IMU Platform for Workshops

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***Abstract*— This document describes a platform planned to use in our workshops on Robotics. It will help the students understand the way how accelerometers and gyroscopes are used for the inertial measurements. Students can train various methodologies of processing the signal coming from these sensors.**

***Keywords*— MEMS, Inertial Measurement Unit, Accelerometer, Gyroscope, Sensor Fusion**

I. Introduction

MEMS components are widely used in the field of robotics. Their usage in some applications is quiet simple. However, more complicated applications such as inertial measurement units need more complex approach to the processing of their output.

Inertial measuring unit measures inertial state variables of an object in space, for example orientation, velocity and gravitational forces. It can be aircraft, space satellite or ground robot (for example Segway®). Usually accelerometers and gyroscopes are used as their basic sensors. MEMS versions of these sensors are nowadays gaining more and more importance.

MEMS sensors have several drawbacks. So combinations of more sensor types are often used to compensate the drawbacks of each other and ensure much better properties of the whole system.

There are many ways [4] how to combine signal from these sensors. It is called sensor data fusion. For example complementary or Kalman filters can be used.

Since it is more interesting to work with real devices than just with simulations and our workshops on service robotics are practically oriented a modular platform with a sensor unit was created to implement these techniques and investigate the properties of the sensors.

II. Mechanical Design

To avoid pure simulation and make the work for students more practical and interesting the design of the platform had to deal with real hardware. It consists of a mechanical part providing some pre-defined movements and an electronic part with sensors and signal processing hardware.

Fig. 1 is a simplified sketch of the mechanical construction. There is a position servo motor mounted on a vertical wall with a drawn protractor. Shaft of the motor is oriented horizontally and holds a deck with the printed circuit boards.

There are two boards. One of them contains the digital signal controller and the other one is the sensor board. Its advantage is the possibility to change the sensor board and test various sensors.

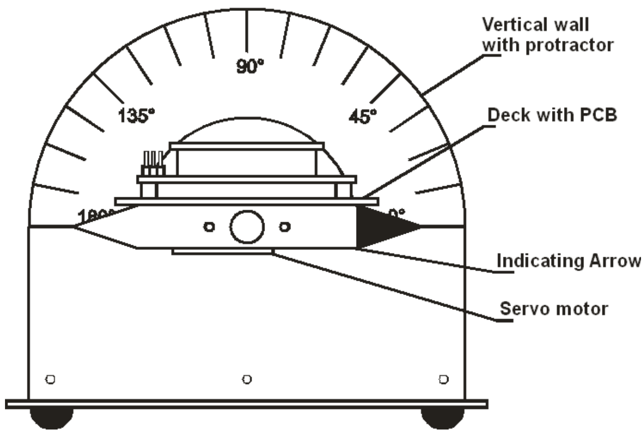

Fig. 1 Mechanical construction of the stand

The angle between the horizontal plane and the plane of the sensor board is indicated by an arrow and it can be easily visually measured on the protractor.

When moving the motor this angle changes and the measuring unit consisting of the sensors and the controller should be able to measure this angle and the angular rate of the rotation just from the information based on sensed gravity projection and the gyroscopic moment.

If an additional mechanical arm is used, the sensor board can be located further from the ax of the rotation and the signal can be more influenced by centrifugal forces.

The goal of this application is to let students process the signal from the sensors, compare the results with the precise angle and develop a method obtaining the best results.

III. Electronics

The block diagram of the schematic is shown in Fig. 2.

The most important parts of the circuit are the MEMS sensors located on the sensor board. Our sensor board contains 3-axis analog output accelerometer MMA7361 by Freescale, dual gyroscopes LPY530AL for measuring in X and Y axis and LPR530A by ST Microelectronics.

The signal from the sensors is then converted and processed by a 16 bit digital signal controller dsPIC33FJ64GP306A by Microchip. It is programmed and debugged via ICSP connector and PICKIT microcontroller.

The servo motor HexTronik HXT500 is controlled by standard PWM signal with frequency 50Hz and impulse duration 1.5ms. The motor was modified in order to obtain its internal position feedback, which is usually not available. The position is measured by an internal potentiometer. The signal from it is also measured by the digital signal controller and used as the real value of the angle and is compared to the angle obtained by the inertial sensors.

The controller is connected to a PC via serial port. USB/Serial port adapter is used.

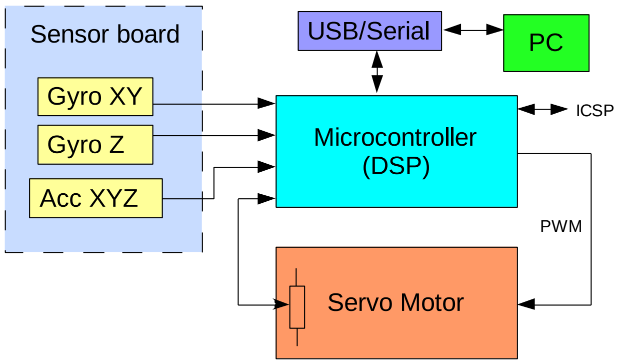

Fig. 2 Block diagram of the circuitry of the platform

IV. Software

There is a pre-prepared application for the digital signal controller. It is programmed in C language and MPLAB IDE is used for programming and debugging during the workshops.

The pre-prepared application has all the basic functionality prepared to work with the signal from the sensors and to drive the servo motor. Things such as interrupts analog/digital conversion, serial port reception and transmit are ready to work with. The assistant will show students how to access the peripherals and they can work on their own modifications.

User interface is very simple and it is based on serial port communication. There are some basic commands implemented, for example:

- go to vertical position
- go to horizontal position

Output is also solved this way. Measured data are sent to the serial port and shown in the following format.

The values are Tab-separated. Period of the data is 10ms. Lines are separated by carriage return character. The values are printed in this order (the meaning is explained in section V):

- Time [ms]
- Angle from potentiometer [degree]
- Angle from filtered gyroscope [degree]
- Angle from filtered accelerometer [degree]
- Angle directly from gyroscope [degree]
- Angle directly from accelerometer [degree]
- Angle from complementary filter [degree]

Since the transfer is in text format, it is easy to use a terminal program to communicate with the stand. Received data can be logged into a file and evaluated in another program.
The students can feel free to modify the output according to their requirements.
We are considering writing a special program or integrate the system to Matlab Simulink too. It might move the complexity of the algorithms from C in controller to sophisticated environment in PC.

V. Algorithms

A. MEMS Accelerometer and Gyroscope Properties

MEMS accelerometers are good sensor especially for static measurements as an inclinometer in cell phones etc. Their output contains high frequency noise and it is sensitive to centrifugal acceleration which can negatively affect the inertial measurement.

In the other hand, MEMS gyroscopes measure angular rate naturally. Hence they have good high frequency response, while integrating of little deviations in steady state modes causes a drift in the output.

It would be useful to find a way how to use just good properties of both types of sensor.

B. Complementary Filter

Complementary filter is a technique used to combine noisy signals. These noises have complementary spectral characteristics.

Assume two measurements y_1 and y_2 of the signal x where μ_1 is high frequency noise and μ_2 are low frequency disturbances.

$$\begin{aligned} y_1 &= x + \mu_1 \\ y_2 &= x + \mu_2 \end{aligned} \tag{1}$$

Assume two complementary transfer functions $F_1(s)$ and $F_2(s)$ which create our complementary filter.

$$F_1(s) + F_2(s) = 1 \tag{2}$$

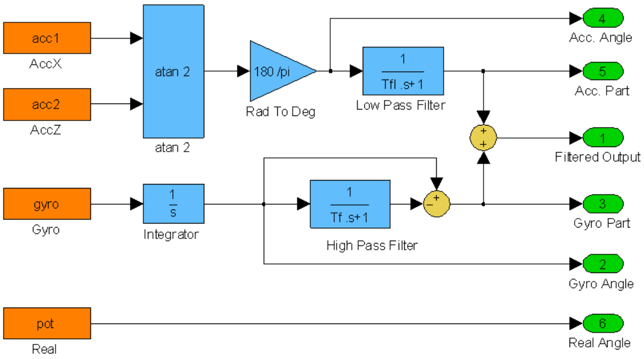

Fig. 3 Block schematic of complementary filter

F₁(s) is a transfer function of low pass filter and *F₂(s)* is a transfer function of high pass filter.

It implies that our complementary filter passes whole frequency range; therefore whole frequency range of the signal *x*. Low pass filter $F_1(s)$ is designed to suppress the noise μ_1 and filter $F_2(s)$ should filter the slowly changing disturbance μ_2.

$$\hat{X}(s) = F_1(s)Y_1(s) + F_2(s)Y_2(s) = \\ = X(s) + F_1(s)\mu_1(s) + F_2(s)\mu_2(s) \qquad (3)$$

Fig. 3 shows a block schematic of complementary filter used at our platform.

C. *Kalman Filter*

Kalman filter is a widely used state estimator. Like other methods, it takes into account model of the controlled system. Unlike the classical approaches, it takes into account also the properties of the measurement (noise, other disturbances). Kalman filter requires the state space model of the system and is usually applied in its discrete version.

Principle of Kalman filter is more difficult to understand than complementary filter and it is also more computationally complex (matrix inversion, transposition and multiplication) what used to be a problem but nowadays it is possible to easily implement them in modern digital signal controllers.

More information on Kalman filter can be found in [2].

We would like the students to work also on this method.

VI. Example

To show the properties of the signal from the sensors and its processing, the following experiment with complementary filter was done.

A step input of angle from horizontal to vertical position (90 degrees) was provided. Fig. 4 shows the signal obtained by the accelerometer and the signal measured directly by potentiometer of the servo. It can be seen that the signal from accelerometer has an oscillating response with a noticeable overshoot. Its steady state value corresponds with the real angle. Hence, the properties for low frequencies are much better than the properties for higher frequencies.

Integrated signal from gyroscope is shown in Fig. 5. The transient response corresponds with the real value but the steady state value is rising in time. Signal with such drift cannot be used directly for angle measurement. In this case, the advantage of gyroscope is its function on higher frequencies and its drawback is at lower frequency range.

Fig. 6 shows filtered signals from accelerometer and gyroscope. A low pass filter is used for accelerometer and a high pass filter for gyroscopes. Fig. 6 shows also their sum which is compared to real angle in Fig. 7.

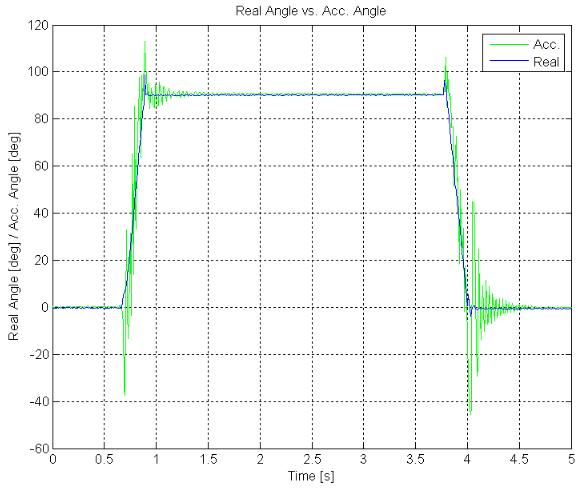

Fig. 4 Comparison of angle directly obtained from accelerometer and real angle

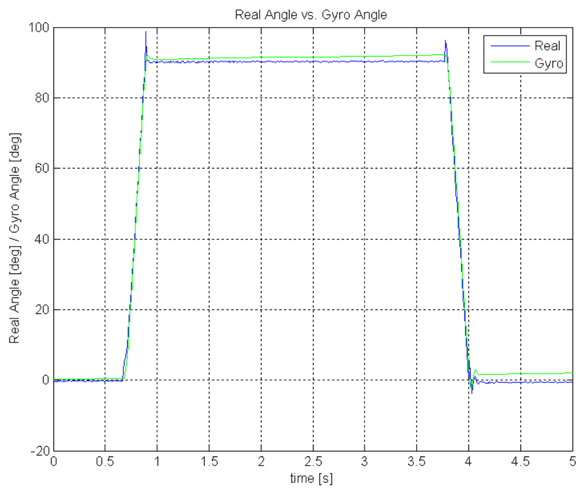

Fig. 5 Comparison of Angle obtained by integrating gyroscope signal and real angle

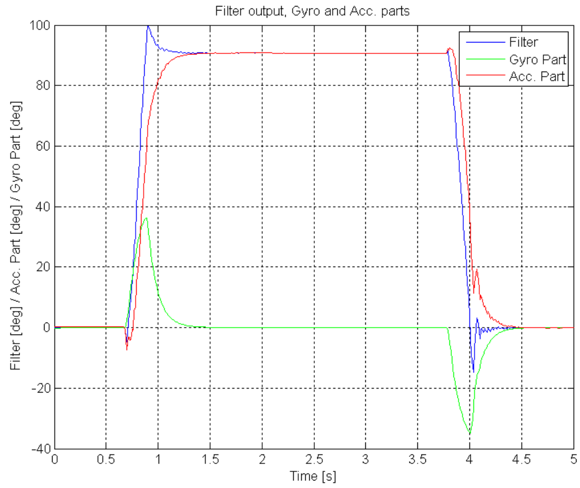

Fig. 6 Comparison of filtered signal from gyroscope and accelerometer and their sum

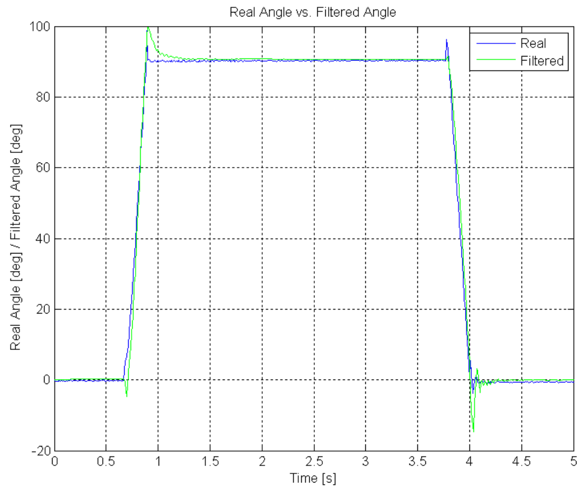

Fig. 7 Comparison of filtered angle and the real angle

VII. Workshops

There are several issues which the students can deal with. First they should get familiar with the platform by modifying the output of the digital signal controller. This requires some knowledge of embedded system programming in C language.

They can control the PWM output of the controller, so they are able to control the motor position. More commands or more sophisticated interface can be implemented for motor control than mentioned in chapter [IV]. Either desired trajectory can be provided from an external source via serial port or some trajectory can be preprogrammed in the flash memory.

The signal processing is the most important part. Students learn how to obtain the information from the sensors and try to compute the state (angle and angular rate) from it. They can compare it with the real trajectory obtained from the potentiometer. Students can implement aforementioned algorithms. Complementary filter will be obligatory. Depending on time reserved for this platform Kalman filter or quaternions can be also applied.

It is preferable to implement the algorithms in the digital signal controller; however, it is possible to do it in more complex software in personal computer.

VIII. Conclusions

A new platform equipped by modern MEMS sensors and digital signal controller was introduced. The platform contains also a plane rotating on the motor shaft. The angle of this plane is measured by processing the signal from the sensors.

The purpose of the platform is to train students on implementation of various algorithms for the estimation of the angle and its derivation.

A description of the mechanical and electrical part was provided together with a simple algorithm based on complementary filter. This algorithm was verified and its results are shown in this paper.

A picture of the platform is shown in Fig. 8.

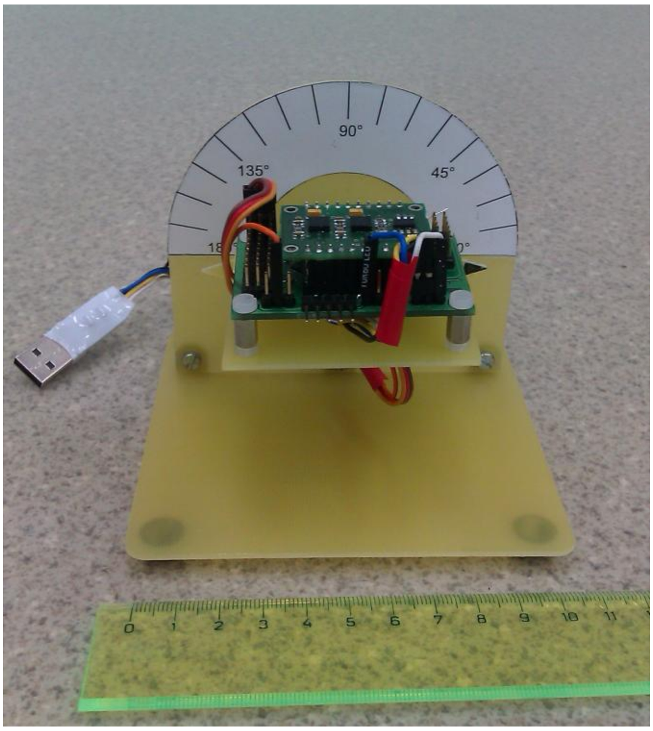

Fig. 8 Picture of the platform

Acknowledgment

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