Design of Machines and Structures, Vol 4, No. 2 (2014) pp. 27–34.
https://doi.org/10.32972/dms.2014.017

THE SATELLITE-BASED ALGORITHM FOR DETERMINING THE LOCATION OF HYDRAULIC LIFT

ANATOLY SHEIPAK–PAVEL NOVIKOV
Moscow State Industrial University
115280, Avtozavodskayast. 16, Moscow, Russia
aseyp@msiu.ru, foad1989@mail.ru

Abstract: The article describes the specialized complex system for the hydraulic lift location determining. System consists of INS, Glonass and odometer. The advantages and disadvantages of used navigation systems are observed. The different error correction methods are also considered.
Keywords: *acceleration, satellite, error model, gyro drift, odometer*

1. Introduction

The fast development of technology for the last ten years has shown a great opportunity for successful solution of different navigation tasks, with the help of different devices that can be sat on the board of any craft or outside it. These tasks are actual not only in aviation, missiles, fleet, but also on the ground transport. But the high price is a reason why people cannot use them everywhere.

2. Statement of the problem

There are two different ways to calculate the way, inertial navigation systems (INS) and Glonass. An Inertial navigation system is a system of sensor designed to measure specific force and angular rates with respect to an inertial frame which, when integrated, provide velocity, position and attitude.

There are two approaches for the navigation frame simulations in the inertial system technology. The first one deals with the physical implementation of the navigation frame using a three-axes gyro-stabilized platform with three orthogonally placed accelerometers. Such type of a system is called INS platform.

The second one, called INS strapdown, provides the analytical image of the navigation frame in an on-board computer, using measurements from accelerometers and rate gyros installed directly on a vehicle body. The platform creates navigation frame on the board of the object, due to which it is possible to define the parameters of motion.

The principle of Glonass working differs from INS working. Glonass is a network of about 24 satellites orbiting the Earth. Wherever you are on the planet, at least 4 satellites are visible at any time. Each one transmits information about its position and the current time at regular intervals. These signals, travelling at the velocity of light, are intercepted by your Glonass receiver, which calculates how far away each satellite is based and how long it takes the messages to arrive.

In general, the Glonass signal contains pseudorange, carrier phase and Doppler measurements. The pseudorange and Doppler measurements can be utilized for position and velocity calculation; these measurements are typically in high sensitivity receiver applications. Pseudrange observations are obtained by measuring the transit time of the signal as it travels from Glonass satellite to the receiving antenna.

Due to non-synchronized receiver and satellite clocks, the measured range (pseudorange) is biased. Therefore, the receiver's clock difference with respect to the

satellite's Glonass time must be taken into account. This leads to a system of equations with four unknown parameters (three coordinates and clock drift); thus at least four satellite observations are necessary for position calculation.

A Glonass receiver calculates its position by precisely timing the signals sent by Glonass satellites high above the Earth. Each satellite continually transmits messages that include time the message was transmitted and satellite position at time of message transmission.

The receiver uses the messages to determine the time transmission of each message and calculates the distance up to each satellite using the velocity of light. Each of these distances and satellites locations defines a sphere. These distances and satellites locations are used to calculate the location of the receiver using the navigation equations. Mistakes don't accumulate during their work.

Glonass orbital errors occur due to the differences in the actual and modelled positions of the satellites. Three types of data, of non-uniform accuracy levels, are accessible for position and velocity determination of the Glonass satellites: almanac, broadcast ephemerides and precise ephemerides. Broadcast ephemerides are available in real time and orbital parameters are uploaded for each interval of two hours.

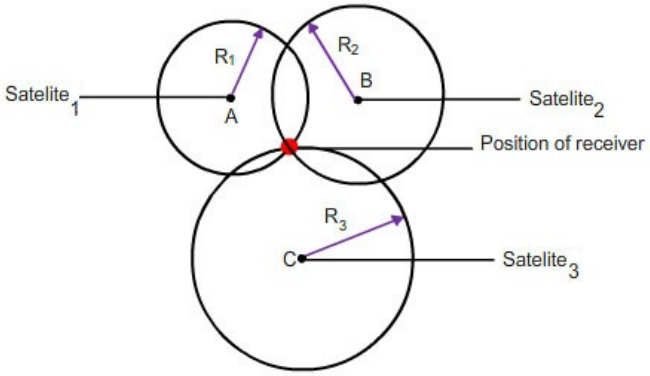


Figure 1. Principle of Glonass working

Another type of error is satellite clock error. These errors are due to the offsets in the clock frequency of each satellite with respect to the reference clock, which is monitored by the Master Control Station. The satellite error is usually less than 1 ms and, after implementing the broadcast correction, the remaining error is in the order of 8 to 20 ns (2 to 3 m). This error can be eliminated by D Glonass (difference in between the receivers), since it is the same for all receivers in the proximity, subject to essentially identical signal paths, simultaneously tracking the same satellite.

Both methods have advantages and disadvantages. INS systems errors are large in magnitude, low frequency in nature and grow over time. These error qualities stem from the solution of the second order differential mechanization equation. INS errors can be divided into two parts. The first is the stationary component (e.g. gyroscope drifts, horizontal attitude errors) which is independent of motion parameters and yields those INS errors oscillating over time with a very small Schuler frequency corresponding to a period of 84,4minutes. Therefore, this large component is quite predictable from an estimation point

of view and, thus it can be compensated in the output. The second non-stationary class of errors (e.g. sensor scale factors, installation errors and azimuth misalignment) is defined by motion parameters (vehicle accelerations and velocities, travelled distance), which makes it different to predict. The advantage of inertial systems is there autonomous working, all calculations are made on the board of the craft.

The universal system, which can work with all kinds of objects, doesn't still create. That's why the creation of system, which allows to use extra information about motion is relevant. The source of this information can be odometer – the device which counts the way. Odometer counts the rotation of wheel and conversion this to the value of the traversed path. There are several automobile systems, which include odometer. Unfortunately most of these systems exist like a prototype. High price and low accuracy doesn't allow produce them serially. That's why the creation of low cost system, which able to determine the position of the object with a given accuracy is still topical. INS errors determined by the accuracy of using sensors. The gyro drift is a very important parameter. If we use these systems on the Earth we can get information about velocity using odometer. Thus there is no need to count these velocity using INS systems.

However, both systems have a number of limitations which challenge their use in many land-based applications. Inertial sensor errors, for example, can be large in magnitude and grow over time without compensation using external information such as Glonass. On one hand, widespread use of a very accurate INS is constrained by their high cost. On the other hand, the operational capability of Glonass degrades in harsh environments such as urban and forest areas, where Glonass signal may be partially or completely blocked by buildings and dense foliage. Glonass receiver does not provide attitude information. The combination of Glonass and INS is well suited to the development of a range of applications as each unit compensates for the other's shortcomings.

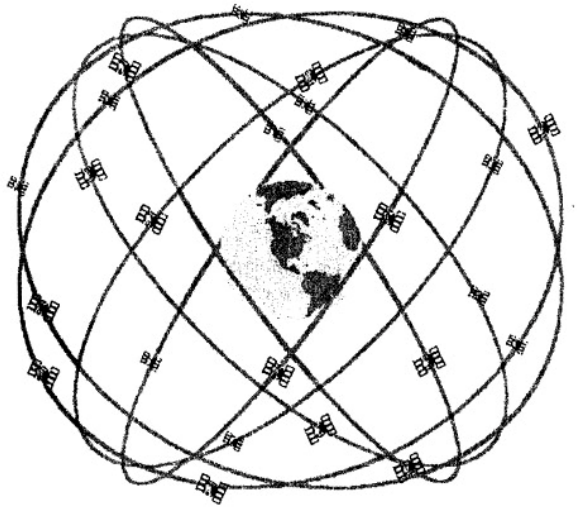


Figure 2. Configuration of orbital grouping system Glonass

The combination of Glonass and INS can deliver superior system performance in comparison to the performance of either system in stand-alone mode. One important

advantage of an INS is the ability to provide attitude data in addition to position and velocity information. The data rate of GPS measurements is typically 1–20 Hz, while the INS data rate is 60–100 Hz on average.

Despite above advantages, system inaccurate due to gyro drifts and accelerometer biases cause a rapid degradation in position quality, while Glonass errors are generally smaller and are not time-dependent. A Glonass receiver has high frequence errors while an INS typically does not. The differences in the nature of errors associated with the two systems benefits their integration through the use of a Kalman filter, which is a linear estimator that uses knowledge of the system dynamics and external measurements to obtain an optimal estimate of the state variables at the current epoch. It follows, therefore, that these two units combined in a common system will provide superior operation in terms of accuracy, integrity and availability than each system in stand-alone operation.

The problem of achieving better performance in terms of accuracy of INS/Glonass systems can be divided into two distinct problems: modeling and estimation. The modeling problem is concerned with the development of error models that describe more accurately the INS/Glonass system. The estimation issue devoted to achieving moro accurate error estimates, which are used for error compensation, trought the proper of the available process and measurement information. However, there is a contradiction between the two issues, since excessive complication of a system degrades the estimation accuracy of the state vector components. To achieve optimal results, a balance of two approaches should be attended.

Although recently a wide variety of different estimationalgorithms have been investigated for INS/Glonass integration. Kalman filter techniques are still more commonly applied for many applications. From the estimation viewpoint, the optimality of a conventional Kalman filter requires, in principle, good a priori knowledge about the process and noise statistics as well as a sufficiently long estimation time or data length. If the above information is inaccurate or varies in a manner that is not readily predictable, the estimation accuracy degrades from the theoretical prediction. These criteria have limited the applicability of the traditional Kalman filter in the case of INS/Glonass systems, both conceptually and practically. Adaptive filters and smoothing techniques sense the properties of the environments in which they operate and adjust the filter parameters accordingly. Therefore, when the properties of the operating environments are not known, or when they change with time in a previously unknown manner, these filters become very useful. Thus, such estimation methods are beneficial for INS/Glonass integration in changing Glonass conditions.

Several different integration schemes have been developed in recent years. They can be divided into two types: loosely coupled (sometimes referred to as centralized) and tightly coupled (referred as decentralized) strategies. In centralized schemes all measurements from INS and Glonass are processed in the same filter. The main advantage of this technique is in preserving data integrity. When there are less than three satellites observable and Glonass receiver does not provide any navigation solution, the pseudorangels of the remaining satellites can be used for a measurement update.

Another benefit of this type of integration comes from the fact, that poor Glonass measurements can be detected and rejected from the solution. However, tightly coupled algorithms usually have a sophisticated system model; consequently, large dimensions of the state vector degrade the estimation accuracy. The decentralized approach has become more popular for many applications. This method is based on the independence of the

Glonass and the INS navigation functions. It is a simple and flexible approach, since the filter size is relatively small compared to the extended Kalman filter in the tight integration. The only limitation of the loosely coupled integration scheme comes from the fact that at least four satellites are necessary to provide Glonass updates for the INS filter.

The high price of INS/Glonass system doesn't allow to produce it. The main goal now is to create a complex cheap system that consists of INS and Glonass with less accurate sensors and creation of data processing algorithm providing the specified accuracy. The main idea of the working system is alternately switching of INS and Glonass.

Error correction of INS by uses classic algorithm from Glonass receiver can be done with the help of the closed method. It is based on the application of additional control actions to the real or imaginary system platform. This system can be done only if for arbitrary motion can be allocated in the output values of the inertial velocity $\delta Ve$and δVn. To avoid errors, we can apply external sources of information about the speed. If we have eastern and northern components of the velocity of the object due to Glonass, then up to its own satellite system errors:

$$\delta \mathrm{Ve} = \mathrm{Ve} - \mathrm{V_E^{Gl}}, \quad \delta Vn = Vn - V_n^{Gl} \tag{1}$$

Damping-K1δV control signal is input to the velocity calculation unit of the navigation algorithm. The single channel error model has a form (E-channel):

$$\delta \dot{\mathrm{V}}_\mathrm{E} = -\mathrm{g}\Phi_\mathrm{N} + \delta \mathrm{f}_\mathrm{E} - \mathrm{K}_1 \delta \mathrm{V}_\mathrm{E}, \dot{\Phi}_\mathrm{N} = \frac{\delta \mathrm{V}_\mathrm{E}}{\mathrm{R}} + \delta \omega_\mathrm{N} + \mathrm{K}_2 \delta \mathrm{V}_\mathrm{E}, \tag{2}$$

Differentiating the first equation and substituting the second in his right part, we obtain the variation of error δVn:

$$\delta \ddot{\mathrm{V}}_\mathrm{E} + \mathrm{K}_1 \delta \dot{\mathrm{V}}_\mathrm{E} + \left(\frac{\mathrm{g}}{\mathrm{R}} + \mathrm{K}_2 \mathrm{g}\right) \delta \mathrm{V}_\mathrm{E} - \mathrm{g}\delta\omega_\mathrm{N} + \delta \dot{\mathrm{f}}_\mathrm{E}, \tag{3}$$

From the last equation it follows that the error in the output data decreases subsequently time, and the frequency

$$\omega_0 = \sqrt{\nu^2 + \mathrm{K}_2 \mathrm{g}} \gg \nu, \tag{4}$$

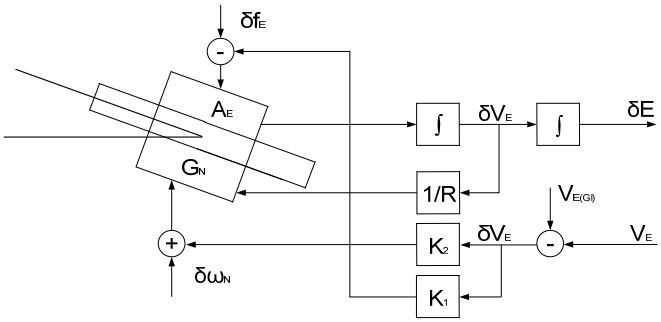


Figure 3. Closed method of error correction

The open method uses special algorithms for estimating errors of uncorrectable (autonomous) inertial system, which can be based on a priori information about their character, as well as the measurement of object motion parameters using external devices,

including Glonass receiver and odometer. The most common and effective algorithm of this kind is the optimal Kalman filter.

Let us consider any linear system that can be described by certain values usually inaccessible for the measurement. These values are elements of state vector $\bar{x}_k$ adopted a linear variation of the system (model):

$$\bar{x}_{k+1} = \Phi\bar{x}_k + G\bar{w}_k \quad (5)$$

whereΦ is the transition matrix, G is the input matrix, $\bar{w}_k = \bar{w}(t_k)$ is the input white noise with covariance matrix Q.

The parts of the state vector components or their linear combinations are directly observable according to the equation:

$$\bar{z}_k = H\bar{x}_k + \bar{v}_k, \quad (6)$$

where$\bar{z}_k$ is the measurement vector; $\bar{v}_k$is the measurement white noise with zero meaning and known covariance matrix R.

Kalman logic allows to obtain the best estimation ξ_k of the system, based on the measurement with errors. The Kalman filterprovides minimization of the mean-square error.

$$J_k = TrM[(\bar{x}_k - \xi_k)(\bar{x}_k - \xi_k)^T] \to \min. \quad (7)$$

At the first stage of applying the algorithm creates a priori estimate ξ_{k+1k} of the state vector of the system based on the assumption that the adopted model is accurate and contains no input noise:

$$\xi_{k+1k} = \Phi\xi_k \quad (8)$$

When the next value of the measurement vector $\bar{z}_{k+1}$ obtained, it is possible to specify a priori estimate by introducing feedback changes with matrix K_{k+1}:

$$\xi_{k+1}=\xi_{k+1k}+K_{k+1}(\bar{z}_{k+1} - H\xi_{k+1k}). \quad (9)$$

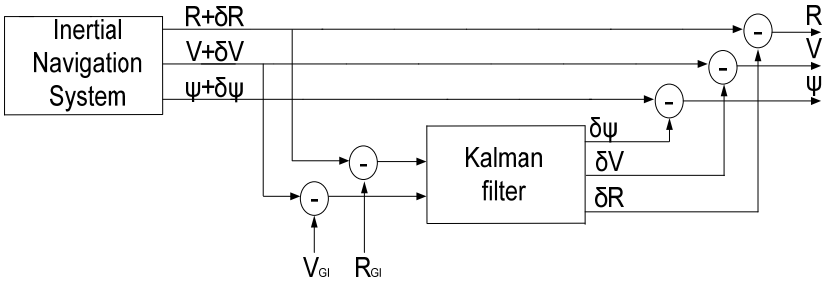


Figure 4. Open method of error correction

The second stage of the application filter algorithm includes finding the optimal value of the matrix K_{k+1} in accordance with the selected criteria:

$$\frac{dJ_{k+1}}{dK_{k+1}} = 0, \quad (10)$$

$$K_{k+1} = P_{k+1k}H^T(HP_{k+1k}H^T + R)^{-1}. \quad (11)$$

where$P_{k+1k} = M[(\bar{x}_{k+1} - \xi_{kk+1})(\bar{x}_{k+1} - \xi_{kk+1})^T]$ is the covariance matrix of estimation errors, which can be calculated:

$$P_{k+1k} = \Phi P_k\Phi^T + GQG_T. \quad (12)$$

Then we can calculate covariance matrix:

$$P_{k+1} = (I - K_{k+1}H)P_{k+1k} \quad (13)$$

If we cannot find measurement vector $\bar{z}_{k+1}$ then Kalman filter is put on prediction mode. For example, take R=∞ and then, according to the above described sequence of operations, the state vector estimation is performed using only a single model, and coincides with the a posteriori estimation of the a priori:

$$\xi_{k+1} = \Phi\xi_k \quad (14)$$

Concurrently with the main estimation function Kalman filter allows to smooth the noise contained in the measurement vector $\bar{z}_{k+1}$.

The principle of open inertial correction relies on the definition of its errors. So, for the eastern channel platform inertial obtain:

$$\begin{bmatrix} \delta E \\ \delta V_E \\ \Phi_N \\ \delta\omega_N \end{bmatrix}_{k+1} = \begin{bmatrix} 1 & T & 0 & 0 \\ 0 & 1 & -gT & 0 \\ 0 & \frac{T}{R} & 1 & T \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \delta E \\ \delta V_E \\ \Phi_N \\ \delta\omega_N \end{bmatrix}_k + \begin{bmatrix} 0 \\ 0 \\ 0 \\ T \end{bmatrix} w_k \quad (15)$$

$$\begin{bmatrix} E & -E^{Gl} \\ V_E & -V_E^{Gl} \end{bmatrix}_{k+1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \delta E \\ \delta V_E \\ \Phi_N \\ \delta\omega_N \end{bmatrix}_{k+1} + \begin{bmatrix} \delta E^{Gl} \\ \delta V_E^{Gl} \end{bmatrix} \quad (16)$$

Knowing at each step of calculating the value E^{Gl}, $V_E^{Gl}$and applying the Kalman filter, we can estimate the errors of the inertial system, including those that are not available for direct measurement (in particular, the deviation Φ_N platform from the horizontal plane and angular velocity $\delta\omega_N$ its drift).

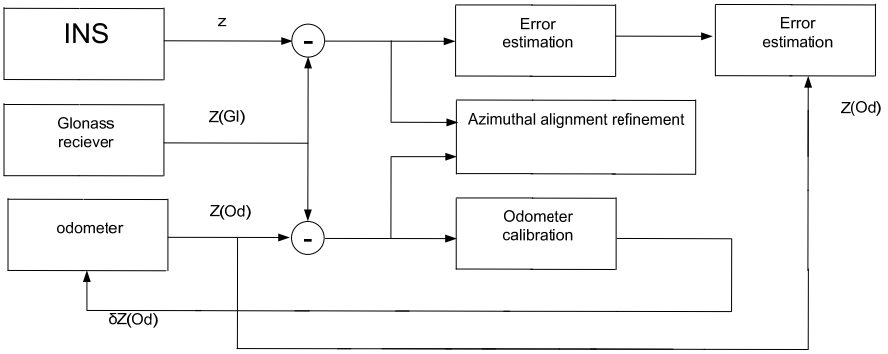


Figure 5. Integration scheme of INS, Glonass receiver, odometer

These estimates are used to amend the output readings of the coordinates $\overline{R} = [E,\ N,\ U_P]^T$, velocity $\overline{V} = [V_E,\ V_N,\ V_{UP}]^T$ and orientation angles $\overline{\Psi} = [\gamma,\ \vartheta,\ H]^T$.

In practice creates different combination techniques to correct the INS output data combining dignity closed and open circuits. One such techniques use information from Glonass receiver, inertial navigation system and odometer. In fact this method repeats the classical scheme of integrated inertial navigation system: errors of the inertial system are evaluated in real time using a Kalman filter, the obtained estimates are used for damping of physical or imagined platform, and to amend in the output data of the system.

This method extended by using the information from odometer. On the one hand they allow to identify and compensate the residual error of azimuthal alignment, on the other - to implement forecasting errors of the inertial part during the absence of high-quality reception of signals from navigation satellites, because odometer measurements are always available. The comparison of the distance traveled, calculated by the Glonass and odometer allows to calibrate the scale factor.

However, there are several reasons impeding of incarnation of described scheme. First of all it is low accuracy of micromechanical sensing elements. It does not allow such testimony to the coordinates and velocity which errors would submit to linear law. Unfortunately we can't use more expensive primary information sensors in this system because the price of the whole system will rise up.

Moving transport occurs in a narrow space, so very often satellite signal disappear, in these circumstances, the most reliable source of information about traversed path speed is odometer. All that means, that we have to develop specialized alternative algorithm of synthesis of navigation information, which we can get from different sources.

3. Conclusion

This paper proposes an alternative approach procedure to evaluate location settings land mobile objects that require precise positioning. The proposed system is fundamentally differs from existing, one because it is based on sensitive elements having a small size, and low market price. The proposed algorithm analysis of the system was tested in actual operating conditions.

4. References

[1] Salychev, O. S.: *Applied Inertial Navigation: Problems and Solutions – M.* BMSTU Press, 2004.
[2] Vlasenko, A.: *Integrated gyroscopes iMEMS – angular velocity sensors of Analog Devices firm / Electronic Components,* 2003.
[3] Hemerly, E. M.–Schad, V. R.: *Implementation of a GPS/INS/Odometer.* 2008.
[4] Hong, S. K.–Park, S.: Minimal-drift Heading Measurement using a MEMS Gyro for Indoor Mobile Robots // Sensors. 2008, Vol.8, pp. 7287–7299.
[5] Smart – V1 Antenna. Data Sheet. Version 0D [Electronic Resource] – NovAtel Inc., 2006.