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MEMS GYROSCOPE AND ACCELEROMETER BASED NORTH FINDING SYSTEM

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ABSTRACT

The ability to precisely determine geographic location information is crucial for many navigation and location systems including in oil mining industry. There are few instruments used to sense north and estimating orientation such as; compass, electronics magnetometer, inertial gyroscope compass, digital magnetic compass, theodolite and Global Positioning System (GPS). The high quality gyroscopes, such as ring laser gyros able to maintain reading at high level, yet the device and technology is bulky and expensive. The accuracy of a compass and electronics magnetometer easily degraded by electromagnetic interference while GPS signals are not very reliable inside buildings. Hence, the MEMS gyroscope and accelerometer based north finding system is proposed to cater the raised problems. The automated system comprises of Micro-Electro-Mechanical System (MEMS) gyroscope and accelerometer mounted horizontal on the rotator laser, where the whole system controlled by microcontroller Arduino Mega. The system proven an accuracy with complementary filter factor, a = 0.97 while the rotator has been calibrated using autocollimator and observed that the rotator successfully rotating at ±0.02° for a rotation angle from 0 ° to 360 °. Moreover, the field test results prove that the developed system achieve an accuracy of ±1.5° with respect to the true north.

Keywords: MEMS gyroscope, MEMS accelerometer, north, complementary filter.

INTRODUCTION

The ability to accurately and autonomously determine geographic location and orientation information is a key factor for many navigation and location systems [1-5]. North point is the main axis rotation of earth which located along the earth surfaces towards Geographic North Pole, and north is the reference point in order to determine any other directions. Generally, there are several instruments used to sense north and geographic information such as; compass, electronics magnetometer, inertial gyroscope compass, digital magnetic compass and Global Positioning System (GPS) [6-12].

North determination traditionally obtained by using magnetic compass which measures the magnetic field of the Earth and geomagnetism. However, the performance of compass or even the one installed in a smartphone greatly depends on its installation location as it relies on the earth's magnetic field to provide heading.

The earth's field is too inconsistent to provide accurate information due to man-made or natural magnetic anomalies which distort the local magnetic field in an unpredictable way, especially indoor area. In addition, the compass system can be easily degraded by nearby ferrous materials, electromagnetic interference and including weather [12-14]. For these reasons, the compass is not reliable when using inside a buildings. In fact, correcting the impact of magnetic field distortions on the heading is quite challenging. Hence, in order to cater issue related to magnetic field sensing, sun sensors [15], theodolite and high quality gyroscopes, such as ring laser gyros (RLG) have been used to maintain the reading at high accuracy level, yet the device and technology is bulky and very expensive. As recent years, Micro-Electro-Mechanical System (MEMS) gyroscope has been widely used to measure the angular rate of rotation [18-20] and it able to measure the Earth's rotation rate [12-13]. There are many advantages of MEMS gyroscope as in [21-24], but the angular rate signal of MEMS gyroscope must be integrated with respect to time in order to produce readable angle where these will caused drift problem [25-29]. Therefore, [30-33] suggested a preventive method by merging outputs of two or multi sensors via digital filtering in order to correct the drift issue of MEMS gyroscope.

[34-36] used Kalman digital filter to reduce drift, yet [37] argues that the mathematical algorithm of Kalman Filter is too complex. [32, 38] claimed that angle can be achieved using less sensors with simpler algorithm as the systems become complicated with many sensors and lead to inaccuracy.

Thus, building the above, due to lackness of MEMS gyroscope that can be easily affected by drift, a method by merging output of MEMS gyroscope and accelerometer through complementary filter is proposed in seeking north. The main idea of developing digital complementary filter is to use the strength of one sensor to overcome the weaknesses of the other sensor. In addition, this paper aiming a low cost north finding system with high accuracy with less complex of algorithm and less CPU intensive.

METHODOLOGY

a) Experimental setup

A combined 3-axis gyroscope and 3-axis accelerometer of MPU6050 sensor is used. The gyroscope provide signal in terms of rotational velocity (rotation distance over time) while the accelerometer produces signal in distance over time. The 5V of power supply from Vcc pin of Arduino Mega is applied to generate the MEMS gyroscope and accelerometer to measure the angular rate of rotation and acceleration force signal. The

MPU6050 will be activated with 5V of power supply from Vcc pin of Arduino Mega and communicates through the I2C protocol. In order to set up the I2C lines, pin labelled as SDA (data) on the MPU 6050 will be connected to the Arduino's analog pin 20 (SDA) and pin labelled as SCL (clock) on the MPU 6050 to the Arduino's analog pin 21 (SCL).

During the experiment, the temperature effects were put under control by keeping the unit of MPU6050 at ambient temperature and the sensor will be warmed up prior to the experiments. The implementation schematic diagram of low cost MEMS gyroscope and accelerometer implementation for north finding systems is shown in Figure-1.

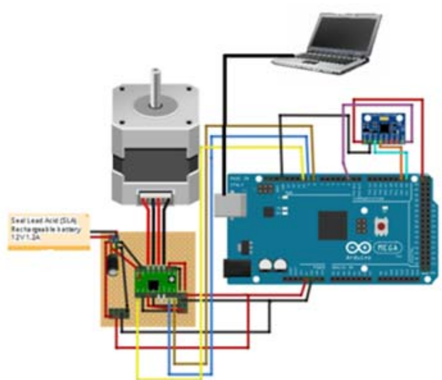

Figure-1. Schematic diagram for north finding system.

Custom made shield two layer of printed circuit board (Figure-2) for micro stepper driver is developed to control the rotation of the micro rotator. These to ensure that the wiring connection fit with the pin of Arduino Mega and rotation of the rotator is accurately control in micro step. The MPU6050 is placed horizontal on the rotator via A4988 micro step driver to control the rotation in micro mode of 0.1125° per step and to switch between different positions. Complete setup as shown in Figure-3.

Figure-2. Custom made shield for micro stepper motor circuit.

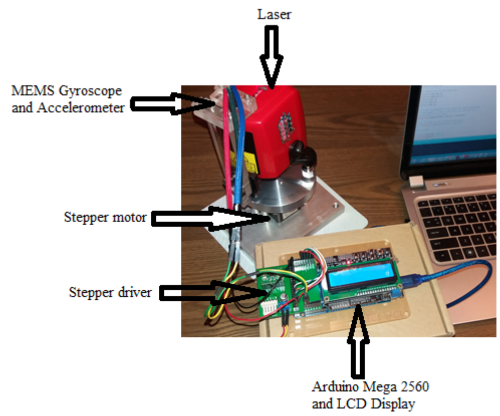

Figure-3. Complete system of MEMS gyroscope and accelerometer for north finder

b) Testing setup for accuracy of micro rotator using optical polygon and autocollimator

There are two industrial standard techniques of angular calibration [39, 40] using polygon mirrors and autocollimator; (i) two optical polygons with the same number of faces with one autocollimator (ii) one polygon with two autocollimators.

In this case, calibration done with one polygon (six faces) and one autocollimator to determine the angular displacement accuracy of rotator. The calibration process conducted at Angle Laboratory National Metrology Institute of Malaysia. The rotator is placed on a flat table where the six faces optical polygon mounted concentrically on top of the rotator. An autocollimator is set separate stand facing the polygon. The face 0º of the polygon is aligned with 0º mark of the rotator and the reading of the autocollimator is noted. The rotator is then rotated corresponding to the nominal angle of the polygon and the autocollimator reading is again noted.

This procedure is continued until all the polygon faces are measured. The reading is then repeated by rotating the rotator in reverse direction as well. Figure-4 presented the setup calibration of rotator using optical polygon and autocollimator.

Figure-4. Setup calibration of rotator using optical polygon and autocollimator.

c) Complementary filter for MEMS gyroscope and accelerometer

Digital complementary filter is implemented as illustrated in Figure-5 where the strength of one sensor will be used to overcome the weaknesses of the other sensor which is complementary to each other. Block diagram in Figure-5 shown two inputs; the accelerometer angle estimation and the gyroscope angular rate. The low pass filter will filters the high frequency signals when the accelerometer sense condition of vibration. The input of gyroscope angular rate will be integrated to emerge an attitude angle before it feed into high pass filter to negate the effect of drift. Both high-pass and low-pass filters work simultaneously, then both signals are summed together.

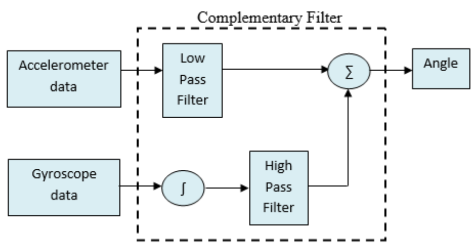

Figure-5. Block diagram of digital complementary filter system for MEMS gyroscope and accelerometer.

In the datasheet of MPU6050, the registers values 0x43, 0x45 & 0x47, hold the raw gyro data where the gyroscope outputs is in angular velocities. In order to convert the velocities from the raw data to degree/second, it will divide by 131 values. When both gyroscope and accelerometer data is scaled, it will then adjusted by the offset, followed by feed into the complementary filter. The gyroscope data is constantly integrated for each time step with the current position. The constant value of 0.99 and 0.01 will need to total up to 1 and both constant values will be tuned throughout the whole experiment in order to obtain the suitable value. The constant value, *a* of the filter always add to one, so that the produced output is accurate and linear estimate. Mathematical relation of complementary filter as shown in (1).

$$Angle = a\times(angle+gyro\times dt) + (a1) \times (accelerometer) \quad (1)$$

d) MEMS gyroscope and accelerometer based north finding system

The MPU6050 is fixed parallel to the local horizontal plane on top of the rotating laser of stepper motor via A4988 micro step driver to control the rotation. The position of MPU6050 is fixed to ensure the g-sensitivity is the same throughout the measurement process, and furthermore, the setup was rotated in clockwise direction of 0.1125 degree per step by horizontal rotating micro stepper motor. The measurement models as follows:

$$\omega_{position1}=\Omega_e cos\varphi cos\psi+\varepsilon(t_1) \quad (2)$$

$$\omega_{position2}=-\Omega_e cos\varphi cos\psi+\varepsilon(t_2) \quad (3)$$

where Ω_e represent Earth rotation rate, φ represent latitude, ψ is angle between sensing axis and North, $\varepsilon(t_1)$ and $\varepsilon(t_2)$ represent bias value of gyroscope at t_1 and t_2. Both formulas (2) and (3) formed an angle between the gyroscope sensitive axis and the north:

$$\psi=arccos[(\omega_{position1}-\omega_{position2})/(2\omega_e cos\varphi)] \quad (4)$$

RESULTS AND DISCUSSIONS

a) Testing accuracy of micro rotator using optical polygon and autocollimator

The testing accuracy of rotator were collected for six samples, coinciding the 90°, 180° - 360° faces of the polygon with 0° of rotator one by one. From Table-1, the micro rotator was found an accuracy of ± 0.02 ° for a rotation angle from 0 ° to 360 ° (rotation in clockwise and counter clockwise) and these proven that the developed rotator in this system is accurate.

Table-1. Six samples calibration results of micro rotator using optical polygon and autocollimator.

Actual angle (°)	Autocollimator reading (°)					
	1	2	3	4	5	6
0	0.00	0.00	0.00	0.00	0.00	0.00
90	89.68	89.93	89.77	89.90	89.73	89.89
180	179.48	179.88	179.62	179.81	179.56	179.81
270	269.66	269.96	269.79	269.94	269.77	269.94
360	359.61	360.00	359.80	360.00	359.80	360.00

b) Complementary filter for MEMS gyroscope and accelerometer

The signal conditioning measured from the MPU6050 gyroscope and accelerometer is connected to the input device of Arduino Mega via I2C communication medium. The measurement graph is captured by importing data from Arduino to excel (at real-time) via Parallax Data Acquisition tool (PLX-DAQ) software. The results of raw data accelerometer and gyroscope at real-time captured via PLX-DAQ presented in [23].

The presented graph in [23] reveals a clear trend of accelerometer sensibility to noise while the gyroscopes experienced drift angle where in reality it is in static condition with zero angle. This clearly proves that the both gyroscope and accelerometer requires a filter to ensure the output free of interference. Factor value, a will be tuned in order to find the best value where simple rotation along X-axis is done throughout the whole experiment. The results obtained from the preliminary analysis shown in [23] for different constant setting complementary filter, the best factor value of 0.97 is chosen.

c) Field test of MEMS gyroscope and accelerometer based north finding system

24 experiments were conducted outdoor at three different locations (Kolej Burhanuddin Helmi, Fakulti Kejuruteraan dan Alam Bina and Fakulti Pendidikan) of Universiti Kebangsaan Malaysia, Bangi, Malaysia between 10.00 a.m. to 2.30 p.m. at latitude of $\varphi = 2.9300°$ N to find north direction. The collected results are then compared with the Sun Compass Application (SCA). SCA also known as Pedoman Suria which developed by Unisza. The SCA was certified of its accuracy by Islamic National Council Malaysia. Table-2 shows the comparison results.

Table-2. Comparison true north results between the developed systems with SCA.

Time	Differences of angles in different locations (°)		
	FKAB	KBH	FPEND
1000	1.5	1.4	1
1030	1.5	1	1
1100	1	1.5	1.5
1130	1.5	1	1
1200	0.5	1.3	1.5
1230	1.5	1	1.1
1300	1	1	1.5
1430	1.5	1.2	1.2

Apparently, experimental results in Table-1 show that the developed low cost systems proven an accuracy of approximately ±1.5° compared with the true North orientation of the certified SCA. Hence, the developed system performed better than universal north-seeking scheme in measurement of time and stability of the accuracy.

CONCLUSIONS

The presented work demonstrates that combining the MEMS gyroscope and accelerometers via digital complementary filter factor, a = 0.97 to find the accurate direction of north has been successfully developed. Based on the industrial standard testing using autocollimator and polygon, it is observed that the rotator precisely rotating at ±0.02° for a rotation angle from 0 ° to 360 ° (clockwise and counter clockwise). Moreover, the field test results prove that the developed system achieve an accuracy of ±1.5° with respect to the true north.

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