter consists of two equations:

1. **The equation describing the object (process),**

$$x_k = A \cdot x_{k-1} + B \cdot u_{k-1} + w_{k-1} \quad \textbf{(1)}$$

2. The equation describing the measurement as conducted on the model,

$$z_k = H \cdot x_k + v_k \tag{2}$$

where:

A – state transition matrix
B – control input matrix
w_k – process white noise
H – measurement matrix
v_k – measurement white noise.

We can then define *a priori* and *a posteriori* estimate errors as

$$\begin{aligned} e_k^- &\equiv x_k - \hat{x}_k^- \\ e_k &\equiv x_k - \hat{x}_k \end{aligned} \tag{3}$$

where:

$\hat{x}_{\bar{k}}$ **– *a priori* state estimate**
$\hat{x}$ **– *a posteriori* state estimate**
$e_{\bar{k}}$ **– *a priori* estimate errors**
e_k **– *a posteriori* estimate errors.**

The overall scenario for calculations (see Figure No. 1) is the same as in the least square method:

new estimate = prognosis + adjustment
adjustment = amplification · measurement prognosis error

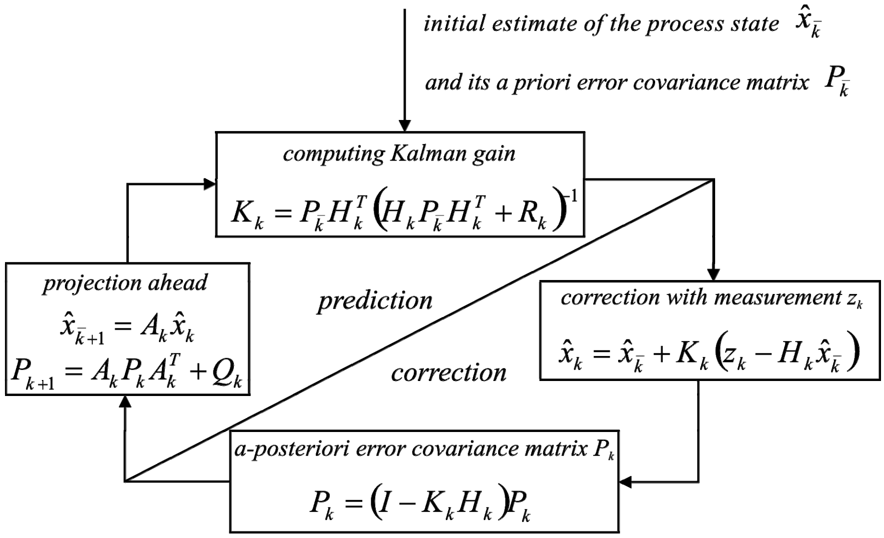

Fig. 1. The Kalman loop (Brown, 1992).

3. MEASUREMENT EXPERIMENTS

Measurement experiments were conducted using the NAWGEO service. Two identical GNSS satellite sets by Leica Geosystems (Leica GX1230 GG) were used. Antennas were mounted on vehicle roofs. The receivers operated in kinematic mode with a one–second period of position registration. The experiments had a duration of approximately thirty minutes. The vehicles moved about the streets of Warsaw on the route from Ursynów to Józefosław as well as on a large parking lot of a retail centres. Figure No. 2 presents the entire route of the two vehicles. The successive two graphs (Figures No. 3 and No. 4) depict selected fragments of the path travelled.

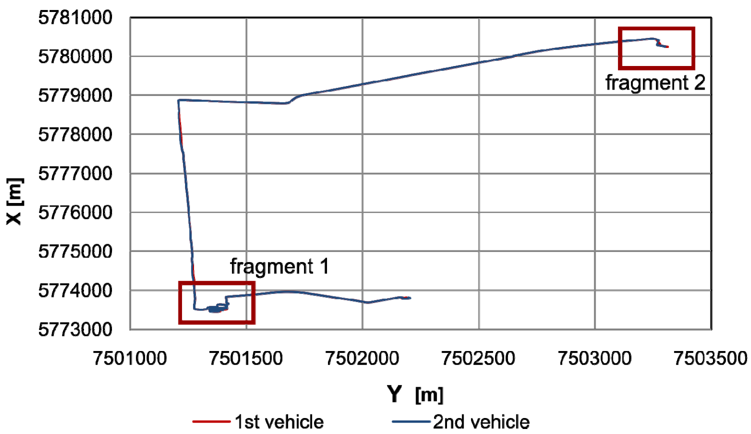

Fig. 2. Entire route of the two vehicles.

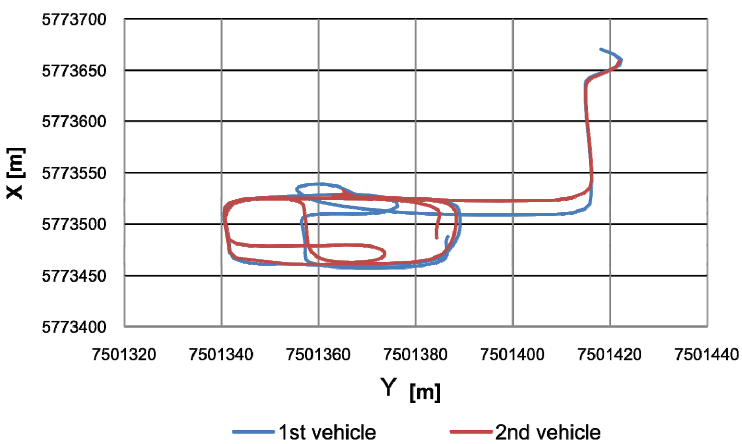

Fig. 3. Measurement experiment, fragment 1.

Velocity and relative velocity were determined for each of the vehicles from satellite observations, as well as changes in distances between the vehicles. Figures No. 5 and No. 6 present the relative differences in velocity and distance between the vehicles for a selected fragment of the path of travel.

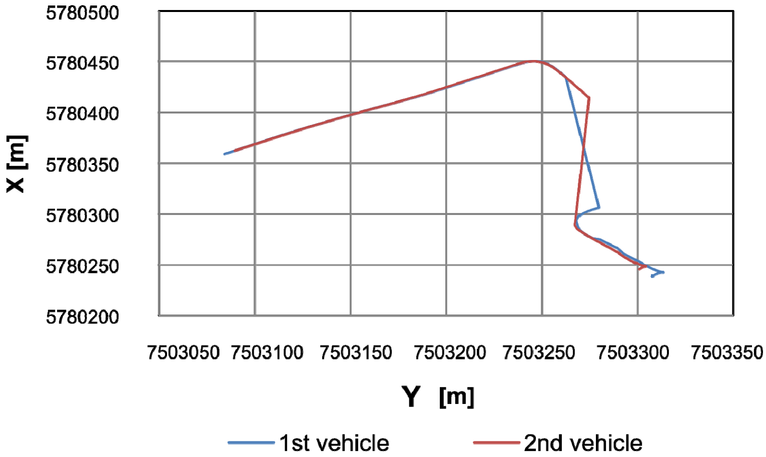

Fig. 4. Measurement experiment, fragment 2.

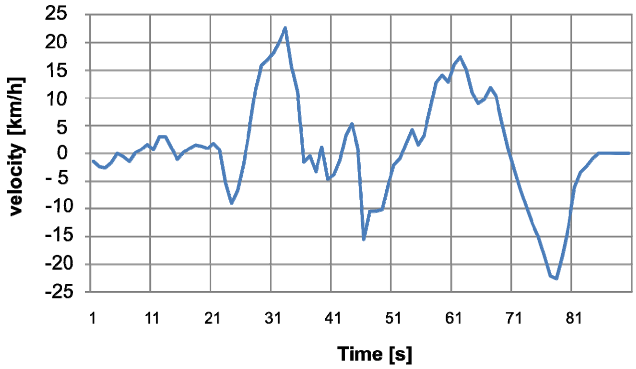

Fig. 5. Relative difference in velocity between the vehicles.

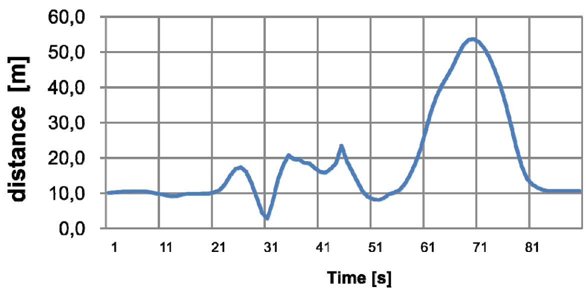

Fig. 6. Relative difference in distance between the vehicles.

Analysis of the selected fragment of the path (Figures No. 5 and No. 6), or actually the mutual location of the two moving antennas, was conducted using two measuring models. The first model assumed that only the difference in distance between the vehicles is subject to measurement (Figures No. 7 and No. 8). The second was supplemented by a measurement of the differences in vehicle velocity (Figures No. 9 and No. 10). In both cases the process at the output provided estimates of the values of distance differences and velocity differences. Attention should be called to the fact that for the same type of covariance matrix (various measurement models), the estimated

values of distance differences do not diverge from the measured value. The picture of value estimates of velocity differences is somewhat different. In this case the Kalman method behaves like a filter smoothing the graph of velocity differences (the estimated values are of the order independently of the assumed measurement model).

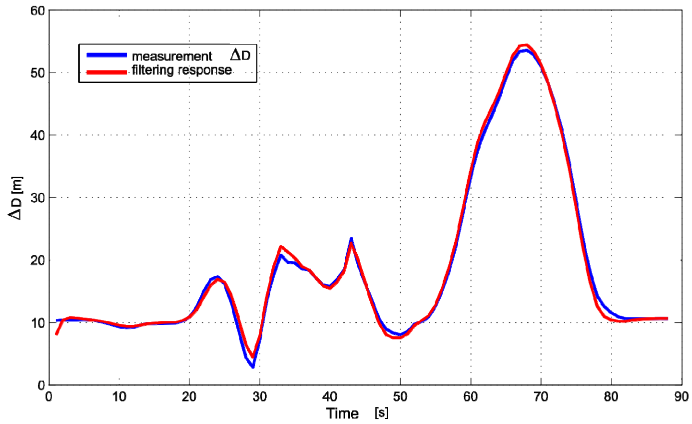

Fig. 7. Estimates of the values of distance differences, model I.

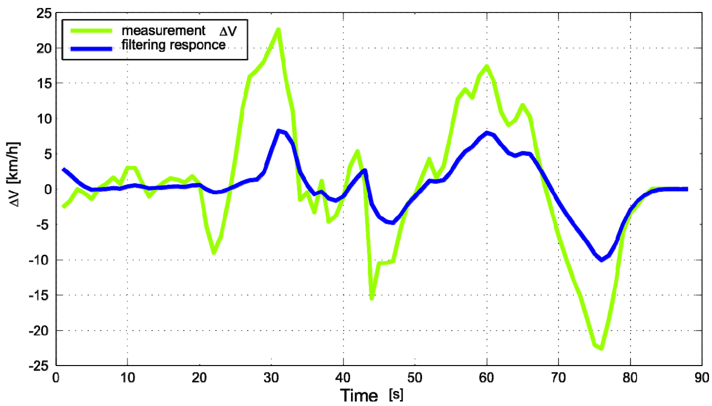

Fig. 8. Estimates of the values of velocity differences, model I.

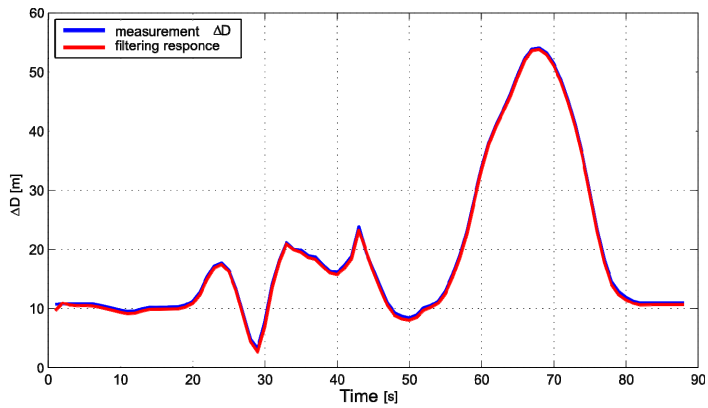

Fig. 9. Estimates of the values of distance differences, model II.

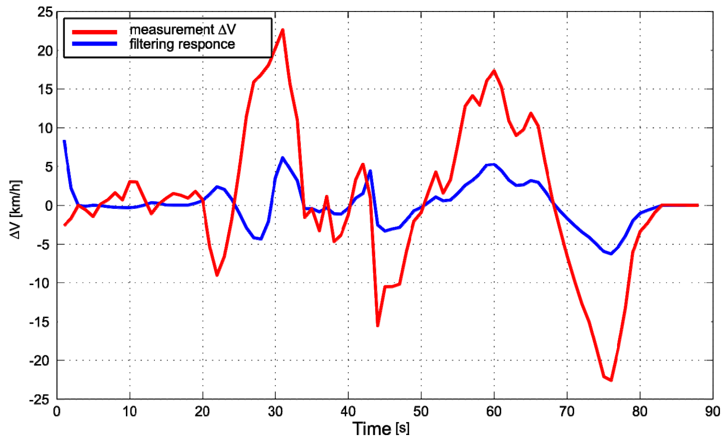

Fig. 10. Estimates of the values of velocity differences, model II.

A successive phase of research tied with the determination of mutual vehicle locations shall be the application of an independent velocity and acceleration sensor in order to supplement the model of the process to include what is known as control.

REFERENCES

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Brown, R. G., Hwang, P. Y. C. (1992): ***Introduction to random signals and applied Kalman filtering.*** **Second edition. Electrical Engineering Department, Iowa State University, Rockwell International Corporation. John Wiley & Sons, Inc.**