Magnetic sensors in Inertial Measurement Units

Sabou Sebastian
Technical University of Cluj-Napoca,
North University Center of Baia Mare,
Victor Babes street, no. 62A, phone 0362401265,
e-mail: sebastian.sabou@cunbm.utcluj.ro

***Abstract*—The aim of this paper is to integrate, among the common sensors from an inertial navigation system, a sensor to measure the magnetic field, magnetic field of the Earth. Basically, we want to integrate a digital'compass, as an additional element for obtaining more accurate data as well as navigation. Advantages of using a magnetic sensor under a IMU (Inertial Measurement Unit) would be determining orientation of an device, relative to the axis of the Earth's magnetic field.**

Keywords— Magnetic sensors, IMU Introduction

I. INTRODUCTION

Determining coordinates and speed of a vehicle by processing of information relating to its acceleration constitutes a so-called inertial navigation method. As a matter of principle, inertial navigation system consists of several instruments which measured acceleration (and other parameters) and and a computing system which, on the basis of algorithms, calculate the navigation parameters relative to a given reference system.

The characteristic of this method is that, unlike all other navigation methods, determination of quantities that define the spatial evolution of one vehicle is independent from external sources of information. Advantages arising from there, made the inertial navigation unit to be used on the wider scale in air navigation, sea and space.

Sensors used in inertial navigation, in literature under generic name of inertials sensors, are most commonly represented by the accelerometers and gyroscopes. The accelerometers shall measure the specific force and the gyroscope sensor measure angular velocity without having an external reference. Instruments which measure the speed, acceleration or angular speed in relation to other elements from the environment do not fall into the category inertials sensors

Combining sensors to improve accuracy and sensor precision is a common practice in the robotics industry.

Accelerometers and gyroscopes are used in IMU systems as a baseline to discern orientation with respect to a given body frame of reference and to calculate velocity and distances from previous position. Gyroscopes sense orientation through angular velocity changes and therefore find orientation, but they have a tendency to drift over time because they only sense changes and have no fixed frame of reference. The addition of accelerometer data allows the bias in a gyroscope to be minimized and better estimated to reduce propagating error and improve orientation readings. Accelerometers sense changes in direction with respect to gravity which can orient a gyroscope to a more exact angular displacement. For a better measurement of direction an magnetic sensor was added to try to compensate the angular velocity, from gyroscope sensor, to drift in time.

A. *Implementation*

A "Sensor stick 9DOF" from Sparkfun.com was used, which contain an accelerometer sensor, a gyroscope and a magnetic sensor, each measuring 3-axis, thus the 9 degrees of freedom in module name. Connection is made using I2C, each sensor will output data in a digital format.

The sensor module was connected to a development system for Atmega328, Arduino Uno board, this system has a great many resources that are available on the internet and it is much easier for algorithms testing.

1.1 Magnetic sensor calibration

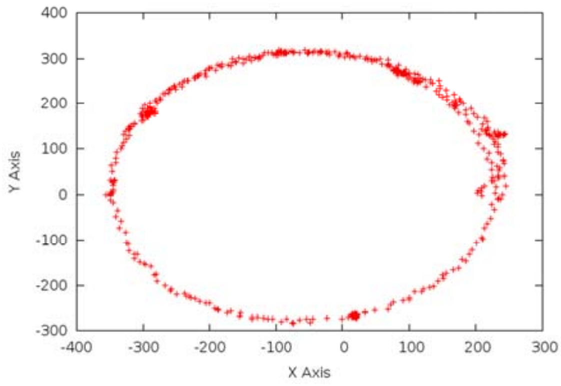

Fig. 1. Errors on X-Y axis in a 2D representation

After successfully connecting sensor board to the development board Arduino Uno, the next step was to record data from the magnetic sensor and verify their correctness, this measurement was done by turning the sensor board around the Z axis and record data on a PC, in a text file.

Next step is to graphically represent measured data. For this step we used a program named 'gnuplot', which is distributed free. Initially was developed for the Linux operating system as a freeware software, later it was developed for other operating systems. We used the Windows version, still freeware, with a script that is developed especially for this purpose. The generated output can be seen in the graph in Figure 1.

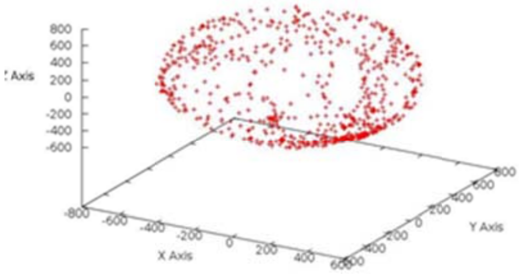

Fig. 2. Errors on the axes X, Y and Z in 3D representation

After displaying recorded data, the shape of graph should be a circle, corresponding to the values from the rotation around the Z axis, without any motion on the other axis. As we can see in this figure, the shape of the measured data it's an ellipse, indicating that certain errors is induced and needs to be compensated to obtain correct results.

The result of rotation on all 3 axes, a 3D representation of the recorded data is shown in Figure 2. As expected, the shape of data represented is not a sphere, it is a shape which is modified by measurement errors.

For calibration data, it will take a couple of reference data and it will compute a scaling factor which will be used to modify the data measured with the scaling coefficient. Because the measured data may vary depending on the location and condition of the sensor at each startup of the system that will use magnetic sensor, it will require a calibration time, actually call the calibration function.

Calibration function does not require many arithmetic operations and hence it can be implemented using low computing resources, as is the case for this situation, the Arduino Uno development system with an 8-bit microcontroller in 16 MHz frequency, allows the processing of data at the maximum frequency at which the sensor can conduct measurements.

The first step for calibration was using Kalman filtering, a classical solution for filtering (Figure 3) , using data from the magnetic compass to correct the equivalent data from gyroscope. This update is made at an interval of a few seconds, interval that changes constantly, depending on the size of the error results. If the error is greater than the interval shrinks if the error is less than the interval range increases. This dynamic correction of errors takes place to reduce possible errors by the magnetic sensor.

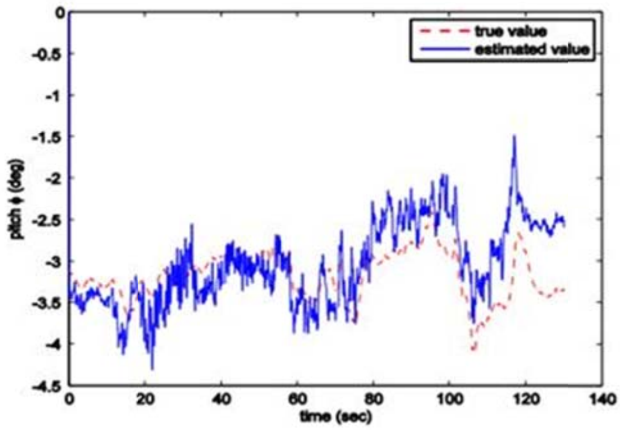

Fig. 3.Kalman filter

Raw data from sensors ar presented in Figure 4 and in Figure 5 is present calibrated data.

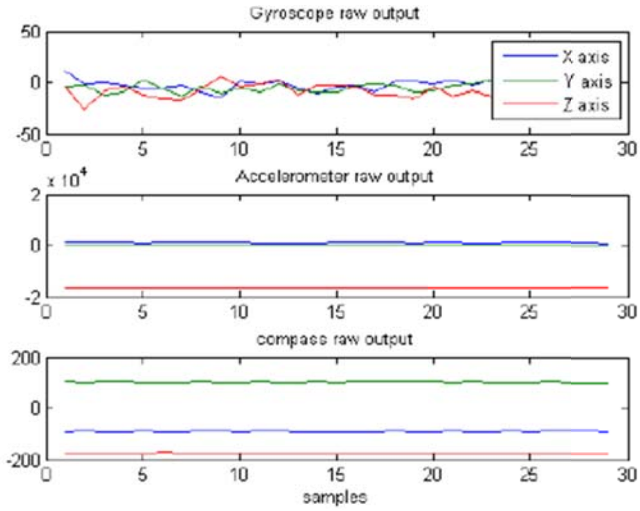

Fig. 4.Raw data from sensors

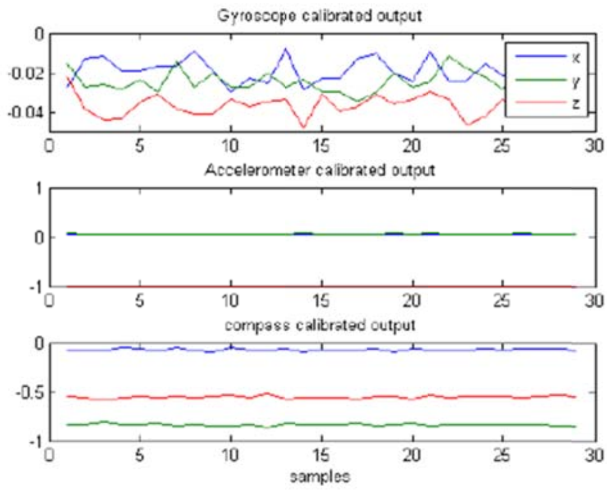

Fig. 5. Calibrated data from sensors

The calibration function for magnetic sensor is very small and requires very few arithmetic operations and is easy to implement for Arduino microcontroller, as show in Figure 6.

```
void HMC5843::calibrate(unsigned char gain)
{
 x_scale=1;
 y_scale=1;
 z_scale=1;
 writeReg(0,0x010+HMC_POS_BIAS);
 setGain(gain);
 float x,y,z,mx=0,my=0,mz=0,t=10;
 for (int i=0;i<(int)t;i++)
 { setMode(1);
 getValues(&x,&y,&z);
 if (x>mx) mx=x;
 if (y>my) my=y;
 if (z>mz) mz=z;
 }
 float max=0;
 if (mx>max) max=mx;
 if (my>max) max=my;
 if (mz>max) max=mz;
 x_max=mx;
 y_max=my;
 z_max=mz;
 x_scale=max/mx; // calc scales
 y_scale=max/my;
 z_scale=max/mz;
 writeReg(0,0x010);
}
```

Fig. 6 : *Calibration function*

For data processing it has been implemented a modified Kalman filter witch use data from magnetic sensor and another filter for MARG sensor (Angular Rate, Magnetic and Gravity). A MARG sensor is a hybrid IMU which incorporates a tri-axis magnetometer.

The filter uses a quaternion representation, allowing accelerometer and magnetometer data to be used in an analytically derived and optimized gradient-descent algorithm to compute the direction of the gyroscope measurement error as a quaternion derivative.

The Kalman filter [3] (and its variants such as the extended Kalman filter and unscented Kalman filter [5]) is one of the most popular data fusion algorithms but the new algorithms (for example MARG) takes big steps in the field of information processing. The MARG's algorithm big advantage is the low computational needs compared to Kalman filter with very similar results.

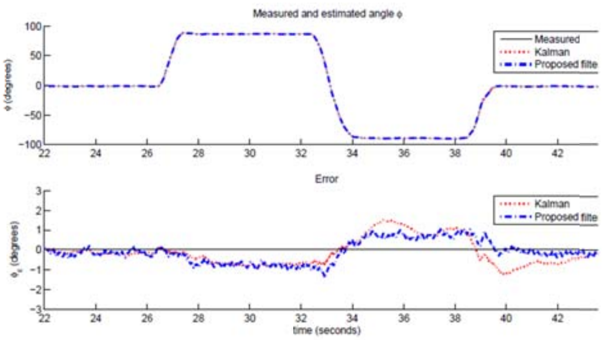

Fig.7: *Values for orientation angle*

For orientation, in Figure 7 is present the measured and estimated angle, the error and the value from filters.

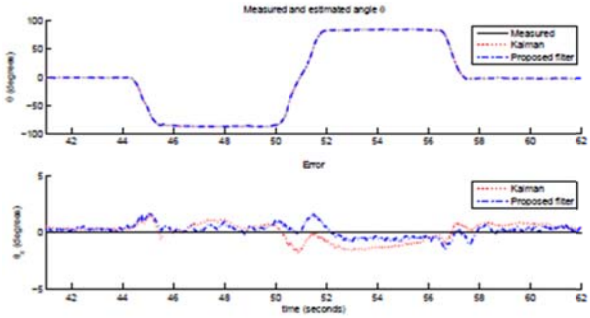

Fig.8: *Tracking the gyroscope bias drift*

In Figure 8 is presented the results for tracking the gyroscope bias drift.

The difference between raw magnetic sensor data, calibrated magnetic sensor data and filtered data (Kalman) is presented in Figure 9.

Advantages of using a magnetic sensor under a IMU (Inertial Measurement Unit) would be determining orientation of an device, relative to the axis of the Earth's magnetic field.

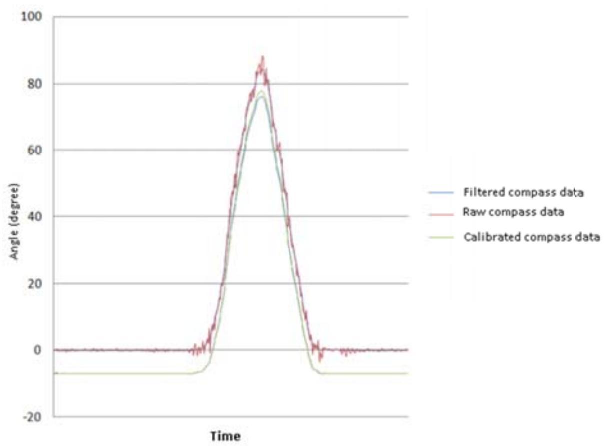

Fig.9:Data from magnetic sensort

Use magnetic sensors in conjunction with others sensors increase the accuracy of determining direction of movement, this being the main benefit of their use in inertial navigation unit as shown in this study.

While many commercial units of IMU's exist, buying low-cost components and implementing almost freeware software is a viable option from financial and performance point of view. With the advancements in microprocessor technology, like the low cost Arduino Uno development platform, computational complexity is deliverable and consequently gives students or enthusiasts the ability to learn-by-doing getting familiar with both hardware and software.

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