Laboratory B: Attitude Estimation

Assistants: Ludovic Daler and Nicolas Dousse

30.09.2014

1 INTRODUCTION

The goal of this second laboratory is to understand how the attitude of a flying platform is estimated by the use of an IMU (Inertial Measurement Unit). The MAV'RIC autopilot has a 6-axes IMU and a 3 axes magnetometer. The IMU is composed of a 3-axes accelerometer and a 3-axes gyroscope. The information from these three sensors are fused in order to get an estimate of the attitude of the platform. This estimate can then be used by the regulator which stabilises and controls the platform (this regulator will be studied during the Lab C).

2 PAIR THE TWO XBEE MODULES

The first task is to pair the two XBee modules to enable the communication between the ground station and the MAV'RIC autopilot board. To do so:

1. Plug one XBee module on the MAV'RIC board and the other one on the ground station board. Connect the ground station and the MAV'RIC board to your computer with USB cables. Open QGroundControl, select the good COM_port on the top right corner of the window and click "Connect". If the connection works you can go to exercise 1, if it does not; follow the next points to pair the two XBee modules.

2. Unplug the MAV'RIC board and plug just the Xbee on the ground station to the computer.

3. Open X-CTU.
    a) In"PC Setting" tab select the corresponding COM Port (e.g. "USB Serial Port (COM78)").

b) In “Modem Configuration” tab click “Read” to check if the reading works (if the reading does not work it is probably that the Baudrate is not correct. If the board has never been programmed the Baudrate is 9600, but if it has been programmed it should be set to 57600. To change the Baudrate go to “PC Settings” tab and change the “Baud” value, and then try again to read).

c) In “Modem Configuration” tab click “Load” and load the file: “Lab_B/XBee/Xbee-Configuration.pro”, which is provided in the Lab B zip file on moodle.

d) Under “Networking & Security - PAN ID” change the ID to the number written on the label of your Xbee, it must contain 4 digits (e.i. “0001”, if you have the Xbee number 1).

e) Click “Save” and change the name of the file to “Xbee-NUMBER” (e.g. “Xbee-1”).

f) Click “Write”.

g) In “PC Settings” tab change “Baud” to “57600”.

h) In “Modem Configuration” tab click “Read” to check the settings.

4. Close X-CTU.

5. Unplug the Xbee ground station. Change the Xbee module and plug it in.

6. Restart X-CTU.

7. Repeat the same steps for the second module but this time load the file that you just saved and also you do not need to save.

8. Once both Xbee are programmed, plug one on the MAV’RIC autopilot board and leave the other on the ground station.

3 Exercise 1: Find the orientation of the sensors on the MAV'RIC board.

For this first exercise the goal is to visualise the RAW outputs from the sensors in order to find the orientations of these sensors on the MAV'RIC autopilot board. To do so:

1. In the "Lab_B" folder open the project named "Mavric_MobRob.cproj".
2. Compile the code.
3. Connect the MAV'RIC autopilot board with the USB cable to the computer. Put the board in boot-loader mode (hold down the boot-loader button and press the reset button). Do not mount the board on the calibration setup yet!
4. In the folder "LAB_B" double-click on "dfu-programming.bat" to flash the autopilot.
5. Open QGroundControl. Check that the good COM_port is selected and that the Baudrate is set to 57600. Click on "Connect".
6. Click on "Pro" and select "Plot" (or press "Ctrl+4"). Now, you will have to understand how the sensors are mounted on the autopilot.
   a) Plot the raw accelerometer values; click on the checkbox on the left of the line (left of the screen). These values are named "RAW_IMU.xacc", "RAW_IMU.yacc" and "RAW_IMU.zacc".
   b) Orient the autopilot in different orientations. When the value is around 4000, the corresponding axis is aligned with the gravity vector (e.i. the axis is pointing upward; if the board is not moving, it is measuring an upward acceleration of g) and when it is around 0 the sensor is perpendicular to the gravity vector. Use this information to understand how the three axes x, y and z are oriented and in which direction they are pointing. It is easier to visualise when one value (one axis) is plotted at a time.
   c) Complete Fig. 3.1 with the good orientations of the accelerometers (you will have to modify the code accordingly later).
   d) Find the orientations of the gyroscopes. The axes are the same because the 6 sensors are in one chip. However, you have to find which are the positive directions. Think about the reference frame and the right hand rule for the positive axis. to do so, enable the raw gyroscopes values named "RAW_IMU.xgyro", "RAW_IMU.ygyro" and "RAW_IMU.zgyro".
   e) Rotate the board around the three axes (one after the other), when the value is positive you are rotating in the positive direction.
   f) Complete Fig. 3.2 with the good orientations of the gyroscopes. The orientations of the magnetometers are already programmed in the code. Explain how you would proceed to find the good orientations of the magnetometers:

      Answer: ____

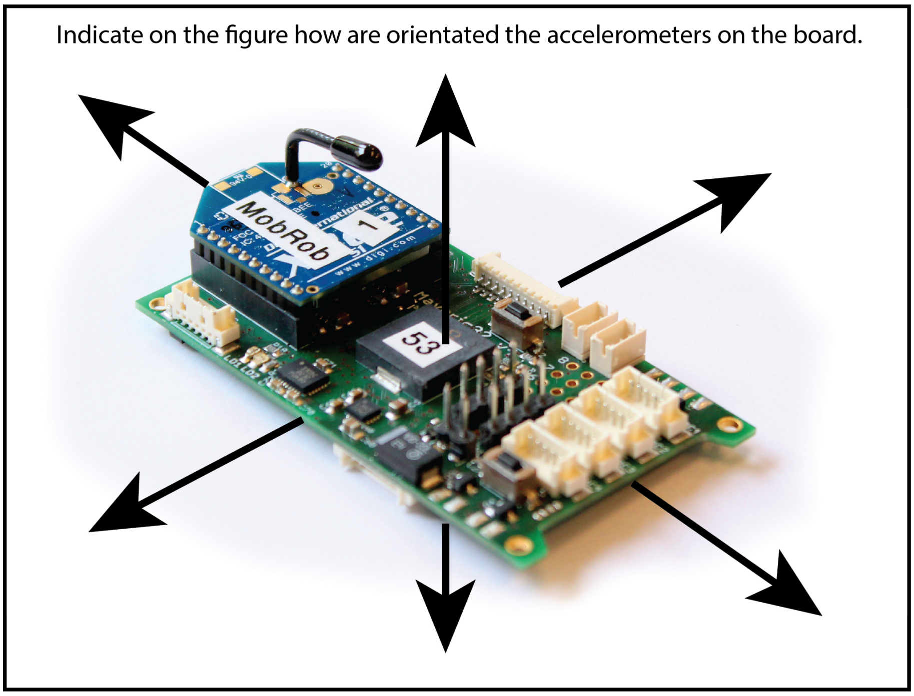

Figure 3.1: Orientation of the accelerometers on the MAV'RIC autopilot board.

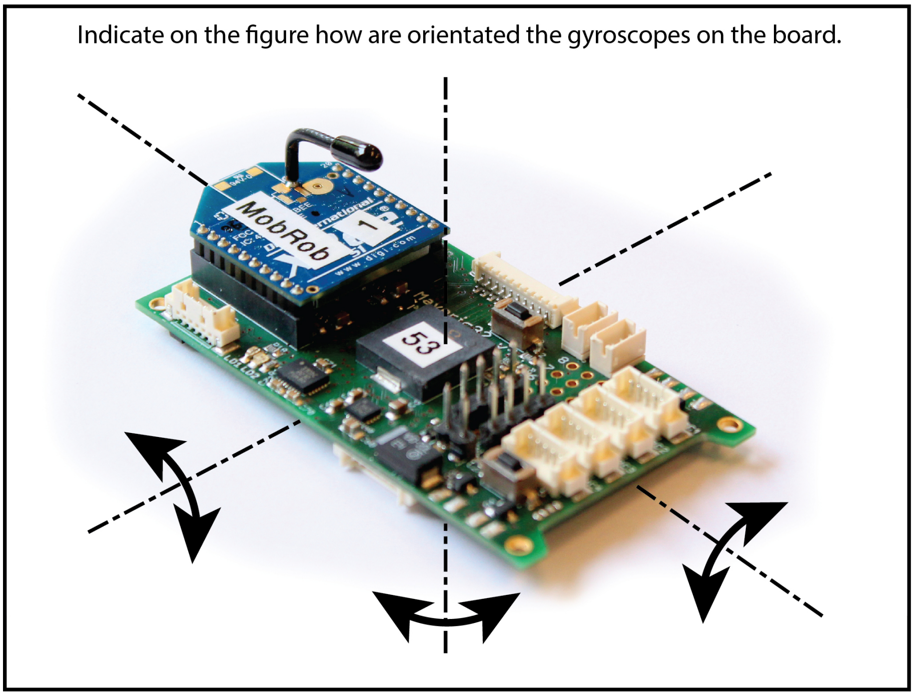

Figure 3.2: Orientation of the gyroscopes on the MAV'RIC autopilot board.

4 Exercise 2: Estimate the orientation of the MAV'RIC board with the gyroscopes

For this second exercise the goal is to estimate the orientation of the MAV'RIC board by using only the information of the gyroscopes. To do so:

1. Level the MAV'RIC board on the table and do not move it.

2. In QGroundControl, go in the "Instruments" tab and restart the MAV'RIC board by pressing the rest button on the board. You should see the orientation levelled as shown on Fig. 4.1.A. If you wait a little bit you can observe that the estimation is drifting (see Fig. 4.1.B). If you take the board in your hand, rotate it randomly and put it back on the table, you will see that the estimation will have changed. Why is the estimation drifting?

   Answer: ______________________________

3. To improve the orientation estimation we will evaluate the biases and add them in the estimation. Go to "Pro->Plot" tab and enable the raw gyroscope values (as in the previous exercise). Next to the names of these variables you can see their current value, their mean value and the variance of this mean value (the mean value is computed over the values which are plotted). You can write down the mean values for the three gyroscopes (fill Table 4.1) and put these values in the "Bias", in "Onboard Parameters" (middle right side of the window). Then click "Set" to add these values to the estimation.

4. Go back to the "Instruments" tab. You should observe that the estimation is still drifting but slower than before (warning: if you reset the board, it will reset the biases!).

Gyroscopes	Mean values (biases)
RAW_IMU.xgyro	
RAW_IMU.ygyro	
RAW_IMU.zgyro	

Table 4.1: Gyroscopes biases.

The estimation is still drifting because the biases are not constant due to the noise. Therefore, the only solution for improving the orientation is to add the information form other sensors. Thus, we will add the information form the accelerometers and magnetometers to correct the estimation. We will use the information from the magnetometers to correct the yaw estimation (it cannot be estimated with the accelerometers since the z axis of the board is aligned with the gravity vector) and we will use the information from the accelerometers to correct the estimations of the roll and pitch axes.

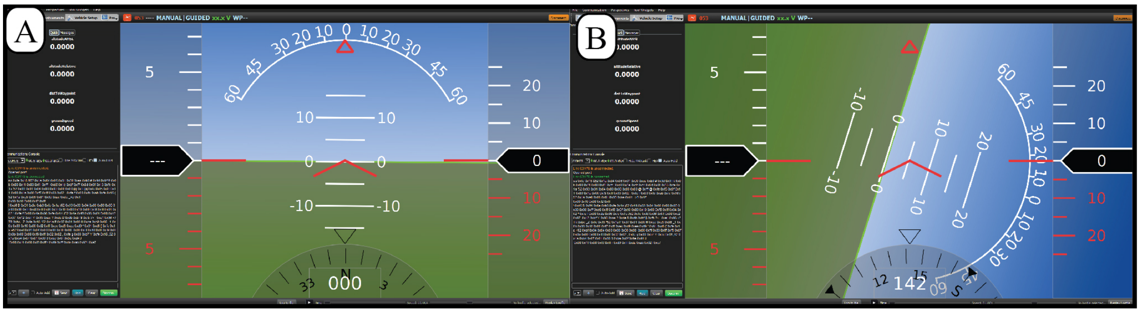

Figure 4.1: Estimation given by the gyroscopes of the MAV'RIC autopilot board. A) At start-up. B) The estimation is drifting with time.

5 Exercise 3: Estimate the scales of the accelerometers and magnetometers.

In this third exercises we will add the information from accelerometers and magnetometers in order to improve the estimation from the gyroscopes. First, we will have to estimate the scales of these sensors. To do so:

1. Mount the MAV'RIC board onto the provided calibration setup (see Fig. 5.1).
   a) Attach the 2s Li-Po battery on the setup as shown in (1).
   b) Slide one extremity of the board into the two slots as shown in (2).
   c) Pull gently on the latch until the second extremity of the board can move downwards, then release the latch to lock the board in position (3).
   d) Plug the battery on the MAV'RIC board as shown in (4).
   e) Check that the XBee module is plugged on the board (make sure not to plug it in the wrong direction).
2. Check that the other XBee module is plugged on your XBee adapter board and connected to your computer.
3. Connect through QGroundControl and check that the connection is working (you should see the attitude moving).
4. Use the setup to log data from the sensors.
   a) Set the MAV'RIC board parallel to the calibration setup with the graduation teeth in front and parallel with the table (see Fig. 5.1 (5)).
   b) In QGroundControl, go in "Pro -> Plot", enable the six values for the raw accelerometers and magnetometers named "RAW_IMU.xacc", "RAW_IMU.yacc", "RAW_IMU.zacc", "RAW_IMU.xmag", "RAW_IMU.ymag" and "RAW_IMU.zmag" (not the gyroscopes!).

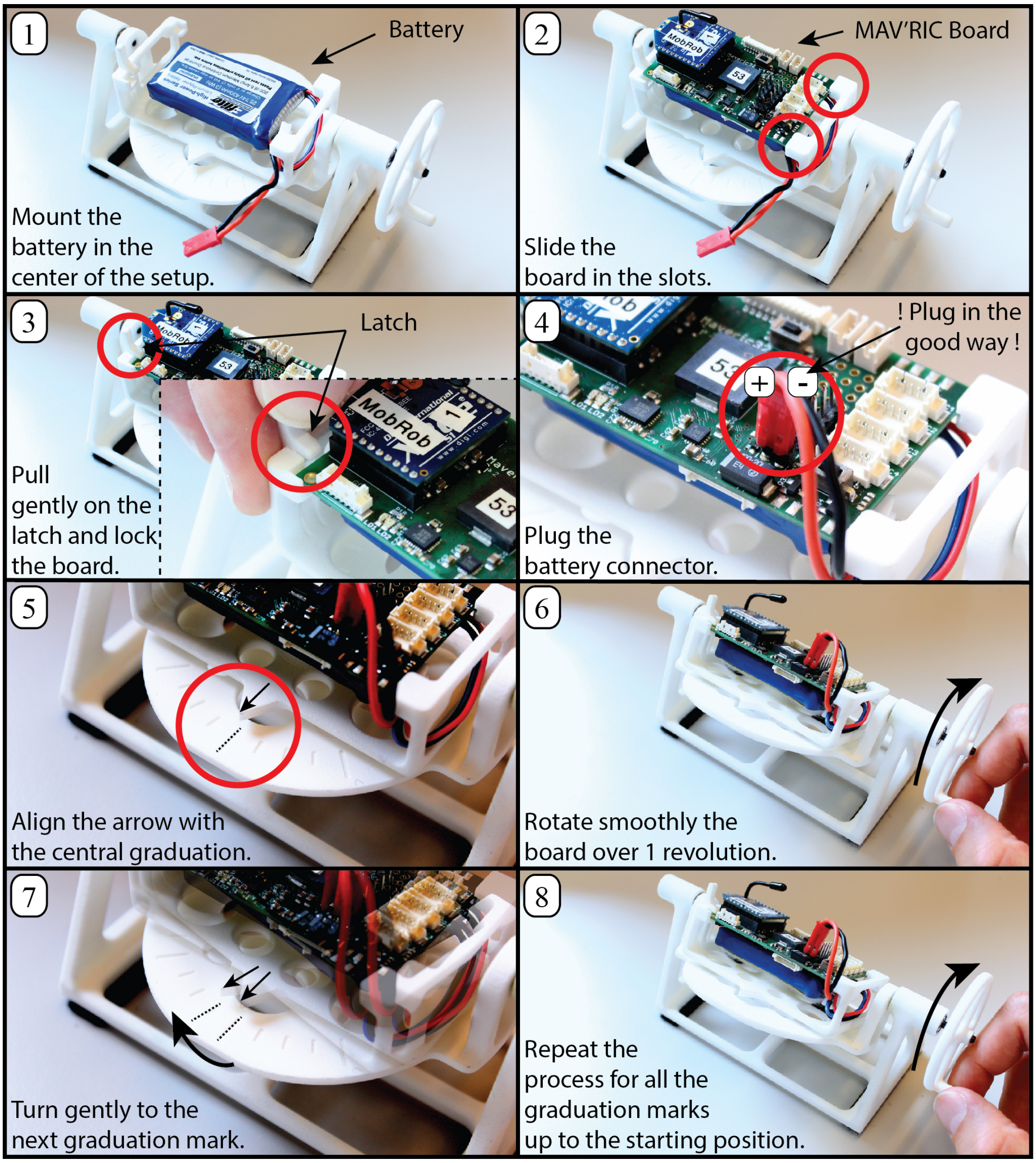

Figure 5.1: Calibration setup.

c) Be ready to rotate the setup smoothly, then press “Start logging” (NOT “Log to file”) at the bottom of QGoundControl window.

d) Set the storage place of the log file to “Lab_B/Calib_IMU”, and call it LAB_B_MAVxxx (e.g. LAB_B_MAV053 for a log made with the MAV’RIC board number 053).

e) Rotate the board smoothly over 1 full revolution (6). Shift smoothly the MAV’RIC board orientation by one graduation (7) and rotate one revolution again, continue until you have done one revolution for each graduation (8).

f) Press on “Stop logging” again, it will end the logging. If it is asked “Should empty fields be filled with the previous value of the same variable?” click “Yes”.

g) Unplug the battery.

5. Use Matlab to process the data from the sensors.

   a) Open Matlab and set the current folder to “.../Calib_IMU”.

   b) Open “Lab_B_calibration_scripts.m”.

   c) Change the “filename” to point to your logging file ending by “_compressed.txt” which should be in the same folder (e.g. LAB_B_MAV033_compressed.txt).

   d) Run the script. You will obtain two times 3 figures (once for accelerometers and once for magnetometers): the RAW plots, an ellipsoid which shows the logged points (check that you get logs all around the ellipsoid), and the scaled plots.

   e) Read in the Matlab console the output scale factors for the accelerometers and magnetometers and copy them in Table 5.1.

6. Update the code with the orientation of the axes, the scale factors and the gyroscopes biases.

   a) In Atmel, open the file “.../src/config/MAVsettings/MAVxxx_conf_imu_rev4.h” (where “xxx” is the ID of your autopilot), change the orientations of the gyroscopes and accelerometers according to the figure that you filled. Change the define values: ACC_ORIENTATION_X, ACC_ORIENTATION_Y, ACC_ORIENTATION_Z, GYRO_ORIENTATION_X, GYRO_ORIENTATION_Y, and GYRO_ORIENTATION_Z; put either “1.0f” or “-1.0f” according to the orientation of the axis. Figure 5.2 gives the desired axes definitions of the MAV’RIC autopilot board, compare this figure with your observations in exercise 1 (see Fig. 3.1 3.2).

   b) Change the scale factors of the accelerometers and magnetometers (RAW_ACC_X_SCALE, RAW_ACC_Y_SCALE, RAW_ACC_Z_SCALE, RAW_MAG_X_SCALE, RAW_MAG_Y_SCALE, and RAW_MAG_Z_SCALE) according to the computed values from Matlab.

   c) Change the gyroscopes biases with the values that you measured (GYRO_BIAS_X, GYRO_BIAS_Y and GYRO_BIAS_Z).

   d) In “.../src/config/MAVsettings/conf_platform.h”, change MAVLINK_SYS_ID with the ID of your MAV’RIC autopilot board.

e) Compile and flash the code on the autopilot.

f) In QGroundControl, in “Pro->Plot” tab, click on “Get” (bottom right corner).

g) In “Onboard Parameters” (middle right), under “Scale”, check the scale factors (you should see the values “1/Your_scale_factor” for each factor).

h) In “Instruments” tab, you should see that the estimation is not drifting any more. However, the estimation is not levelled and if you point the board (x axis) towards the North, it will not indicate the North. Why?

Answer: ____

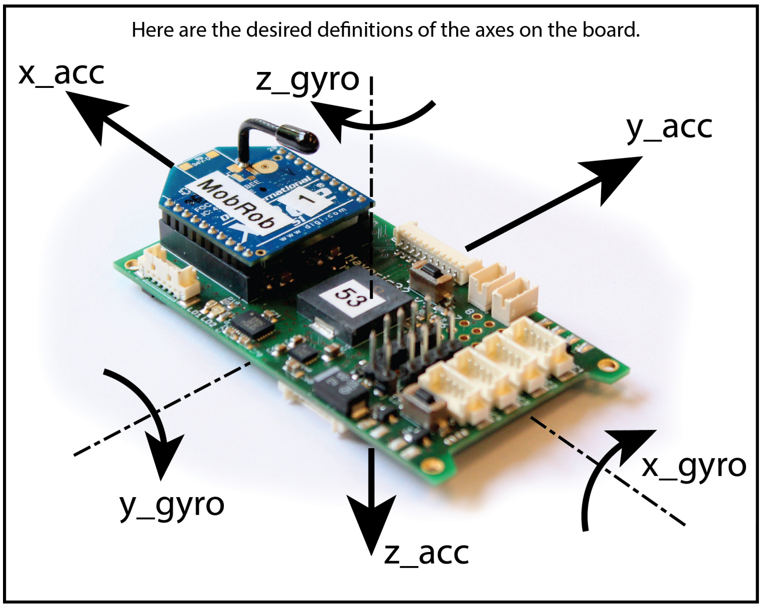

Figure 5.2: Desired axes definitions for accelerometers and gyroscopes on the MAV’RIC autopilot board.

Accelerometers	Scale values
RAW_ACC_X_SCALE	
RAW_ACC_Y_SCALE	
RAW_ACC_Z_SCALE	
Magnetometers	Scale values
RAW_MAG_X_SCALE	
RAW_MAG_Y_SCALE	
RAW_MAG_Z_SCALE	

Table 5.1: Accelerometers and magnetometers scale values.

6 Exercise 4: Estimate the bias factors of accelerometers and magnetometers.

For this part, you would need to screw the MAV'RIC board to your quad and put the quad on a flat and levelled surface. However, since we will not use the quads now, you will leave the board on the table. The goal is to obtain a mean value of 0 for the scaled values of the x and y accelerometers ("SCALED_IMU.xacc" and "SCALED_IMU.yacc"), and for the z axis ("SCALED_IMU.zacc") a value of -1000 (= -1 gravity unit * 1000). To do so:

1. Level your autopilot on the table and do not move/touch it during the calibration.
2. In QGroundControl, go in "Pro->Plot". In "Onboard Parameters", change the "Bias" values of the accelerometers to fit the mean values, to do so:
   a) Display the accelerometers values (one axis after the other); raw values and scaled value ("RAW_IMU.xacc" and "SCALED_IMU.xacc").
   b) Estimate the mean error of the raw measurements and insert this value in the according "Bias" in "Onboard Parameters" (click on "Set" to change the value). The scaled value should now be around 0. If not update the bias value until it is close to 0.
   c) Repeat the same thing for the y axis.
   d) The mean calibrated value for the z axis must be around -1000; change the bias until it is the case (the bias is not equal to the mean of the raw value this time!).
   e) Once you are happy with the three scaled values, click on "Set". Fill Table 6.1.
3. Click on "Instruments" tab to display the attitude estimation and check that it is levelled correctly.
4. Calibrate the magnetometer bias factors. Any magnetic interference would mess up your calibration of the magnetometers; try to do the manipulations away from metallic parts and electronic equipment (ideally you would do it outside).
   a) In QGroundControl, go back in "Pro->Plot".
   b) As the x, y and z values of the magnetometers are in 3D, you must level perfectly the autopilot. You can use the calibrated x and y values from the accelerometers to check that you are levelled.
   c) Place the x axis of the autopilot pointing towards North. Oscillate a bit around this orientation in order to find the maximum value of "RAW_IMU.xmag". Write down this max value in Table 6.2.
   d) Repeat the same with x axis pointing towards the South. Write down the min value. Compute the mean value and write it down.
   e) Do the same for the y axis. We will not calibrate the bias for the z axis as it is not used in the code for the attitude estimation.

f) In “Onboard Parameters” set the two biases for the x and y magnetometers to their mean values, and click on “Set”.

5. In Atmel, update the configuration file with the biases that you measured.

6. Compile the code and flash the board.

7. In QGroundControl you should now see a good estimation of the attitude which should be levelled and which should not drift with the time. If you think that the estimation is working correctly you can save in your folder the configuration file (“MAVxxx_conf_imu_rev4.h”) and send it to us so that you will not have to do the calibration again when you will use the board for another TP or for the mini-projects (send it to ludovic.daler at epfl.ch). You are done!

Accelerometers	Mean values (biases)
Bias_Acc_X	
Bias_Acc_Y	
Bias_Acc_Z	

Table 6.1: Accelerometers biases.

Magnetometers	Max. values	Min. values	Mean values (biases)
RAW_IMU.xmag			
RAW_IMU.ymag			

Table 6.2: Magnetometers biases.