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Hardware Implementation of Low Cost Inertial Navigation System Using Mems Inertial Sensors

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Abstract- *This work deals with a new approach to calibrate low cost six degree of freedom MEMS inertial Navigation system to be used in Unmanned Air Vehicle (UAV). The accelerometer and gyroscope are modeled with inter axis misalignment correction. To determine calibration parameters of a tri axis accelerometer at least nine equations will be required to solve for nine unknowns (3 scale factor, 3 zero bias, 3 misalignment angles). In this new approach three new linear equations were formulated to determine the calibration parameters thereby reducing number of positions needed in multi position test. The formulated methodology for accelerometer is validated by conducting twelve position tests. All combination of positions was attempted iteratively. After identifying the singularities, the Study on the results suggests that only six different positions of the sensors are enough to solve nine unknowns within 3 equations. Similar methodology was applied to calibrate tri axial Gyroscope in rate test. Rate test results were studied and analyzed with standard values provided my sensor manufacturer. An inertial sensor (SINS) error model is introduced based upon the calibrated data. Final algorithm is uploaded in the ATMEGA 328 micro controller which is embedded in the IMU in order to remove errors from the sensors output. Navigation algorithm is also coded to track the object in the desired frame using MALAB and Arduino software. The 3D view of the attitude and position variation of sensors in a real time plot is viewed by Python software and MATLAB.*

I. Introduction

Inertial Navigation System (INS) is a method of navigation which determines the states of a moving vehicle using motion sensors. States of the vehicle refers to position, velocity and orientation of the vehicle. INS is used in aircrafts, ships, guided missiles and UAVs.. But the MEMS INS systems available currently in market are very expensive. There are low cost sensors but with less accuracy which cannot be relayed upon. The accuracy of these low cost MEMS inertial sensors can be improved by doing proper calibration.. So efforts are taken in this paper to reduce the cost of calibration and improve the accuracy of low cost MEMS inertial sensors. Additionally, improving the performance of IMUs is aimed by using these estimated parameters. Therefore an error calibration algorithm is implemented and estimated parameters are used in the calibration algorithm

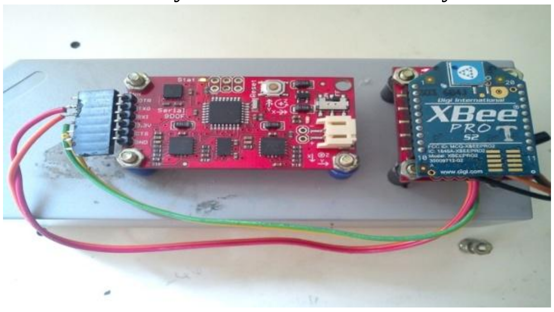

Figure 1. Developed INS platform

Sensor Selection

The board includes four sensors- an LY530AL (single axis gyro), LPR530AL (dual axis gyro), ADXL345 (triple axis accelerometer), and HMC5843(Triple axis magnetometer), which gives nine degrees of inertial measurement. The board comes along with an analog to digital converter which saved more time in going for a design of converter. The output of all sensors are processed by an onboard ATmega328 and output over a serial interface. To make the sensors communicate with computer and process data live with the coding XBEE module, a wireless link is used. As shown in FIG 1 the IMU sensor setup assembling was made.

Accelerometer Calibration

Calibration is the procedure for comparing instrument output with the known reference information about the quantity to measure. . In the current work the calibration for accelerometer is done using the gravity vector as a reference input. And to calibrate gyroscope a precise rate table rotating at known rotation rate is used.A wide range of study is done especially in calibrating the accelerometers of the IMU. A linear model of the accelerometer is formulated and the sensor is subjected to Multi position test in the Inclinometer. It is attempted to find a possible solution to calibrate tri-axial accelerometer that utilizes minimum static positions, using a simple test platform. Data for calibration is collected by placing the accelerometers in 12 positions and 6 positions method of calibrating accelerometer is also performed.

Sensor Modelling With Error Correction

The output precision of the accelerometer suffers from small angle inter-axis misalignments (α_{xy}, α_{xz}, α_{yx}, α_{yz}, α_{zx}, α_{zy}) between the sensor axis and the platform co-ordinate. Skog showed that the error model can be simplified by assuming s^p coincides with s^a as shown in equation (1)

$$s^p = T_a^p s^a , \; T_a^p = \begin{bmatrix} 1 & -\alpha_{yz} & \alpha_{zy} \\ 0 & 1 & -\alpha_{zx} \\ 0 & 0 & 1 \end{bmatrix} \quad (1)$$

The sensor can be linearly modelled in equation (2)

$$V_i = K\left[T_a^p\right]^{-1} s_i^p + b \quad (2)$$

V_i – Output vector $[v_x, v_y, v_z]^T$ at i- sample in volts;

K- Diagonal matrix of scale factors. Diag$[k_x, k_y, k_z]$ in volts/g;

b-Zero bias vector of each axis $[b_x \; b_y \; b_z]^T$ in volts. (a)

T_a^p-inter-axis misalignment correction matrix. (b)

s_i^p- gforce vector in platform coordinate $[g_x \; g_y \; g_z]^T$at i-sample.

(a)

(b)

Figure 2. Multi position test

From the equation the nine parameters going to be determined are

$$\left[K_x \; K_y \; K_z \; \alpha_{yz} \; \alpha_{zy} \; \alpha_{zx} \; b_x \; b_y \; b_z \right]$$

It can be seen that at least nine different samples will be required to solve the equation. An attempt to reduce the number of samples required is performed.

$$\begin{bmatrix} V_x \\ V_y \\ V_z \end{bmatrix}_i = \begin{bmatrix} K_x & 0 & 0 \\ 0 & K_y & 0 \\ 0 & 0 & K_z \end{bmatrix} \begin{bmatrix} 1 & -\alpha_{yz} & \alpha_{zy} \\ 0 & 1 & -\alpha_{zx} \\ 0 & 0 & 1 \end{bmatrix}^{-1} \begin{bmatrix} g_x \\ g_y \\ g_z \end{bmatrix}_i + \begin{bmatrix} b_x \\ b_y \\ b_z \end{bmatrix} \quad (3)$$

From equation (3) it is obvious that Z- axis is the simplest among the three and only two unknowns *(b_z k_z)*, followed by Y- axis with three unknowns *(b_y k_y α_{zx})* and lastly X- axis with four unknowns *(b_x k_x α_{yz} α_{zy})*.

Each combination will produce a solution, if the linear equation is non-singular and unique. A *Matlab m-file* was programmed to generate the results iteratively. The singular and non singular solutions were segregated and the count is tabulated for both 12 and 6 position method in table (1).Here the non singular solution could be found out by the principle of *matrix rank*From the table it is clear that lot of effort and computation is needed in order to solve the equation with 12 position method. Finding singular and non singular solutions and segregating them in 12 position method is a tedious job. But it is comparatively simple in 6 position method.The calibration parameters are determined for both the set of inputs. A comparison of 12 position and 6 position

Solution in	**singular**	**Non-singular**	**total**
X(6 pos)	8	7	15
12pos	452	43	495
Y(6pos)	14	6	20
12 pos	160	60	220
Z(6pos)	9	6	15
12(pos)	42	24	66

Table 1. solution for 6 and 12 positions test has been analysed. From the solutions of the equation, it can be inferred that there is very less deviation between 6 and 12 position calibration parameters. Hence it is suggested that 6 position test itself is sufficient to calibrate the tri-axial accelerometers. Samples collected from angular block and precision inclinometer yielded the similar result.

ERROR MODELLING

Accelerometer values contain the value of acceleration in addition with bias, scale factor, misalignment error and also sensor noise. Hence before going in to Navigation algorithm, it is necessary to eliminate errors by using the below mathematical model. Estimated calibrated value as shown in table (2) used as an input for the below equation (4). After developing the mathematical model, create a separate module for error model in the coding algorithm and integrate the module in to the initial data acquisition module. In the ATmega328 controller, first developed the algorithm for signal acquisition from the sensor and signal conversion. Once the calibration work over the Euler angle algebra is used to integrate the accelerometer data and gyroscope data in order to obtain the position for desired frame.

	Kx	Ky	Kz
Mean (6pos)	1.0767	1.0395	1.4461
12pos	1.0686	1.0392	1.4482
	∝yz	**∝zy**	**∝zx**
Mean(6pos)	-0.0098	-0.0051	-0.0121
12 pos	-0.0098	-0.0048	-0.0200
	bx	**by**	**bz**
Mean(6pos)	0.6346	0.9221	0.9328
12 pos	0.6338	0.9234	0.9408

Table 2. Comparision of calibration parameters obtained From 6 & 12 positions

$$\begin{bmatrix} a'_x \\ a'_y \\ a'_z \end{bmatrix} = \begin{bmatrix} 1+\delta+\delta_x & M_{xy} & M_{xz} \\ M_{yz} & 1+\delta+\delta S_y & M_{yz} \\ M_{zx} & M_{zy} & 1+\delta+\delta S_y \end{bmatrix} \begin{bmatrix} a_x \\ a_y \\ a_z \end{bmatrix} + \begin{bmatrix} B_x \\ B_y \\ B_z \end{bmatrix} \begin{bmatrix} \delta B_y \\ \delta B_y \\ \delta B_z \end{bmatrix} + \begin{bmatrix} n_x \\ n_y \\ n_z \end{bmatrix} \quad (4)$$

a' = accelerometer output; a = actual acceleration

δS_x = scale factor instability δB_x = Bias instability

n_x = sensor noise M_{zy}= misalignment error

B_x = Bias S_x = scale factor error

RATE TEST FOR GYROSCOPE

Gyroscope calibration is performed using precise rate table capable of rotating at three different speeds (90 deg/min, 180 deg/min, 360 deg/min). A rate table will **have** extremely tight design tolerances which keep the rotational axis which is precisely perpendicular to the sensor platform plane. The rate table is also capable of very precise angular positioning which allow for dynamic testing of the accelerometer and IMU package. Data were sampled for 10 seconds in each axis for three different rates. Similar to accelerometer calibration, using six position methods Gyroscope is calibrated. Here instead of gravity vector the known angular rate is taken as reference. The bias and sensitivity of the Gyroscope in the entire three axes is determined.

Gyro axis	Bias(V)	Sensitivity(V/^{O}/S)
x	0.85	0.00320
y	0.85	0.00293
z	0.845	0.00285

Table 3. Estimated Gyroscope parameters

GYROSCOPE ERROR MODELLING AND EULER ANGLE ALGEBRA

A separate module is created for including calibration data in the coding. From table (3) bias, scale factor and misalignment value is taken. This estimated data is taken as input value for mathematical modelling of error calibration

$$\begin{bmatrix} w'_x \\ w'_y \\ w'_z \end{bmatrix} = \begin{bmatrix} 1+\delta+\delta_x & M_{xy} & M_{xz} \\ M_{yz} & 1+\delta+\delta S_y & M_{yz} \\ M_{zx} & M_{zy} & 1+\delta+\delta S_y \end{bmatrix} \begin{bmatrix} w_x \\ w_y \\ w_z \end{bmatrix} + \begin{matrix} B_x & \delta B_y \\ B_y & \delta B_y \\ B_z & \delta B_z \end{matrix} + \begin{matrix} B_{gx} & 0 & 0 \\ 0 & B_{gy} & 0 \\ 0 & 0 & B_{gz} \end{matrix} \begin{matrix} a_x \\ a_y \\ a_z \end{matrix} + \begin{matrix} n_x \\ n_y \\ n_z \end{matrix}$$

(5)

w'_x = actual acceleration

Figure 3. Rate Table Test

w_x = acceleration from the accelerometer

EULER ANGLES ALGEBRA

A transformation from one co-ordinate frame to another can be carried out as three successive rotations about different axes. For instance, a transformation from reference axes to a new co-ordinate frame may be expressed as:

$$C = \begin{pmatrix} \text{Cos}\Theta\cos\psi & -\cos\Phi\sin\psi + \sin\Phi\sin\Theta\cos\psi & \sin\Phi\sin\psi + \cos\Phi\sin\Theta\cos\psi \\ \text{Cos}\Theta\sin\psi & \cos\Phi\cos\psi + \text{sinsinsin} & -\sin\Phi\cos\psi + \text{cossinsin} \\ -\sin\Theta & \sin\Phi\cos\Theta & \cos\Phi\cos\Theta \end{pmatrix} \quad (6)$$

Figure 3. Rate test using Single axis Rate table.

A. RESULTS

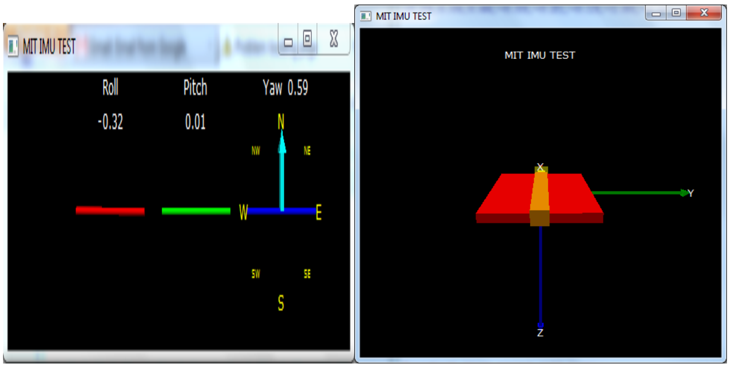

Figure 4. Sensor 3D view from Python software

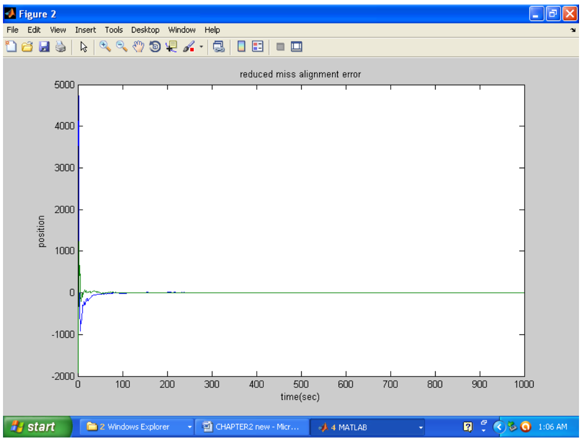

Figure 5. sensor output after calibration

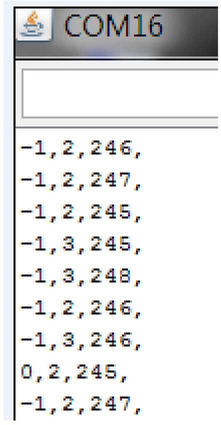

Figure 6. Sensor output after calibration via Arduino

SUMMARY OF THE WORK

The work aims in developing an inertial navigation system using low cost MEMS inertial sensors. Preliminarily inertial sensor suitable to our specification has been chosen (9 DOF razors IMU), then an INS platform is created with wireless communication enabled using XBEE module. Since it is necessary to remove errors from the sensors to improve accuracy calibration for both accelerometers and gyroscope in all three axes is done and the calibration parameters were found out. An algorithm is proposed to remove the deterministic errors and stochastic errors. Deterministic errors such as bias, misalignment and sensitivity are calibrated by multi-position test. Stochastic errors are removed by means of adding random noise. Mathematical model is developed based upon the calibrated data. Final algorithm is uploaded in the ATMega 328 micro controller which is embedded in the IMU in order to remove errors from the sensor.

Since the calibration data and Navigation algorithm is directly burned in to the sensor controller, now the sensor is capable of producing Navigation results with fewer sensor errors. Navigation algorithm is also proposed to track the object in the desired frame which carries INS. Three dimensional view of the attitude and position variation in a real time plot is viewed by Python software. Position and attitude variation is a real time is viewed by Arduino software.

VI Future Work

The future scope of the work is:

- To find a low cost and simple calibration procedures to calibrate inertial sensors.
- Improvising the position algorithm thereby improving the accuracy.

To improve the navigation algorithm using dual quaternion method and also the integration method of INS and GPS

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References

[1]. Anthony Kim, M. F. Golnaraghi, "**A Quaternion-Based Orientation**

[2]. **Estimation Algorithm Uning an Inertial Measurement Unit"** Proceedings of International Conference on Intelligent Robots andSystems, IEEE press, May 2001

[3]. Aggarwal.P, Syed Z,Niu X and El-sheimyN ,"**Standard testing and calibration procedure for low-cost MEMS Inertail sensors and units**" journal of navigation,pg-323-336,2008.

[4]. Alberto Olivares,J.M.Gorriz,"**high efficiency low cost Accelerometer aided Gyroscope Calibration**" International conference on Test and Measurement,2009.

[5]. G.Artese,A.Trecroci"**Calibration of a low cost MEMS INS sensor for an Integrated Navigation System**",Remote sensing and spatial information sciences,VolXXXVIII,Beijing 2008.

[6]. W.T.Fong,S.Kong and AYC Nee"**Method of infield user calibration of an inertial measurement unit without external equipment**",Measurement and science technology,2008.

[7]. Frantisek Adamcik"**Error analysis of Inertial Measurement Unit**" ISSN1648-778,vol 15,2011.

[8]. Isaac Skog, Peter Handel ,"**Calibration of a MEMS inertial measurement unit" ,**XVII IMEKO World Congress Metrology for a Sustainable Development,Rio de Janeiro, Brazil ,2006.

[9]. KianSekTee,MohommedAwad,AbbasDehghani"**Tri-axial accelerometer static calibration**" , Proceedings of world congress on engineering,2011.

[10]. KouroshParsa,Ty A. Larky, BahramRavani,"**Design and Implementation of a Mechatronic all-Accelerometer Inertial Measurement Unit**" , IEEE/ASME transactions on Mechatronics,Vol.12,December 2007.

[11]. Wassim Khoder, Bienvenu Fassinut-Mombot, Mohammed Benjelloun,"**Inertial Navigation Attitude Velocity and Position Algorithms**

[12]. **using Quaternion Scaled Unscented Kalman Filtering**". Industrial Electronics, 2008. IECON 2008. 34th Annual Conference of IEEE.

[13]. Lurtz"**Design and analysis of Inertial Navigation System with Skew Redundant Inertial sensors**",technical report,Department of URUC-HAI Engineering, Morhdorh,2011.

[14]. Nebot E,DumantWhyle H"**Initial calibration and alignment of low cost Inertial navigation units for a land vehicle applications**", journal ofRonoticssystems,vol 16,pp-81to 92,feburary 1999.

[15]. Oliver.J.Woodman,"**An introduction to Inertial Navigation** ", Technical report ,Cambridge University,2000.

[16]. PriyankaAggarwaal,ZainabSyed,Dr,Naser El Sheimy,"**Cost effective testing and calibration of low cost MEMS sensors for IntegratedPositioning,Navigation and Mapping system**s", Shaping the change XXXIII congress Munich,Germany,2006.

[17]. L.Sahawnesh,M,A.Jarrah"**Development and Calibration of Lowcost MEMS IMU for Uav applications**", Proceedings of 5th International symposium on Mechatronics and its applications,Jordon,2008.

[18]. Xiao Xuan,FuMengyin,Wang, QingZhe"**Improved Calibration Algorithm for strap down Inertial Navigation System**", Proceedings of the 29th Chinese control conference,china.

[19]. Gebre-Egziabher, Demoz, Elkaim, Gabriel,Powell, J.D., and Parkinson, Bradford, "**A Gyro-Free Quaternion-Based Attitude Determination System Suitable for Implementation Using Low Cost Sensors**," Proceedings of IEEE 2000 PositionLocation and Navigation Symposium, March 13-16, 2000, pp. 185-192.2011