Development of a Low Cost Inertial Measurement Unit for UAV Applications with Kalman Filter based Attitude Determination

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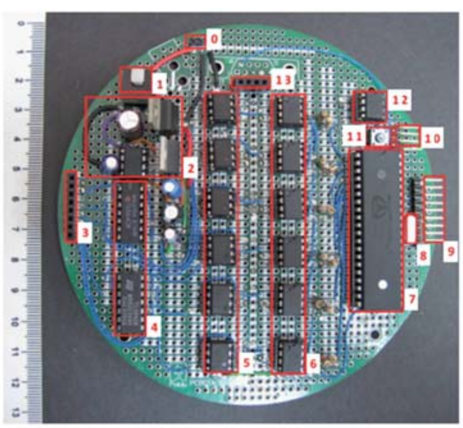
Abstract

This paper presents the development of an inertial measurement unit (IMU) specially designed for unmanned aerial vehicles (UAV) applications. The design was intended to be a low cost solution of high performance for robotic applications using 3-axis accelerometers and 3-axis gyroscopes MEM sensors.

We present simultaneous sampling to avoid the loss of orthogonality of the inertial measurements due to multiplexed data acquisition commonly used in low cost IMUs, as well as anti-aliasing processing. The IMU was implemented in two boards to separate the sensors from the processing hardware in order to be able to use it with different sets of sensors. The sensor fusion algorithm for attitude determination is based on the Kalman Filter.

As testing process, the IMU was installed in a 2-DOF helicopter and the results were compared with those obtained from the encoders for the pitch and roll angles. We also present the results of the IMU installed in a T-REX 450 scale helicopter inside a motion analysis laboratory, using a custom-design safety stand that supports the helicopter allowing only its rotational 3-DOF (roll, pitch and yaw movements). Those demanding experiences tested the IMU performance under true UAV conditions and the results exhibited a maximum RMS error of 1.2°.

It is well known that an important requirement for UAVs instrumentation is low weight. This first prototype, which is shown in Fig. 1, was made using DIP package chips and weights 140g., which is low enough for UAVs. Based on the next design, it is expected to achieve 30g. with a second prototype using surface mounted components as well as a reduction of 70% of its physical dimensions. These characteristics make the future prototype a competitive product when it is compared with those already in existence.



0 – Power Connector
1 – Global switch
2 – Voltaje regulation
3 – Sensors board connector
4 – Voltage buffer
5 – Antialiasing filters
6 – ADC
7 – Microcontroller Propeller
8 – 5MHz Crystal
9 – Expansion port
10 – Communication port
11 – Reset button
12 – EEPROM
13 – Wireless communication port

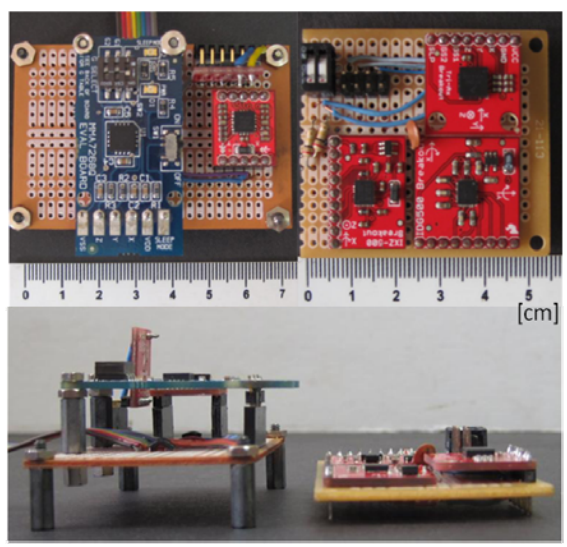


Fig. 1. Prototype of the IMU. Procesing board (left), two diferent sensor boards (right) with gyroscopes of 30°/sec and 500°/sec

Experiments and Results

The first evaluation was performed installing the IMU on a 2-DOF helicopter commercial platform by Quanser commonly used for research projects. The test set up is shown in Fig.2, where it can be seen that the processing board is located in the center of the structure, while the sensor board is on the back of the helicopter for best accommodation.

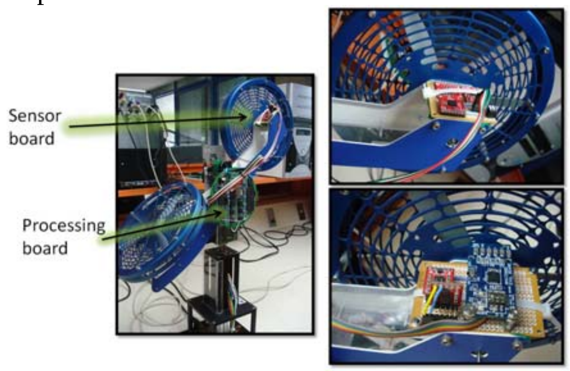


Figure 2. Test set up. Quanser encoders vs. IMU

Notice in Fig.3(a) the difference between the pitch calculated exclusively from the accelerometers data through tilt equations, i.e. the raw result without sensor fusion, and the result provided by the Kalman Filter. Then, Fig.3(b) compares the KF result with the Quanser encoders.

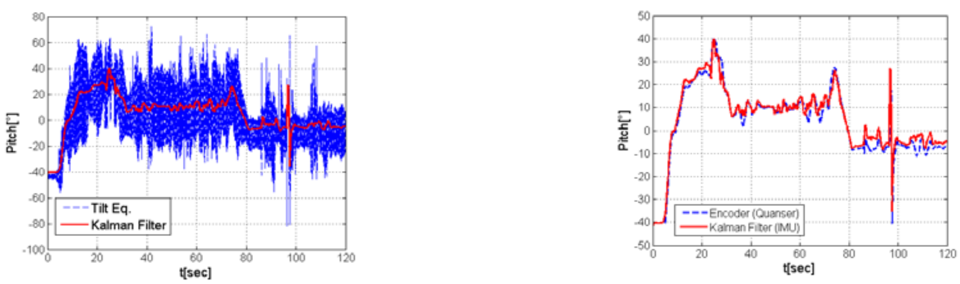


Figure 3. Results for pitch angle. Quanser encoders vs. IMU

In the case of the yaw angle, we must notice that counting on only the gyroscopes it is not possible to estimate the yaw angle without the well known time-dependent drift. In the case of roll and pitch, the gyroscopes are fused with the accelerometers information, but in the yaw case, that is not possible because accelerometers do not measure any quantity related to yaw. Having explained all this, it is clear that the estimation of the yaw needs the aid of another kind of sensor, as a 3-axis compass, to avoid the drift. A compass is not included in the presented IMU for this moment, but the effect of its correction was computed using the encoder information as compass.

A more challenging test was performed with a T-REX 450 scale helicopter inside a motion analysis laboratory. This lab allows to track the position of several markers inside a test space using a set of 5 infrared calibrated cameras. Those markers were installed on the scale helicopter as well as the IMU (processing board + sensor board) as shown in Fig.4.

The objective is to compare the result given by the IMU in attitude determination (roll, pitch and yaw) with the measurements of the motion lab. The cameras work at 200fps while the IMU works at 514Hz. A process of synchronization and interpolation is needed in order to compare both sources of signals. The results for pitch angle are shown in Fig. 5.

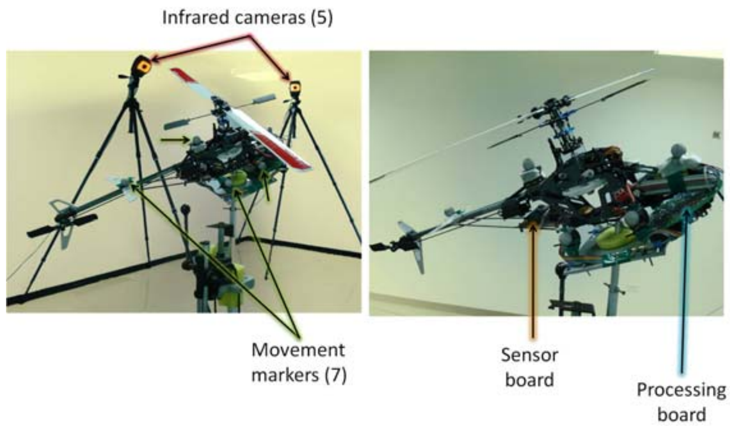


Figure 4. Test set up. Motion analysis lab vs. IMU

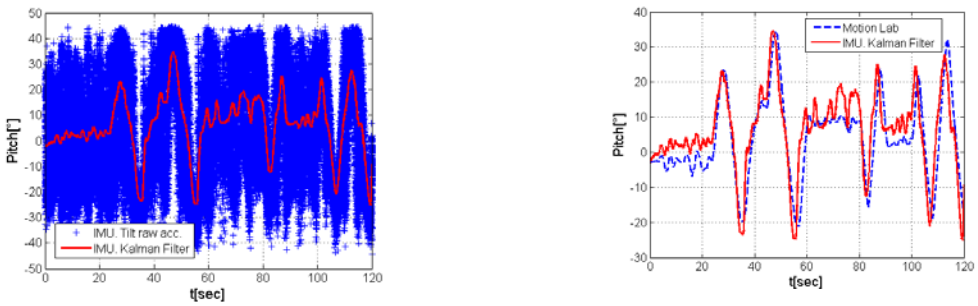


Figure 5. Results for pitch angle. Motion analysis lab vs. IMU

Conclusions and Remarks

The objective of this work was to develop a low-cost IMU for AUV applications as well as the design of test experiments under true UAV conditions in a laboratory framework. The attitude determination algorithm is based on the Kalman Filter. The ideas of modularity, anti-alliasing, low weight, fast dynamics, and simultaneous sampling are some of the key factors that we took into consideration in the design.

This work fits in the conference theme because it represents the development of a sensing device specifically design to be applied in UAV robotics, and its low cost characteristic makes it a great option for projects development in our area. This work represents technology for practical applications. The authors consider that the paper represents an innovative way of producing IMUs with a proven good performance for UAVs. The results were obtained under true UAV conditions trough experiments that can be a model for other projects in sensor fusion, UAVs and inertial navigation systems.

Our ongoing work is focused on the surface mounted prototype, further improvements of the IMU and the attitude determination algorithm, as well as the application of the IMU for an underwater unmanned vehicle. The project aims to reach a final product which will be helpful for further research projects.

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