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# Algorithms of Mobile Object Location with Satellite Systems


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### Introduction

Main problems for mobile object location with satellite systems are solving a return navigation task when coordinates are unknown and filtering noise errors. These problems must be solving when object is moving with high speed and acceleration. The second task is developing using same else systems for velocity and acceleration measurements. In this case complex information processing algorithms are used.

For algorithms execution it was necessary to modeling satellite systems space objects, main errors of signal propagations and receiving. Satellite distribution modeling is described in [1] and all satellite parameters are used for GPS "NAVSTAR". Next step is to select of all satellites only best configured for minimized dilution of precision factor. Algorithms for satellite selection are used from [2]. For solving return navigation task tow methods and algorithms are research. First is the minimum mean-square (MMS) recursive algorithm. Second is recursive Kalman filtering algorithm

### Estimation of MMS recursive algorithm for mobile object place determination

For mobile object place location with minimum mean-square method is used algorithm:

$$\hat{X} = X_0 + (H^T H)^{-1} H^T (\widetilde{D}_M - D_M(\hat{X}_0)) . \qquad (1)$$

Where: $\mathbf{X_0}$ - vector of mobile object coordinates before estimation, $\hat{\mathbf{X}}$ - estimated coordinates, $\widetilde{\mathbf{D}}_\mathbf{M}$ - measured distances vector, $\mathbf{D_M}$ - calculated distances vector.

Vector **H** is processing using equation:

$$H = (\partial D_M^T(\hat{X}_0)/\partial X)^T . \qquad (2)$$

Results of modeling object location using (1) in case when coordinates before estimation are in center of Earth and clock time move called distance error is 85000 m is shown in Fig.1. Distance measuring errors are modeling as random processes with mean square value 10 m. For mobile object place location is used three coordinates X, Y, Z and move of clock time measured in meters. How it is obvious from Fig.1 after 3-4 cycles the place location is obtained with high precision. Fig.2 shows modeling results using MMS algorithms, when the coordinates and clock move before estimation are known with high accuracy. How it is obvious from Fig.2 random errors of coordinates are between values 20 – 50 m. In Fig.1 these errors also are present, but the scale of figure do not allow seeing them.

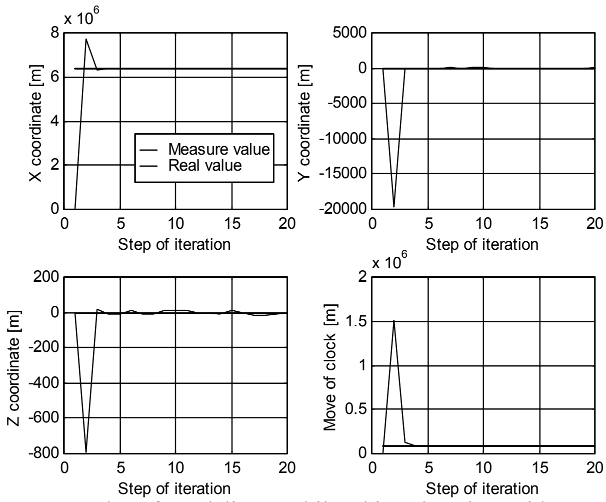


**Fig. 1.** Results of modeling mobile object location with MMS recursive algorithm when coordinates before estimation are in center of Earth and clock time move called distance error is 85000 m

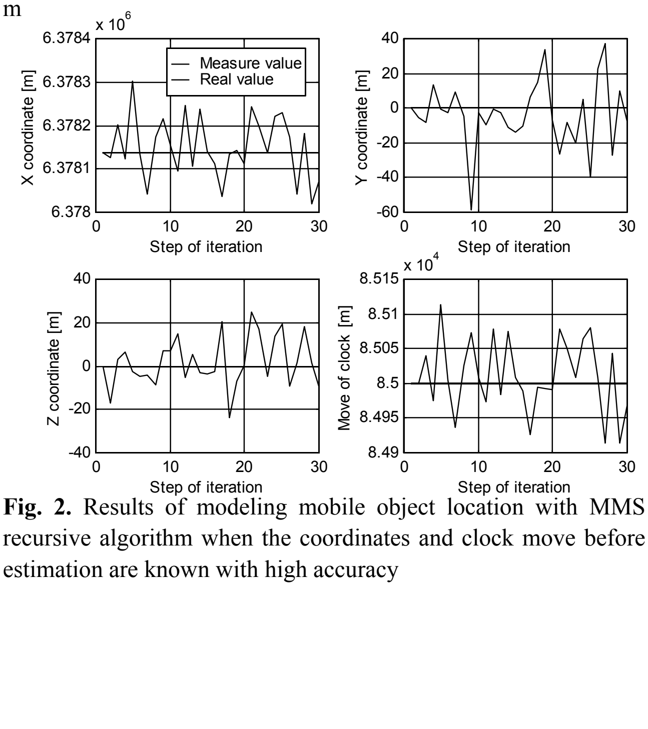


**Fig. 2.** Results of modeling mobile object location with MMS recursive algorithm when the coordinates and clock move before estimation are known with high accuracy

**Estimation of recursive Kalman filtering algorithm for mobile object place determination**

For mobile object place location with Kalman filter are used following algorithms:

$$K_k = P_k^- H_k^T (H_k P_k^- H_k^T + R_k)^{-1}, \quad (3)$$

$$\hat{X}_k = \hat{X}_k^- + K_k (Z_k - H_k \hat{X}_k^-), \quad (4)$$

$$P_k = (I - K_k H_k) P_k^-, \quad (5)$$

$$P_{k+1}^- = \Phi_k P_k \Phi_k^T + Q_k, \quad (6)$$

$$\hat{X}_{k+1}^- = \Phi_k \hat{X}_k. \quad (7)$$

Where $\boldsymbol{H}_k$ – measurement transmission matrix, $\boldsymbol{Z}_k$ – vector of measured parameters, $\boldsymbol{X}_k$ – systems state matrix, $\boldsymbol{K}_k$ – Kalman filter transmission matrix, $\boldsymbol{\Phi}_k$ – system state transmission matrix, $\boldsymbol{P}_k$ – measurement noise covariance matrix, $\boldsymbol{Q}_k$ – systems noise covariance matrix.

Index " $^-$ " show that parameters are calculate before measurements in "k" cycle.

Control of Kalman algorithm work was done in conditions so as for MMS algorithms. When noise is not influence the measurements after 3-4 cycles the place location is obtained with high precision, in case when coordinate before estimation is in center of Earth and clock time move called distance error is 85000 m. This result is absolutely equal with result show in Fig.1.

If there are noise of measurements the time of coordinate estimation is many times more than if the MMS algorithm is used. In Fig.3 are shown results of coordinate estimation for Kalman algorithm when noise of measurement is normal with sigma 10m and place point before estimation is turn of 1km and clock time move called distance error is 85000 m and is know.

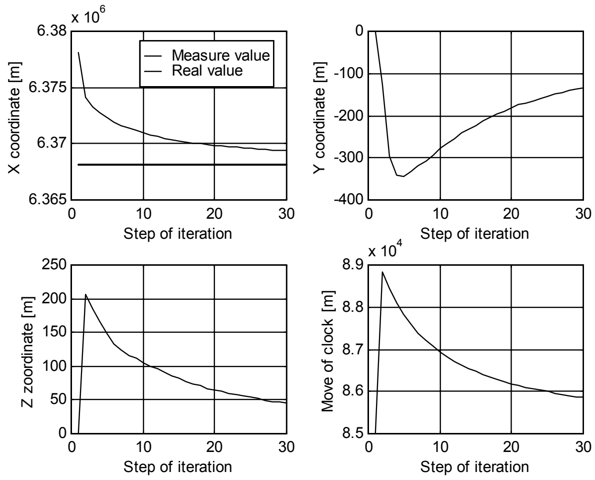


**Fig. 3.** Results of modeling mobile object location with Kalman recursive algorithm when the coordinates are turn off 1 km and clock move before estimation are known with high accuracy

As it is visible from Fig. 3. the error of coordinates estimation after 30 cycles are more then 100m, but fluctuations are very small. Better it is seen from Fig.4. where Kalman filtering of coordinate estimation is used without place turn off . How it is seen fluctuation error is about 5 – 10 m.

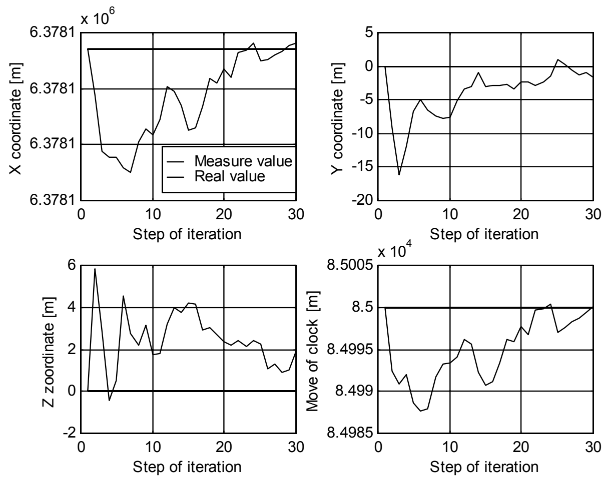


**Fig. 4.** Results of modeling mobile object location with Kalman recursive algorithm when the coordinates and clock move before estimation are known with high accuracy

Explore of MMS and Kalman recursive algorithms show that in case of large indeterminate of object start coordinates best results may be obtain with MMS algorithms, but precision of coordinates determination is higher in case when Kalman recursive algorithms are used.

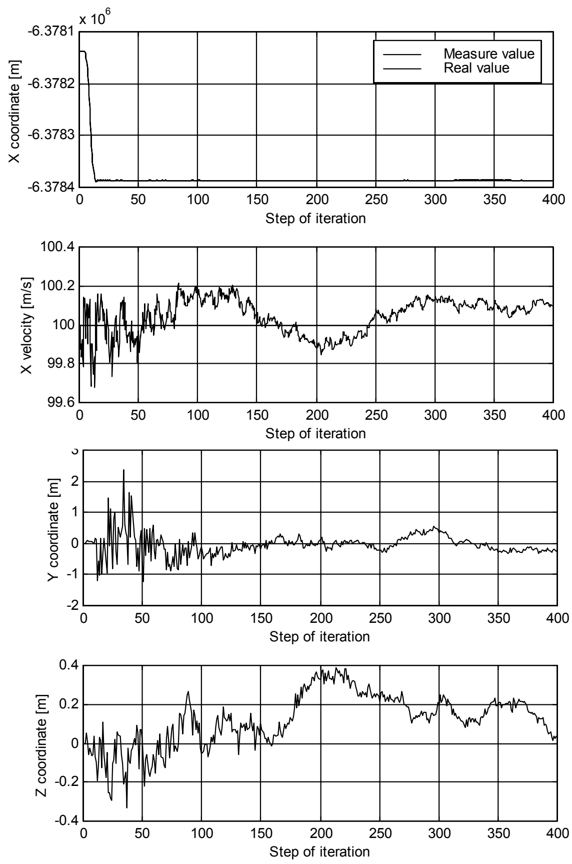


**Fig. 5.** Results of modeling mobile object location with MMS and Kalman recursive algorithm when coordinates before estimation are in center of Earth and clock move before estimation is known with high accuracy

Kalman filtering also determinates the parameters of mobile object motion, such as speed and acceleration. So it is recommended use MMS algorithms in fist stage of coordinate determination and then uses Kalman recursive filtering. The results of tow step algorithm modeling are show in Fig. 5. First minimum mean-square method is used and when correction of coordinates is les then 10m Kalman recursive algorithms is executed. How it seen measured errors les than 2m is reach. Used of Kalman algorithms also allow estimated the velocity of mobile object. In Fig. 5. are show results of modeling when speed is 100m/s and it is direct while X axis.

If the parameters of object dynamic are change in filtering process, the errors are growing. In this case Kalman algorithms must be corrected. How it is do is show in [4].

## Conclusion

The described method of increase in accuracy of an estimation of position of mobile objects due to complex used of minimum mean-square algorithms and Kalman recursive algorithms may be exploit in global satellite systems. The offered complex algorithm reduce time of coordinate estimation because MMS algorithms are very effective for quick place processing, but Kalman recursive algorithm allows to reduce fluctuation errors and estimate the dynamic parameters of mobile object.

## References


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Pateikta spaudai 2005 02 28



**A. Kluga. Mobilaus objekto vietos nustatymo naudojant palydovines sistemas algoritmai // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2005. – Nr. 3(59). – P.55–57.**

Pateikiamas povandeninių objektų vietos nustatymo panaudojant palydovines sistemas algoritmų palyginimas. Pirmasis algoritmas – tai rekursinis minimalios vidutinės kvadratinės paklaidos metodas. Antrasis – Kalmano filtracijos rekursyvinis algoritmas. Palyginimas atliktas panaudojant mobilaus objekto vietos nustatymo modeliavimą esant įvairioms triukšmų ir dinamikos sąlygoms. Parodyta, kad nei vienas iš algoritmų nedirba tinkamai esant įvairioms situacijoms, todėl mobiliose kompleksinėse sistemose turi būti naudojami abu algoritmai vienu metu. Il. 5, bibl. 4 (anglų kalba, santraukos lietuvių, anglų ir rusų k.).

**A. Kluga. Algorithms of Mobile Object Location with Satellite Systems // Electronics and Electrical Engineering. – Kaunas: Technologija, 2005. – No. 3(59). – P.55–57.**

Comparison of tow most frequently used algorithms for mobile object place location with satellite systems is shown in this work. First is the minimum mean-square (MMS) recursive algorithm. Second is recursive Kalman filtering algorithm. Estimation of algorithms was obtained by modeling mobile object place location with satellite systems in various dynamic and noise signal situations. Is show, that no one of algorithms is working perfect in all situations and thy can be used complex in mobile systems. Ill. 5, bibl. 4 (in English, summaries in Lithuanian, English, Russian).

**А. Клуга. Алгоритмы для определения местоположения подвижного объекта с помощью спутниковых систем // Электроника и электротехника. – Каунас: Технология, 2005. – № 3(59). – С.55–57.**

В работе рассмотрено сравнение двух наиболее часто используемых алгоритмов для определения местоположения подвижного объекта с помощью спутниковых систем. Первый это рекурсивный метод минимальной среднеквадратической погрешности. Второй это рекурсивный алгоритм Калмановской фильтрации. Оценка алгоритмов получена путем моделирования место определения мобильного объекта с помощью спутниковых систем в различных условиях помех и динамики. Показано, что не один из алгоритмов не работает исправно во всех ситуациях и поэтому должны быть использованы совместно в мобильных комплексных системах. Ил. 5, библ. 4 (на английском языке; рефераты на литовском, английском и русском яз.).