Sensor Fusion Project Report: Part 1

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Dataset: 2

***Abstract*—The project aims to develop an autonomous tracking algorithm for a ground robot. The *part 1* of this project is aimed at calibrating a few on-board sensors and find their gain parameters and biases such that useful information about the environment can be measured from these sensors.**

I. Introduction

This report contains a brief explanation of the solutions implemented for the tasks 1-4. Alongside with this report, a Jupyter notebook named `part1.ipynb` is submitted. There is also another file `part1.html` which is an HTML export of the same Jupyter notebook file that has been submitted for easier viewing and readability. The solutions are highlighted in blue and have been truncated to four decimal places.

II. Measurement Model

The sensor model is a mathematical formulation that relates the quantities of interest to the physical variables that are measured. For each of the tasks, the sensor model used is a standard linear model as written in equation (1) where $\mathbf{y}$ is the multi-dimensional vector containing the measurements, $\mathbf{x}$ is the quantity of interest, $\mathbf{b}$ is the bias, $\mathbf{G}$ is the gain matrix that relates measurements to the quantities of interest, and $\mathbf{r}$ is the measurement noise.

$$\mathbf{y} = \mathbf{G}\mathbf{x} + \mathbf{b} + \mathbf{r} \tag{1}$$

For example, in the first task, the gyroscope model can be written in a form where $\mathbf{x} = \boldsymbol{\omega}$ and each measurement $\mathbf{y}_n \in \mathbb{R}^3$.

III. Sensor Data Modeling

This section describes the methods that were used to solve each of the tasks in **Part 1** of the project and explains the approach taken in the code.

A. Task 1

The measurement log file provided in *Dataset 2* is a CSV file that consists of timestamps, linear acceleration in x, y, z, roll and pitch angles in degrees, angular velocity data in the form of gyroscope measurements in x, y, z, and magnetometer field strength.

A few observations from this data include:

- The accelerometer data is in gravity units, which means that the acceleration in the z-direction is around $1g$.
- The timestamps are provided in seconds. More specifically, the timestamps are represents in ”seconds from epoch,” i.e., the time elapsed (in seconds) since the 1^{st} of January, 1970.
- The magnetometer data also has one value greater than the others, representing the axis along which the flux lines were the strongest. This data helps in perceiving which direction is aligned with the magnetic north and south pole of the Earth.

Since this is a static experiment, the true values of the angular velocities are taken as 0. This means that the bias and variance of the gyroscope can be computed by taking the mean and variance along each axis.

The biases and the variances are found to be:

$$\mathbf{b} = [b_x \quad b_y \quad b_z]^\top = [0.0858 \quad 0.2221 \quad -0.0646]^\top$$
$$\mathbf{R} = \text{diag}[\sigma_x^2 \quad \sigma_y^2 \quad \sigma_x^2] = [0.0373 \quad 0.1297 \quad 0.0373] \tag{2}$$

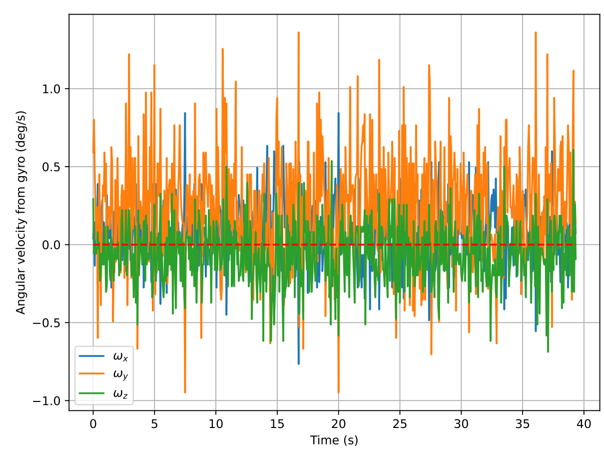

Fig. 1. Gyroscope data plotted against time (s).

B. Task 2

By plotting the accelerometer data provided, it is observed that the robot is kept stationary along on both opposite orientations along each axis. In other words, it is kept upside-down ($-z$), then right-side up (z), then in the sideways (along $+x, +y, -x$ and $-y$) directions.

To find the biases, the accelerometer data along each axis was trimmed such that only about 20 seconds of useful data is taken. The exact time intervals that it was trimmed for, and the code for how the trimming is done on the basis of timestamps, is provided in the Jupyter notebook.

The gains and the biases are found to be:

$$\begin{aligned} \mathbf{k} &= \mathrm{diag}[k_x \quad k_y \quad k_z] = \mathrm{diag}[0.1017 \quad 0.1006 \quad 0.1026] \\ \mathbf{b} &= [b_x \quad b_y \quad b_z]^\top [0.0121 \quad -0.0035 \quad 0.0178]^\top \end{aligned} \tag{3}$$

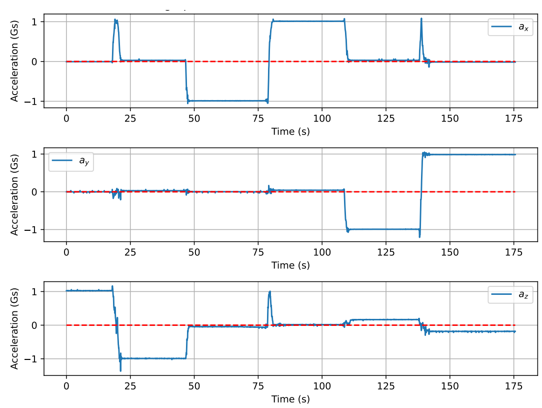

Fig. 2. Untrimmed accelerometer data along each axis (g) plotted against time (s).

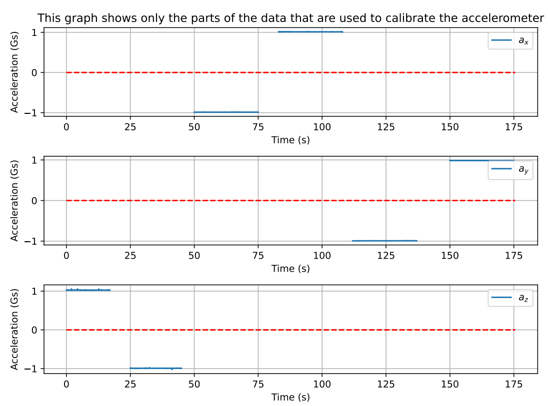

Fig. 3. Trimmed accelerometer data along each axis (g) plotted against time (s).

C. Task 3

The data provides the heights measured by the camera (in pixel) against the corresponding distances (in centimeters) measured by the infrared sensor. The distances are corrected by a factor of $6.7\mathrm{cms}$ to account for the distance between the camera and the IR sensor, and the distance between the wall and the wooden list.

The given datapoints are plotted as shown in figure (4) where the inverse of the heights ($1/\mathrm{pixel}$) are plotted against the distances. The NumPy function `polyfit` is used to fit a straight-line through these points. The resulting regression is also plotted in the same figure. This fit yields the gradient and the bias of the sensor measurement. Dividing the gradient by h_0 (which is $11.5\mathrm{cm}$) yields the focal length f (in pixel).

The gain, bias, and the focal length are found to be:

$$\begin{aligned} x_3 &= g\frac{1}{h} + b \\ x_3 &= 6220.92\frac{1}{h} + 3.11 \\ f &= 540.9497\,\mathrm{px} \end{aligned} \tag{4}$$

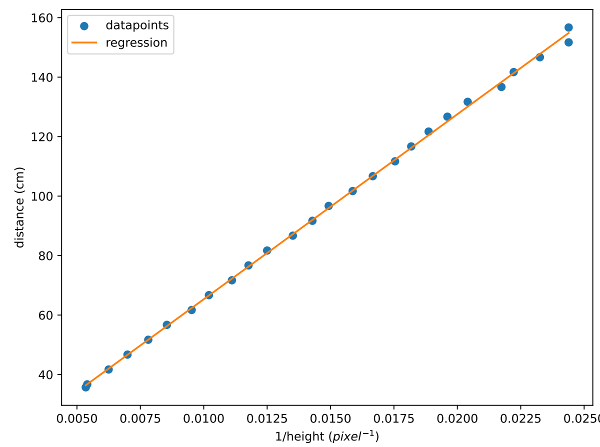

Fig. 4. Distance (cm) measured by the IR sensor plotted against height detected by camera ($1/\mathrm{pixel}$)

D. Task 4

The data provides the time taken by the robot to cover each $40\mathrm{cms}$ distance interval. Each time interval is plotted as shown in figure (**??**) and its average is taken. The average speed is given by the average distance ($40\mathrm{cm}$) divided by the average time interval. The average time interval is found to be 7.6942 seconds for every 40 centimeters, and the average speed of the robot is found to be $5.1986\ \mathrm{cm/s}$.

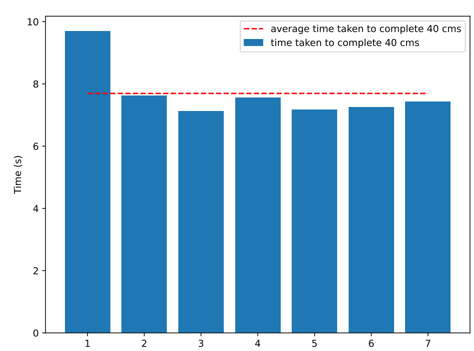

Fig. 5. Time taken to cover each 40 cm distance.

IV. Conclusion

By finding the gains and the biases of the sensors, at the end of **Part 1**, the gyroscope and the accelerometer in the IMU, the camera, and the motors of the robot have been calibrated.