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VEHICLE POSITIONING SYSTEM BASED ON GPS AND AUTONOMIC SENSORS

ABSTRACT

In many real situations like in tunnels, forests and in urban canyons GPS position calculation became impossible or not accurate enough. The solution of the problem is to integrate Global Positioning System with Inertial Navigation System. In such a solution it is possible to determine object position with temporary disappearance of GPS signals and improve precision. The paper presents an idea of data integration from two navigation sensors (subsystems). The aim of such an approach is to improve estimation precision of vehicle position and ensure autonomy of the system.

System consists of two positioning subsystems: Dead Reckoning (DR) and Global Positioning System. Sensors fusion is realize by 32-bit microprocessor with ARM architecture and interfaces circuits. DR/GPS algorithm was implemented in 32-bit microprocessor with ARM SAM7S core.

Keywords:
GPS, integration, inertial navigation.

INTRODUCTION

The position calculation on the base of Global Positioning System (GPS), when signals received by receiver are not corrupted, is relatively simple. However when GPS signals are week, disturbed or when number satellites are not sufficient for system performance, the position calculation became impossible or not accurate enough. Such situation can be observed in tunnels, forests and in urban canyons. The solution of the problem is to integrate Global Positioning System with Inertial Navigation System. In such a solution it is possible to determine object position with temporary disappearance of GPS signals and improve precision. The paper presents an idea of data integration from two navigation sensors (subsystems). The aim of such an approach is to improve estimation precision of vehicle position and ensure autonomy of the system.

System consists of two positioning subsystems Dead Reckoning (DR) and Global Positioning System. DR subsystem consists of distance sensor, azimuth sensor and angle velocity sensor. Azimuth sensor is build on the base of two magnetometers.

Angle velocity is provided by gyroscope. All DR sensors are integrated in Inertial Measurement Unit. GPS subsystem is built on GPS receiver. Sensors fusion is realize by 32-bit microprocessor with ARM architecture and interfaces circuits. Because azimuth sensor is very sensitive to electromagnetic field it must be corrected by gyroscope. Kalman filter algorithm is used for sensors integration. Instantaneous position of vehicle in DR subsystem is calculated by modeling the path of the vehicle as pieces of lines with length and direction provided by azimuth and distance sensors.

DR subsystem is integrated with GPS subsystem by Kalman filter which estimates errors of both subsystems and corrects position. The paper contains algorithms of DR GPS integration, results of examination by use the simulation and real data.

KALMAN FILTERING

The Kalman filter [2, 3] is a recursive estimator. It has two phases: predict and update. The predict phase uses the state estimate from the previous step $\widehat{\mathbf{x}}_{k-1}^{-}$ to produce an estimate of the state at the current step $\widehat{\mathbf{x}}_k^{-}$. Moreover an estimate covariance matrix $\mathbf{P}_k^{-}$ is predicted. In the update phase, measurement information $\mathbf{z}_k$ at the current step is used to refine this prediction to arrive at a new, more accurate state estimate $\widehat{\mathbf{x}}_k$, again for the current step. Kalman gain $\mathbf{K}_k$ characterize influence of correction of estimating state. Last equation describe correction of error covariance matrix $\mathbf{P}_k$. In DR/GPS system following formulas can be applied:

$$\widehat{\mathbf{x}}_k^{-} = \mathbf{F}\,\widehat{\mathbf{x}}_{k-1} \tag{1}$$

$$\mathbf{P}_k^{-} = \mathbf{F}\,\mathbf{P}_{k-1}\mathbf{F}^{T} + \mathbf{Q} \tag{2}$$

$$\mathbf{K}_k = \mathbf{P}_k^{-}\mathbf{H}_k^{T}(\mathbf{H}_k\mathbf{P}_k^{-}\mathbf{H}_k^{T} + \mathbf{R}_k)^{-1} \tag{3}$$

$$\widehat{\mathbf{x}}_k = \widehat{\mathbf{x}}_k^{-} + \mathbf{K}_k(\mathbf{z}_k - \mathbf{H}_k\widehat{\mathbf{x}}_k^{-}) \tag{4}$$

$$\mathbf{P}_k = (\mathbf{I} - \mathbf{K}_k\mathbf{H}_k)\mathbf{P}_k^{-} \tag{5}$$

where:

$\widehat{\mathbf{x}}_k^{-}$, $\widehat{\mathbf{x}}_k$ — state vectors: a priori, a posteriori;

F, **H** — state and observation matrixes;

Q, **R** — matrixes of state and measurement noise;

I — identity matrix.

DATA PROCESSING IN DR/GPS POSITIONING SYSTEM

Vehicle positioning system integrates two subsystems: Dead Reckoning and Global Positioning System. Difference between position calculated by DR and GPS receiver is estimated by Kalman filter. DR position are corrected by filter response [1, 4, 5]. The structure of the designed positioning system and its data flows are presented in figure 1.

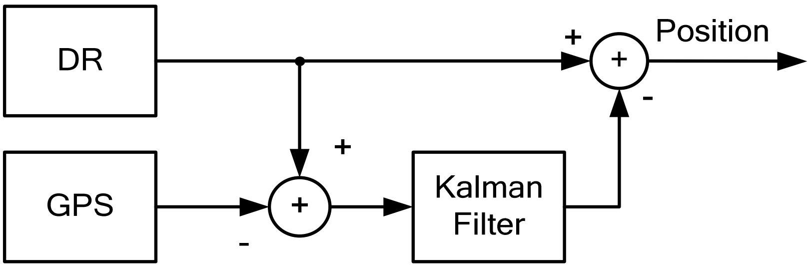

Fig. 1. DR/GPS positioning system

The key operations realized in integrated positioning system include: estimation of heading, dead-reckoning position calculation and correction of DR position with GPS data [1, 5].

State equation **x** and matrix **F** are shown below:

$$\mathbf{x} = \begin{bmatrix} \Delta\lambda & \Delta\phi \end{bmatrix}^{\mathrm{T}}, \quad \mathbf{F} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \tag{6}$$

where

$\Delta\lambda$, $\Delta\phi$ are longitude and latitude increment, respectively.

DEAD-RECKONING ALGORITHM

Position of vehicle in DR subsystem is calculated by modeling measuring and counting distance increments, travelled by a vehicle in short time spans, with respect to known initial position [4, 5]. Method of position calculation is presented in figure 2.

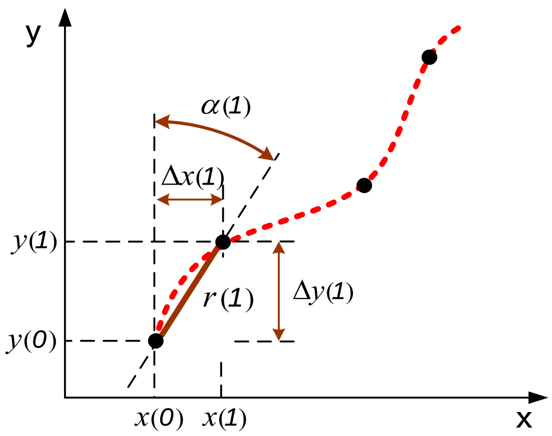

Fig. 2. DR subsystem calculation

$$x(n) = x(0) + \sum_{i=0}^{n} \Delta x(i) \quad \text{for} \quad \Delta x(i) = r(i) \cdot \sin\alpha(i); \tag{7}$$

$$y(n) = y(0) + \sum_{i=0}^{n} \Delta y(i) \quad \text{for} \quad \Delta y(i) = r(i) \cdot \cos\alpha(i), \tag{8}$$

where:

$x(n)$, $y(n)$ — Cartesian co-ordinates;
$\Delta x(n)$, $\Delta y(n)$ — co-ordinate increments;
$r(i)$ — distance increment;
$\alpha(i)$ — heading of the vehicle;
n — time index.

As a distance increments meter odometer was used. Odometer makes measurement indirectly by counting wheel revolution multiplied by wheel circumference. Headings α of the vehicle are estimated with use of two devices providing information on angular orientation of the vehicle, a gyro and an electronic compass [1, 4, 5]. Compass calculate heading indirectly by magnetic field intensity measurement. Sensors are situated in perpendicular directions and measure ingredients of magnetic field vector.

$$\alpha(n) = \alpha_m + arctg\left(\frac{H_y(n)}{H_x(n)}\right), \tag{9}$$

where:

α_m — magnetic inclination;
H_x, H_y — magnetic field intensity measurement in x, y directions.

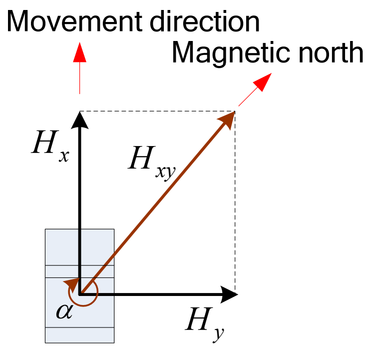

Fig. 3. Component of Earth magnetic field

Because magnetic field sensors are sensitive to electromagnetic and magnetic distortion heading measurement must be corrected by gyro. The gyro is aligned with the body vertical axis of the vehicle and measures angular velocity of the vehicle around this axis. Relative heading is calculated by integration angular velocity ω. A calculation of the absolute heading requires an addition of the external initial heading $\alpha(0)$. Standalone gyro in calculation of the heading is limited to relatively short time intervals Δt. It is caused by drift effect existence

$$\alpha(n) = \alpha(0) + \Delta t \sum_{i=0}^{n} \omega(i)\,, \tag{10}$$

where

$\alpha(0)$ is initial heading.

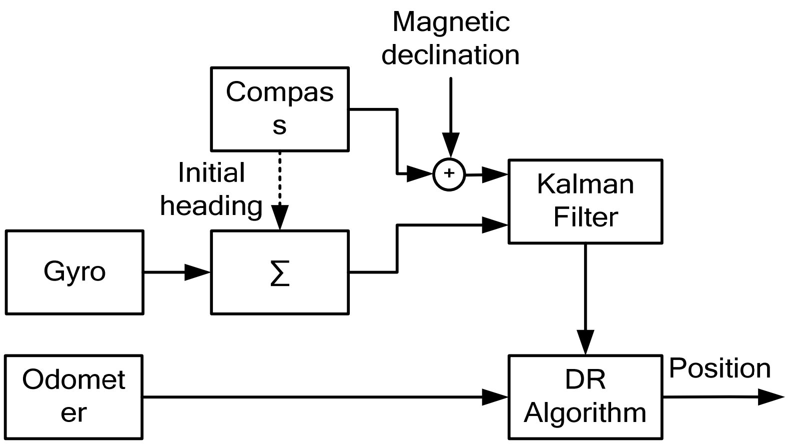

Fig. 4. DR subsystem

These problems can be overcome with use of an electronic compass that measures the absolute heading. Its data can be used to initialize the calculation of the gyro heading. Stochastic properties of compass and gyro errors are different. From the foregoing, one can see that integration gyro and electronic compass in a positioning system can be beneficial. Data of both sensors are jointly processed by means of a Kalman filter.

$$\alpha(n) = \alpha(n-1) + \left[\omega(n-1) - g_{bias}\right]\Delta t \,, \tag{11}$$

where:
$\alpha(n)$ — heading;
$\omega(n)$ — angular velocity from gyro;
g_{bias} — gyro drift.

The dynamics model of the subsystem describes time propagation of the gyro errors, in the following state-space form

$$\mathbf{x}_k = \mathbf{F}\,\mathbf{x}_{k-1} + \mathbf{B}\mathbf{u}_{k-1} \,. \tag{12}$$

The state vector **x** has two components and state matrix **F** is as follows

$$\mathbf{x} = \begin{bmatrix}\alpha & g_{bias}\end{bmatrix}^{\mathrm{T}},\ \mathbf{F} = \begin{bmatrix}1 & \Delta t \\ 0 & 1\end{bmatrix}. \tag{13}$$

The steering vector **u** has one component and steering matrix **B** is as follows

$$\mathbf{u} = g_{bias}\,,\ \mathbf{B} = \begin{bmatrix}\Delta t & 0\end{bmatrix}^{\mathrm{T}}. \tag{14}$$

The predictions are realised with small time steps 0.01 s, whereas the corrections are realised when the new compass data become available. The measurement update of the state vector and its associated covariance matrix is performed with a time step 0.2 s.

IMPLEMENTATION AND TEST RESULTS

To demonstrate the quality of the integrated DR/GPS positioning system a comparison of stand only GPS receiver and DR subsystem, a test results is presented. DR/GPS algorithm was implemented in 32-bit microprocessor with ARM SAM7S core [6]. System was mounted on civilian vehicle as shown on figure 9. Results of heading estimation is demonstrated in the figure 5. Longitude and altitude estimation are presented on the figures 7–8. Finally figure 6 shows how DR/GPS is working in comparison to stand alone GPS or DR.

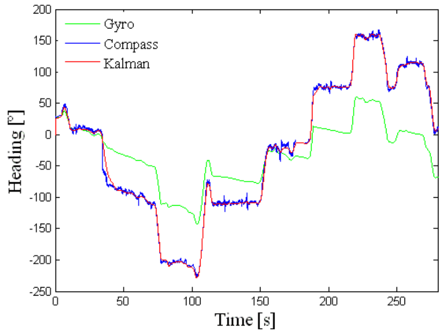

Fig. 5. Heading estimation

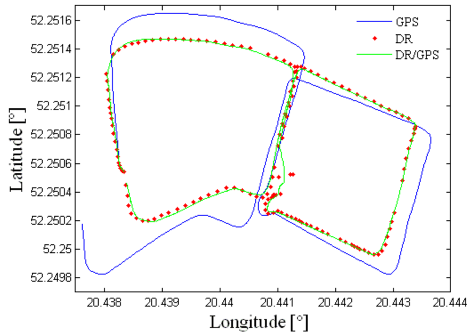

Fig. 6. Track estimation

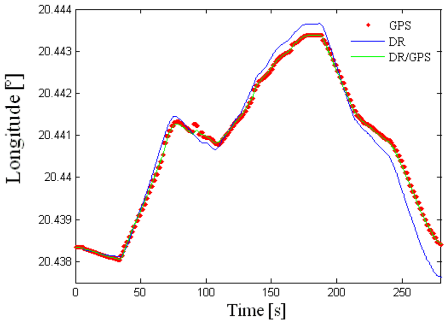

Fig. 7. Latitude estimation

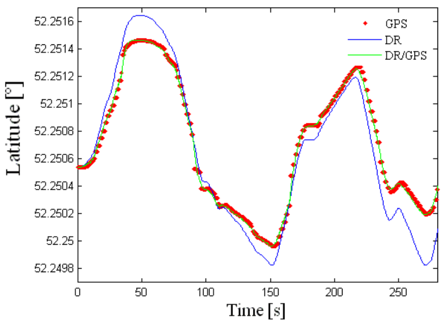

Fig. 8. Longitude estimation

Fig. 9. Prototype of DR/GPS system

DR/GPS algorithm was implemented in 32-bit microprocessor with ARM SAM7S core. DR and GPS integration make system more accurate in comparison to any of them alone. Algorithms eliminate errors increasing with time of operation appearing in DR subsystem. Moreover, it reduce time-uncorrelated errors appearing in GPS subsystem. DR/GPS join autonomy and high precision of position calculate. Described system is fully autonomous. Disappearance of GPS signals does not disappearance of position calculating.

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