Dynamic Compensation of the Gyro Bias by E-compass

Rosen Miletiev[1], Radostin Kenov[2], Ivaylo Simeonov[3], Emil Iontchev[4]

Abstract – **The paper discusses the dynamic compensation of the gyroscope bias offset based on the e-compass data. The static compensation is not very effective process because the bias offset depends from the temperature, supply voltage, chip statistics, etc. and bias instability (BI) refers to the additive error in a gyroscope's output with stochastic characteristics. The compensation is very important if the magnetic field data are lost or there are magnetic disturbances caused by soft-iron or hard-iron effects. The experiments are accomplished to proof the gyroscope bias offset compensation ability of the system.**

Keywords – **gyro bias, e-compass, compensation.**

I. INTRODUCTION

The integration of the inertial data defines the most important problem of this navigation system – an unlimited error accumulation [1]. Typical factors, which have influence on the inertial sensor accuracy may be described as follows – null offset (bias), temperature hysteresis, gyroscope sensitivity to the linear accelerations, sampling noise, non – orthogonal sensor axes, etc. [2,3]. The additive error leads to the unlimited error accumulation due to the data integration. The bias offset is the main source of integration errors in IMU systems when velocity and distance are calculated on the bases of the accelerometer and gyroscope data. In the most of cases these errors may be grow rapidly if the bias offset is not be compensated.

In our previous paper [4] we proposed the dynamic compensation method based on the e-compass data which requires a smooth filter to eliminate data spikes generated by the differentiation step. The current paper this disadvantages is overcome by using the training and working gyroscope modes. The detection of the modes is based on the analysis of the total linear object acceleration.

II. BIAS COMPENSATION ALGORITHM

The bias compensation algorithm is based on the information of the linear accelerometer and e-compass. The system calculates the pitch, roll and yaw angles (Fig. 1) by means of the Kalman filter and e-compass. The corrected Z gyro data are calculated by subtraction of the raw Z gyro data with the last known mean value while the switch was closed.

If the object is stationary for a certain period of time (n_{lim} samples) the switch is closed (Fig. 1) and the raw gyro data are integrated for time duration τ_u. The obtained calculated heading angle is compared with the e-compass heading angle and the result rotation angle is divided to the integration time to calculate the average gyro bias value which is subtracted from the raw data. If the object is non-stationary the last obtained average gyro value is not updated until the object become stationary again. The state of the object is detected according to the total linear acceleration $A = \sqrt{A_x^2 + A_y^2 + A_z^2}$ (Fig. 2). If this acceleration exceeds the given threshold value A_{lim} then the object is defined as non-stationary and the switch is opened. In this case the correction is made by the last known bias value.

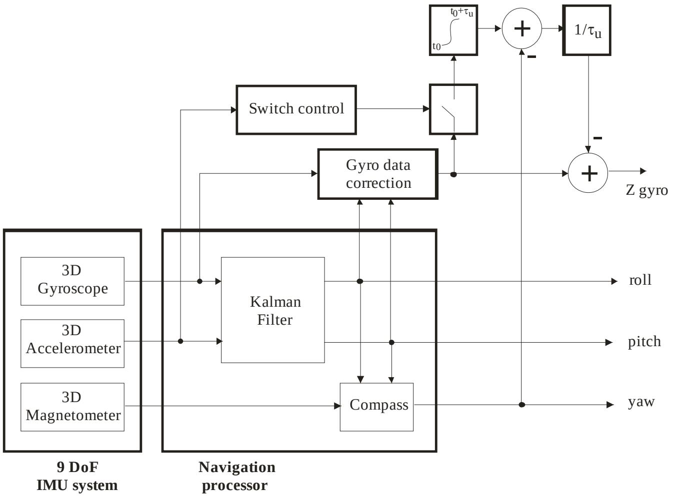

Fig. 1. Bias compensation algorithm

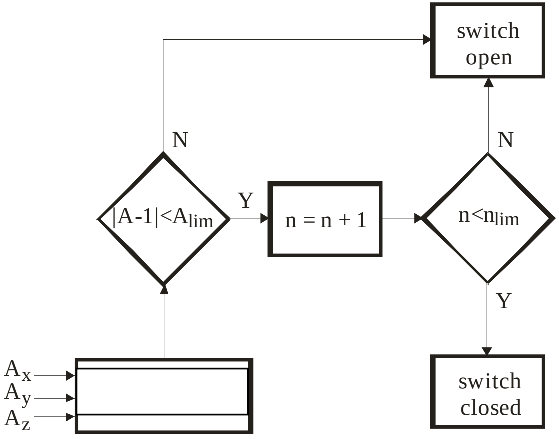

Fig. 2. Switch control algorithm

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The bias calculation algorithm is accomplished after the gyro correction block. The data are corrected on the basis of the object tilt angles according to the equations (Fig. 3).

$$\begin{bmatrix}\dot{\phi}(t)\\ \dot{\theta}(t)\\ \dot{\psi}(t)\end{bmatrix}=\begin{bmatrix}1 & \sin\phi(t)\tan\theta(t) & \cos\phi(t)\tan\theta(t)\\ 0 & \cos\phi(t) & -\sin\phi(t)\\ 0 & \frac{\sin\phi(t)}{\cos\theta(t)} & \frac{\cos\phi(t)}{\cos\theta(t)}\end{bmatrix}\begin{bmatrix}\omega_\phi(t)\\ \omega_\theta(t)\\ \omega_\psi(t)\end{bmatrix}$$

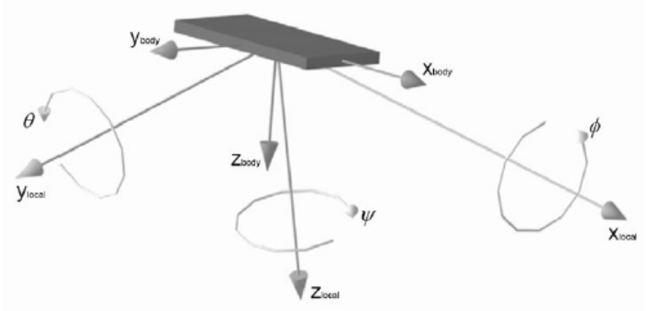

Fig. 3. Gyro data tilt compensation [5]

The proposed algorithm is tested using the hardware platform described in our previous paper [4].

III. EXPERIMENTAL DATA ANALYSIS

The comparison analysis of the bias compensation is accomplished by the test drive. The inertial data are measured using a sampling frequency equal to 20Hz and the total measurement time is set to 18000s which corresponds to $3{,}6.10^5$ data samples. The threshold values A_{lim} and n_{lim} are set to 0.1 and 1200 respectively.

The data analysis results of the switch control algorithm is shown at Fig. 4 and the Z angular acceleration graphics before and after bias compensation is shown at Fig. 5. The result of the comparison analysis between the proposed algorithm and the static compensation are written at Table I and are illustrated at Fig. 6.

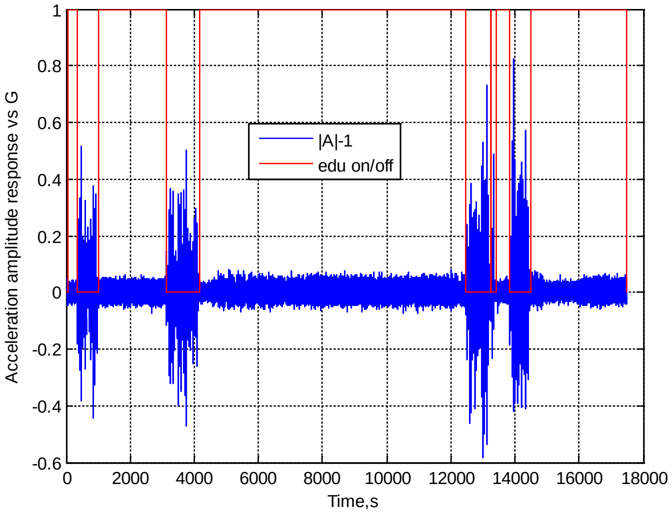

Fig. 4. Illustration of the switch control algorithm

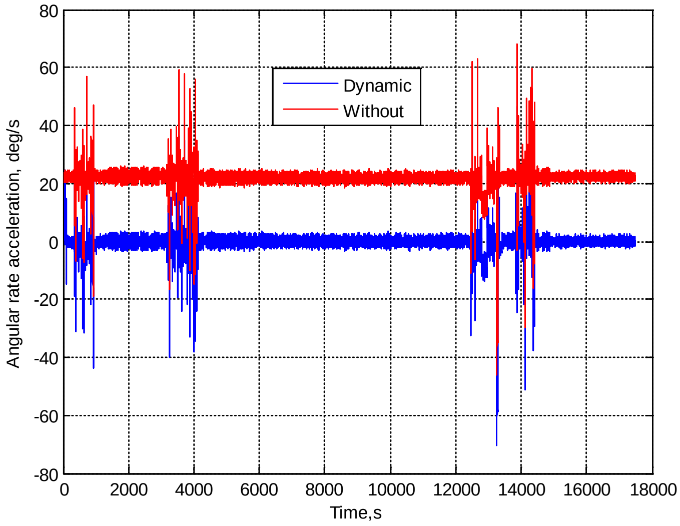

Fig. 5. Angular acceleration graphics before and after dynamic bias compensation

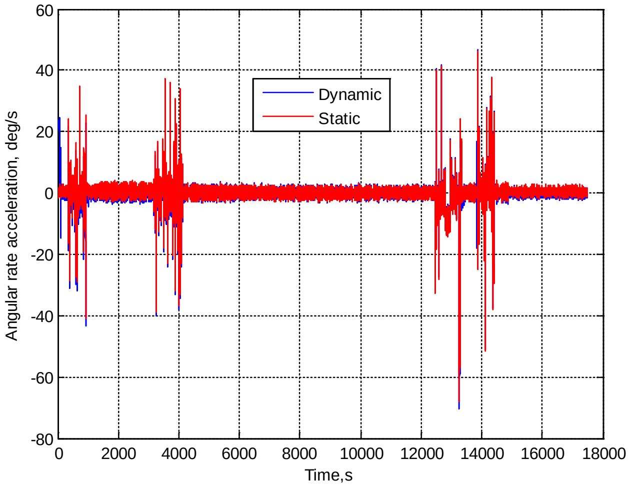

Fig. 6. Angular acceleration graphics with static and dynamic compensation

TABLE I
EXPERIMENTAL RESULT SUMMARY

	Gyro bias, deg/s		
Sample interval*	Without ompensation	With static compensation	With dynamic compensation
$1\ldots6.10^3$	22,705	$8{,}60.10^{-1}$	$4{,}50.10^{-3}$
$2.10^4\ldots6.10^4$	22,477	$6{,}19.10^{-1}$	$-1{,}79.10^{-2}$
$9.10^4\ldots2{,}4.10^5$	21,856	$-7{,}48.10^{-14}$	$1{,}55.10^{-6}$
$3.10^5\ldots3{,}5.10^5$	22,229	$3{,}72.10^{-1}$	$2{,}62.10^{-5}$

*time intervals may be calculated by a sample interval divided by 20 (sampling frequency).

The static compensation is accomplished on the basis of the bias calculation between sample numbers $9.10^4\ldots2{,}4.10^5$. In this sample interval the bias is fully compensated by the static compensation but in the other interval the bias values vary from 10^{-1} to 10^0 deg/s. In the same time the bias values are below 10^{-2}deg/s in all tested intervals.

IV. CONCLUSION

The current paper describes a gyro bias compensation algorithm which is based on the calculation of the mean value when the object is stationary according to the e-compass heading angle data. The object state is detected according to the total linear acceleration and the acceleration threshold. If the object is non-stationary the raw gyro data are processed by tilt compensation algorithm initially and bias compensation algorithm after that. If the object remains stationary for a certain period of time a new bias value is calculated.

The comparison analysis results show that the dynamic compensation algorithm reduces the bias values from 10^1 to 10^4 times compared to the static compensation.

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