# Exercise Manual

# For

# SC2104/CE3002

# Sensors, Interfacing and Digital Control

## Practical Exercise #3:

## Sensor Fusions for

## Accelerometer and Gyroscope

**Venue: SCSE Labs**

**COMPUTER ENGINEERING COURSE**

**SCHOOL OF COMPUTER SCIENCE AND ENGINEERING**

**NANYANG TECHNOLOGICAL UNIVERSITY**

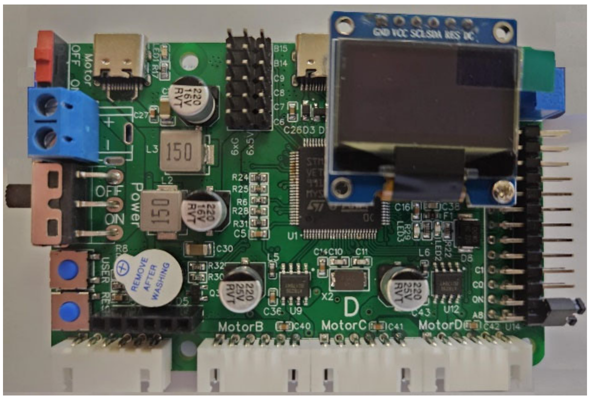
**SC2104/CE3002**
**Practical Exercise #3**

## Learning Objectives

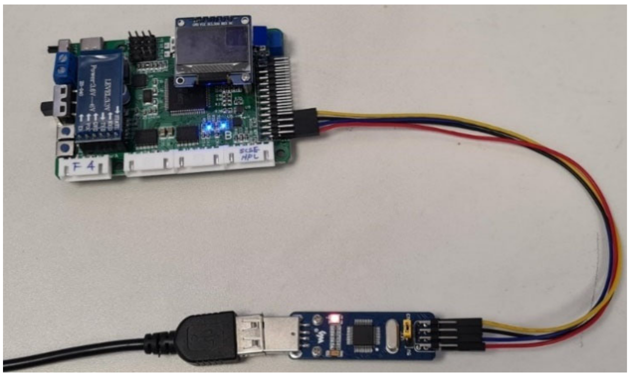
Exercise #3 is a continuation from Exercise 2. In this exercise, you will apply sensor fusion techniques to the readings collected from the Accelerometer and Gyroscope to calculate the Roll and Pitch angles and observe their performance.

## Equipment and accessories required

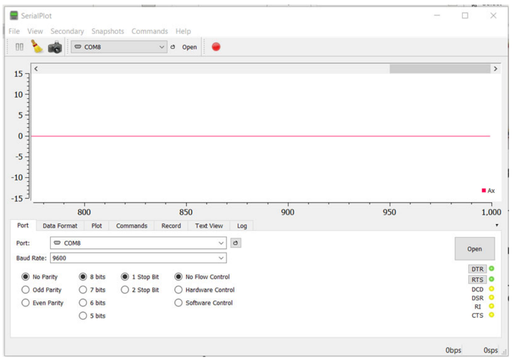
i) One desktop computer installed with STM32CubeIDE, PuTTY and SerialPlot software.
ii) One STM32F4 board (version D)
iii) One ST-LINK SWD board



STM32F4 board



ST-Link for downloading and debugging code



SerialPlot's UI

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## Introduction

In Exercise #2, you would have learned how to read data from the IMU's Accelerometer and gyroscope and use them to calculate the Pitch and Roll angles of the board and observe their characteristics. In the exercises here, you will combine the readings from the Accelerometer and Gyroscope to calculate the roll and pitch angles using two sensor fusion techniques: (i) Complementary filter (ii) Kalman Filter, and observe their performances.

Note:

a. The library functions and other related information needed in Exercise #3 are the same as that in Exercise #1 and Exercise #2, and hence will not be re-stated here.
b. In case of suspected board problem, reset it by disconnecting all the cables from the board, then re-connect the cable to power it up.

## 1. Pitch and Roll Angles

Sensor Fusion techniques are used to overcome the limitations displayed by the two individual sensors observed in Exercise #2.

### 1.1 Pitch and Roll Angles by Complementary Filter

In this exercise, you will implement the Complementary Filter to perform the Sensor Fusion function, whose equation is as indicated below:

$$\Theta[n] = (1-\alpha) * (\Theta_A[n]) + \alpha * (\Theta[n-1] + \omega_G[n] * \Delta t)$$

where

- $\Theta$ can be the Pitch or Roll angles derived based on sensor fusion
- $\Theta_A$ is the corresponding angle derived from the Accelerator's outputs values
- $\omega_G$ is the rate of change of the corresponding angle output by the gyroscope.
- $\Delta t$ is the sampling interval.

(a) Code the above equation in your program for Roll (and then Pitch) angle, and compare its performance against those derived from the Accelerometer and Gyroscope in Lab Exercises 2.

(b) Change the values of α and observe its effect on the performance.

### 1.2 Pitch and Roll Angles by Kalman Filter

In this exercise, you will implement the Kalman Filter to perform the Sensor Fusion function. The following shows the steps in implementing the logic of the Kalman Filter.

1. Get the readings of the Gyroscope and Accelerometer.
2. Calculate the roll and pitch angles from the Accelerometer
3. Estimate the roll and pitch angles from the Gyroscope $\check{x}_{gyro}$
4. Calculate the uncertainty/Variance $\breve{\sigma}^2_{gyro}$ of the Gyroscope's roll and pitch angles

$$\breve{\sigma}^2_{gyro} = \breve{\sigma}^2_{gyro} + \Delta t^2 \sigma^2_{gyro}$$

5. Calculate the Kalman Gain $K_G$:

$$K_G = \frac{\breve{\sigma}^2_{gyro}}{\breve{\sigma}^2_{gyro} + \sigma^2_{acc}}$$

   where $\sigma^2_{acc}$ is the uncertainty of the Accelerometer readings

6. Use the Kalman Gain to correct/update the estimated roll and pitch angles of the Gyroscope obtained in step 3 above

$$\hat{x}_{gyro} = \check{x}_{gyro} + K_G(x_{acc} - \check{x}_{gyro})$$

7. Use the Kalman Gain to correct/update the uncertainty of the Gyroscope readings obtained in step 4 above

$$\hat{\sigma}^2_{\mathrm{gyro}} = (1 - \mathrm{K_G})\breve{\sigma}^2_{\mathrm{gyro}}$$

8. Repeat from step 1

(a) Code the above logic in your program for Roll (and then Pitch) angle. Refer to the lecture notes for the detailed description of each of the steps shown above. You can assume that the values of the Accelerometer and Gyroscope uncertainty/variance are as follow:

$\sigma^2_{\mathrm{acc}}$ = 3x3 = 9
$\sigma^2_{\mathrm{gyro}}$ = 4x4 = 16
Initial value of $\breve{\sigma}^2_{\mathrm{gyro}}$ = 2x2 = 4

(b) Compare its performance against those derived from the Complementary filter.

## 2. Summary of Exercises

Compare and comment on the accuracy and behavior of the Pitch and Roll angles derived from the individual Accelerometer and the Gyroscope with those derived using the two Sensor Fusions techniques.