Bachelor Thesis
Electrical Engineering
06 2020

Estimation of altitude

using ultrasonic and pressure sensors

Vasanta Sai Darahas Yeedi

Catherin Carisma Veedhi

Dept. Mathematics and Natural Sciences
Blekinge Institute of Technology
SE–371 79 Karlskrona, Sweden

This thesis is submitted to the Department of Mathematics and Natural Sciences at Blekinge Institute of Technology in partial fulfillment of the requirements for the degree of Bachelor of Science in Electrical Engineering.

Contact Information:
Author(s):
Carisma Catherin Veedhi
Vasanta Sai Darahas Yeedi
E-mail:
cave19@student.bth.se
vaye19@student.bth.se

University Supervisor:
Irina Gertsovich
Dept. Mathematics and Natural Sciences

University Examiner:
Irina Gertsovich

Abstract

The Parrot Mambo mini drone is one of the most used technologies for experimental purposes in educational system. This paper deals with the estimation of altitude of Parrot Mambo mini drone for which the sensors like ultrasonic, barometric pressure sensors and their readings play a major role. To maintain the altitude of drone, we had used the Simulink software and its blocksets like Simulink support package for Parrot mini drones. Apart from the hardware and software description, we discuss several issues regarding the equipment, abilities and performance of the drone.

The drone has been controlled by the software design which we have adapted in Simulink. The altitude values were obtained from the ultrasonic and barometric pressure sensors. To evaluate the altitude of the drone, we have performed several tasks by placing the drone in different positions and noted the sensor readings. The variations in the sensor values indicate that there is a possibility for performance of the drone to be affected by the performance of sensors.

Keywords: Altitude, Parrot Mambo mini drone, Simulink, Ultrasonic sensor, Barometric pressure sensor.

Acknowledgments

We would like to extend our special gratitude to our professor Irina Gertsovich who gave us the golden opportunity to do this experiment on drone with the topic “Estimation of Altitude Using Ultrasonic sensor and Pressure Sensor" and led us with the proper guidance since the very beginning of the project. We are truly privileged to be supervised under such dedicated faculty. This project helped us in doing a lot of research and to learn many things which would be definitely profitable for our further studies.

Secondly, we would also like to thank our parents for encouraging us to go forward and to achieve more in this field. Also, we would like to thank our friends Hemanth, Tabu who contributed their valuable time in helping us during the project.

Sincerely,
Carisma Catherin Veedhi
Vasantha Sai Darahas Yeedi

List of Figures

Contents

Chapter 1

Introduction

Nowadays drones are used in various scientific activities. Generally, drones are small sized robots which can fly. Drones are of different types and are classified based on the structure and its internal components. Based on the number of rotors it has, drones can be classified into quadcopters, hexacopters, octocopters, etc. [1]. In our project we are using Parrot Mambo mini drone which is classified as a quadcopter. In 1956 Oehmichen and Bothezat were inspired from the concept "Convertawings Model A" and successfully built a four-rotor aircraft [2].

The quadcopters are widespread interest due to the usefulness for many applications for instance, mobile measurement, surveying and inspection, agriculture, environment monitoring, disaster rescue.

The mini drones have been increasing their market and they are used for multiple purposes. They consist of onboard cameras which produces photos and videos. These drones are widely used for accident reconstruction photography, real estate, industrial inspection and even in military [3]. They can even conduct search and rescue operations as the drones are powerful to detect electronic beacons, trace wildfires by photography and wireless beacons attached to victims' clothing, track wildlife by photographing. These drones can fly around buildings and hence they are used to locate criminals abusing Wi-Fi such as hacking or downloading child pornography.

Several control theories have been applied to the quadcopters motion control for improving their performance and robustness.One among them is CRA (Characteristic Ratio Assignment). This method applied to mini-drone quadcopter system to achieve the performance and robustness of control system. The results demonstrated that the proposed approach is the effective scheme for improving the performance of mini drone altitude motion control.

Our project mainly focus on estimating the altitude of the drone based on sensors and to analyse the results of how the sensor readings can actually affect the performance of drone. We preferred to use ultrasonic and barometric pressure sensors in order to estimate the altitude of drone. To implement the project we have adapted a software design in MATLAB using Simulink. With the software design as our main tool, we run our project.

We have decided to implement our project using MATLAB and Simulink [4]. Simulink is a graphical programming language and it has very close integration with the MATLAB operation. For the model-based designs, Simulink becomes handy and easy to be operated with just click drag options.

Generally, Parrot Mambo mini drone has several sensors and actuators which help it to fly. These sensors are:

- Ultrasonic Sensor
- Camera Module
- Pressure Sensor
- Inertial Measurement Unit

Parrot Mambo mini drone has an ultrasonic sensor at its bottom, which is used to calculate the distance between a surface and drone. Camera module, which is found beside ultrasonic sensor, helps in calculating horizontal motion and speed of the drone. This drone has pressure sensor, which is placed inside the drone and is used to measure the change in altitude. This drone includes inertial measurement unit, which is made up of 3-axis accelerometer and 3-axis gyroscope. Using this inertial measurement unit, we can know about the factors like acceleration of drone and its relative angle to floor. And coming to actuators of Parrot Mambo mini drone, it has four motors which are confined into two pairs. These two pairs of motors will rotate in opposite direction to each other. Based on these motors speed we can obtain the action of drone we need.

We chose to work with the Parrot Mambo mini drones for their availability and their compatibility with the Simulink unlike the other drones. This paper explains our work in step by step as we discuss the introduction part in chapter 1 and chapter 2 comes with the background research on related works. Chapter 3 will explain about the objectives and contribution for our project whereas in chapter 4 the detailed explaination of sensors used, software application used, system design we implemented is found. Chapter 5 shows the results we obtained and chapter 6 with the conclusion part, future scope on how the project can be extended. Finally the paper ends with providing the references we have approached for writing this report.

Chapter 2

Related Work

The most common used sensors in commercial drones to determine its altitude are IMUs (accelerometer and gyroscope), GPS (Global Positioning Systems) and barometers [4]. Altitude can be determined by GPS, altimeter, radar, or laser. Attitude can be provided by Inertial Measurement Unit (IMU), and motion by GPS or radar. Raw GPS have a poor accuracy both vertically (accuracy between 25 and 50 meters) and horizontally (less than 15 meters). Moreover, GPS is sensitive to interruptions in transmission in urban environments. Radar can estimate both altitude and velocity with greater accuracy, but it requires active sensors that consume power. Altimeters are very widely used, but they depend on pressure variations, which implies an accuracy error of between 6% and 7%. Laser altimeters, on the other hand, are highly accurate, but they have very specific requirements concerning reflecting surfaces. Finally, IMU can provide indications of velocity, acceleration, attitude and orientation, but it is subject to drift and error accumulation [5].

The contributions of several sensors to altitude estimation of the drone had been studied by D. L. Kulhavy et al. [6]. The authors tested a DJI Phantom drone for height measurement at four different levels, 2, 5, 10, and 15 m above ground along a height pole. When the drone was hovering at a height mark, the height reading of the drone displayed on a remote control screen was recorded and compared to its real height on the height pole. The process was repeated with different settings of whether having the GPS on or off; and whether landing the drone before each measurement or having the drone continue to fly to different height level marks. The results showed that to achieve the highest level of accuracy possible that the drone should land and be turned off before each flight to reset the elevation algorithm before each flight. The author stated that "Although GPS is able to measure elevation, its low precision could often introduce error to the height measurement. The drone relies mainly on the barometer for measuring height that is referenced to the ground level. So it confirms that choosing barometric pressure sensor for estimating altitude over GPS is a better choice.

There have been many approaches to estimate the altitude. One of the proposal involved in examining the ability of commercial, hobbyist Small Unnamed Aircraft System (sUAS) pilots to estimate the altitude of their ownship during a realistic flying task. For that paticular experiment, the pilots flew a DJI Phantom 4 Pro to three prescribed altitudes: 50 feet, 200 feet, and 350 feet. In each trial, the participant flew the sUAS from its starting point, hovered at what he or she estimated to be the prescribed altitude, and took a photo of a target. Four methods of altitude measurement were used namely sUAS, range finder, inclinometer, image analysis. Results indicated that participants' altitude estimates were below the prescribed altitude of 50 feet (i.e., they flew the sUAS at a lower altitude than instructed) 52% of the time and below prescribed altitudes of 200 feet and 350 feet 89% of the time. On the other side, the altitude measurements from barometric pressure sensor were also obtained. The altitude estimated by sUAS pilots and the altitude from barometric pressure sensor were compared with the prescribed altitude. It was proven that the sUAS pilots, regardless of their experience, are poor at judging the altitude of their ownship. Though participants were "somewhat confident" in their performance regardless of altitude, participants overestimated their achieved altitude, flying lower than instructed, especially at higher altitudes [7]. From this particular research, we can say that the altitude value determined from barometric pressure sensor would be more accurate to the absolute altitude.

A. Cherian et al. [8] investigated the possibility of predicting the altitude of a UAV looking at the image sequences taken from a single onboard camera from ground. They have found that sparse coding can effectively capture the texture in an image. Supervised regression using that sparse basis against a training set of altitudes provided a good prediction setup. Then the spatio-temporal MRF model is introduced to estimate the altitude of a patch in the image to the altitude of other patches in the same image and patches across images in the earlier time frames. The Markov Random Field (MRF) model is later solved for the Maximum A Posteriori (MAP) estimate of the altitude. With their experiment, it was proved that as the altitude of the UAV goes over a certain height, the images become textureless (which depends on the specific environment though) and their algorithm performs poorly. The predicted altitude gives a very good approximation to the true altitude most of the times. The prediction error increases as true altitude of the UAV increases. This is expected, as at higher altitudes, the ground is seen as almost textureless. This says that their mechanism is most suited for situations where the UAV flies at low altitudes and at low speeds. Also, since the prediction is based on the texture variations in the image, the mechanism performs poorly when the ground surface is textureless. Following this method would definitely stand as better experiment to estimate the altitude but it is limited to give better results at low altitude.

According to our research the ultrasonic and Barometric Air Pressure (BAP) sensors can estimate the altitude at both lower and higher altitudes. However we only focus on estimating the altitude using sensors in it and not by using external equipment.

Chapter 3

Method

3.1 Aim and Objectives

The main goal of our project is to study the possibility to implement an obstacle avoidance during a drone flight by using ultrasonic and the barometric pressure sensors, that are mounted on the drone. Here we assume that the obstacle is represented by a the sudden change in the distance between the ground and the drone along the flight path of the drone. To achieve this goal we need to estimate the altitude of the drone by obtaining signals from ultrasonic and barometric pressure sensor while the drone is operated manually in Simulink.

If the obstacle is appeared during the flight of the drone, the altitude cannot be determined using the ultrasonic sensor. In this case we had used the pressure sensor to measure the altitude of drone. Our work also includes the study of ultrasonic and barometric pressure sensors that are placed inside the drone and their performance. The outcome of the project would stand as very helpful information to understand and improve the performance of the mini drones.

The objectives need to be mentioned in this paper are as follows:

- We monitor the drone using the system design which is developed in MATLAB software.
- We extract the altitude values from sensors with the developed system design.
- We use several setups to record the signals from the drone sensors, while the altitude of the drone is varied between setups.
- We validate that the values obtained from the ultrasonic sensor of the drone are correlated with the distance between the drone and the object.

3.2 Main steps and authors contributions to the project

This project is implemented in the following steps:

- The Parrot Mambo mini drone has been selected as an experimental device
- The Parrot Mambo mini drone is setup with our personal pc through an external CSR 4.0 bluetooth adapter.
- The system design has been developed in MATLAB with Simulink software using Simulink support package for minidrones [9].
- The drone was placed in several positions to measure its altitude.
- Mean and variance for the recorded altitude and pressure signals have been calculated from the recorded values.
- The altitude values are extracted directly from the ultrasonic sensor as well as using the pressure signal.

We had contributed total of 400 hours on this project. The system design, drone operation, mathematical calculations and the chapter 4, chapter 5, chapter 6 in the report were handled by Vasantha Sai Darahas Yeedi whereas the research on articles, validation scenarios and chapter1, chapter 2, chapter 3 were handled by Carisma Catherin Veedhi.

3.3 Sensors

The Parrot Mambo mini drone is intended to be used in an indoor environment which has a size of 4x4 in meters. The drone is equipped with 6-DOF (3-axis accelerometer and 3-axis gyroscope) Inertial Measurement Unit (IMU), an ultrasonic sensor, a pressure sensor and a downward facing camera that has a 120x160 pixel resolution with a 60FPS measurement speed. The handled mini drone has a MATLAB/Simulink support package that gives the opportunity to access the internal sensor data and deploy control algorithms and sensor fusion methods in real-time. The generated MATLAB/Simulink codes are deployed wirelessly to a parrot Mambo mini drone over Bluetooth [10].

In our project we estimate the altitude of the drone using the sensors. For estimation of altitude of Parrot Mambo mini drone, we used two sensors,
1.Ultrasonic sensor
2.Pressure sensor

3.3.1 Ultrasonic Sensor

An ultrasonic sensor which plays a vital role in our project is an instrument that is used to measure the distance to an object by generating sound waves. Ultrasonic sensor measures the distance between the object and the sensor by using the time difference between the generated wave from the the transducer and the reflected wave from an object. The ultrasonic sensor value depends on the time period of the echo and the frequency of generated sound wave. The longer time period of echo of the generated wave, the longer is the distance to an object. Figure 3.1 shows the bottom view of the drone, where the ultrasonic sensor is clearly visible and marked by the arrow. There is one small opening under ultrasonic sensor which is the camera.

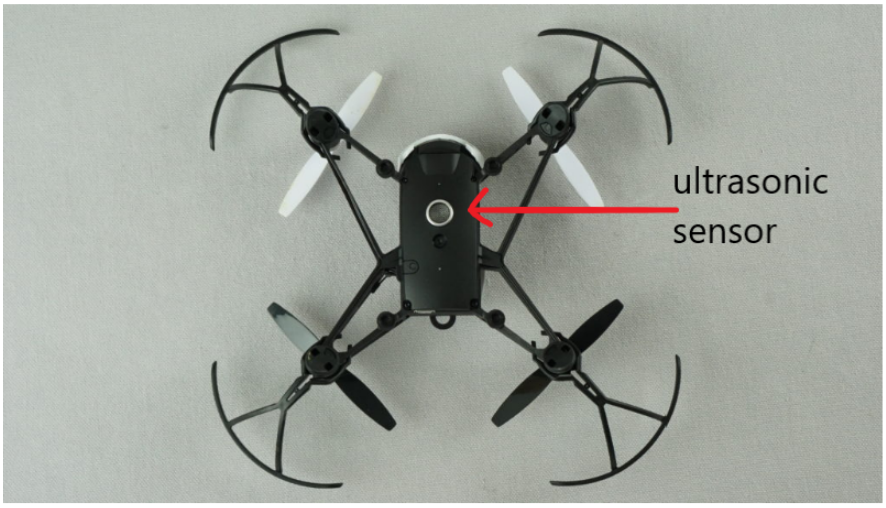

Figure 3.1: Bottom view of the Parrot Mambo mini drone where the ultrasonic sensor is clearly visible

Distance between the ultrasonic sensor and the obstacle can be calculated using the time period measured by ultrasonic sensor [11].

$$d = 0.5 * t * C \tag{3.1}$$

From the formula,
d is the distance of an object or an obstacle, meters,
t is the time period of generated wave and echo, seconds,
C is the speed of sound wave, meter per second.

The ultrasonic sensor can be found at the bottom of the drone as it is shown in Figure 3.1. The signal from ultrasonic sensor shows the distance between the sensor and the closest surface, therefore we can use it to measure the distance from the drone to the ground. The signal from ultrasonic sensor also can be used to measure altitude of the drone assuming that there is no obstacle between the ground and the drone. Ultrasonic sensor is also used in obstacle avoidance application.

3.3.2 Barometric Pressure Sensor

Pressure sensors are usually made out of piezoelectric materials. They are very cheap in price and miniaturized. These piezoelectric materials have the peculiar characteristics of deforming under an electric field or to generate an electric field when deformed [12]. This sensor has many applications as follows

- They are used to predict the weather changes.
- They are used in vehicles for measuring the atmospheric pressure of the environment that the vehicle is driving in.
- They are used to rectify the outputs of sensors which are sensitive to pressure variations.
- There exists a portable barometric pressure measuring devices which are used frequently for mountain climbing so it would be very convenient if not only the pressure but also altitude could be measured simultaneously.

This pressure sensor is also known as Barometric Air Pressure (BAP) sensor that measure air pressure. The altitude of drones can be extracted from the air pressure. Almost every drone contains such BAP sensor as it plays a crucial role in stabilizing the altitude of drone. The principle and technology behind this process are pretty simple, but air pressure readings are prone to drifting due to winds or any rapid changes in the drone's movements. Autonomous drone missions where changes in altitude are essential also make use of the readings from the on board barometer. The barometers can produce more accurate data about the altitude when compared to GPS and provide faster feedback, as long as they have been properly calibrated [13].

According to the 3-D x, y and z axis coordinate system, the altitude of the drone which is measured using ultrasonic sensor is considered as z-axis coordinate. As the altitude of the drone is directed vertically downwards or upwards, this altitude factor is considered as as z-axis of the drone following the right-hand rule. So based on the altitude of the drone, it can be flown up and down along z-axis.

We are using a barometric pressure sensor to measure the altitude of the drone. This barometric pressure sensor of the drone gives us the air pressure values through which we can calculate altitude of the drone. Generally we have barometric formula to calculate pressure from altitude or vice versa [14],

$$P = P0 * exp(-g * M * (h - h0)/(R * T)) \tag{3.2}$$

where P is the air pressure of the drone at altitude 'h',
P0 is the reference pressure taken when the drone is placed on the floor,
g is the gravitational force of earth, g = 9.80665 m/s2,
M is the molar mass of air, M = 0.0289644 kg/mol,
h is the altitude of the drone,
R is the universal gas constant, R = 8.31432 N*m /(mol*K) and
T is the temperature in Kelvins, T = 288.15 K.

From the equation 3.2 we can calculate altitude from pressure. From this equation we obtained a modified equation through which we can calculate altitude from the pressure values obtained from the barometric pressure sensor.

$$h = 8453.669 * ln(P0/P) \tag{3.3}$$

These calculated altitude values h are compared to the altitude values d acquired by using time signal t from the ultrasonic sensor as defined by equation 3.1. From these altitude values calculated from pressure sensor and measured altitude values from ultrasonic sensor, we can estimate the altitude of the drone.

3.3.3 Mean and Variance of Acquired Data

From the values we obtain from ultrasonic and barometric pressure sensors, we calculate the mean and variance of altitude and pressure values to calculate the error or deviation from the actual altitude and pressure values.

We calculated mean using equation 3.4,

$$\mu = \frac{\sum(X)}{N}. \tag{3.4}$$

We calculated variance using equation 3.5,

$$\sigma^2 = \frac{\Sigma(X - \mu)^2}{N}, \tag{3.5}$$

where
μ = Mean of recorded values X,
N = Number of values of X,
σ^2 = Variance of recorded values X.

Chapter 4

Implementation

As our project is about estimation of the altitude of the Parrot Mambo mini drone using ultrasonic sensor and pressure sensor, we need an environment or a software application to implement. We are using MATLAB as the main software application to implement our project. We use Simulink which is a MATLAB based environment used for modeling, simulating and analyzing dynamical systems. In Simulink we can customize user defined systems as required and can study its characteristics using several plots.

In Simulink we are having some add-ons which are predefined, these predefined add-ons have a wide variety of apps, support packages, and toolboxes. In Simulink there is an add-on 'Simulink support package for Parrot Mambo mini drones' which is used to build flight control algorithms for Parrot Mambo mini drones. The 'Simulink support package for parrot mini drone' is installed and setup to our Parrot Mambo mini drone using the guide given by Simulink support package [9]. We used an external CSR 4.0 bluetooth adapter for connection between host computer and the Parrot Mambo mini drone we use. For this bluetooth dongle, we installed the CSR-specific driver.

4.1 System Design

Figure 4.1 represents the main block diagram for the process to estimate the altitude of Parrot Mambo mini drone. This block diagram includes three blocks. The first block includes two input ports 'AC cmd' and 'Sensors'. 'AC cmd' input port generates bus signals which includes the values of position and orientation references. And the second input port 'Sensors' consists of data from sensors such as accelerometer, gyroscope, ultrasonic and pressure. The second block consists of flight control system, which includes all functionalities, subsystems, operations and the logic. And the third block consists of motor control variables.

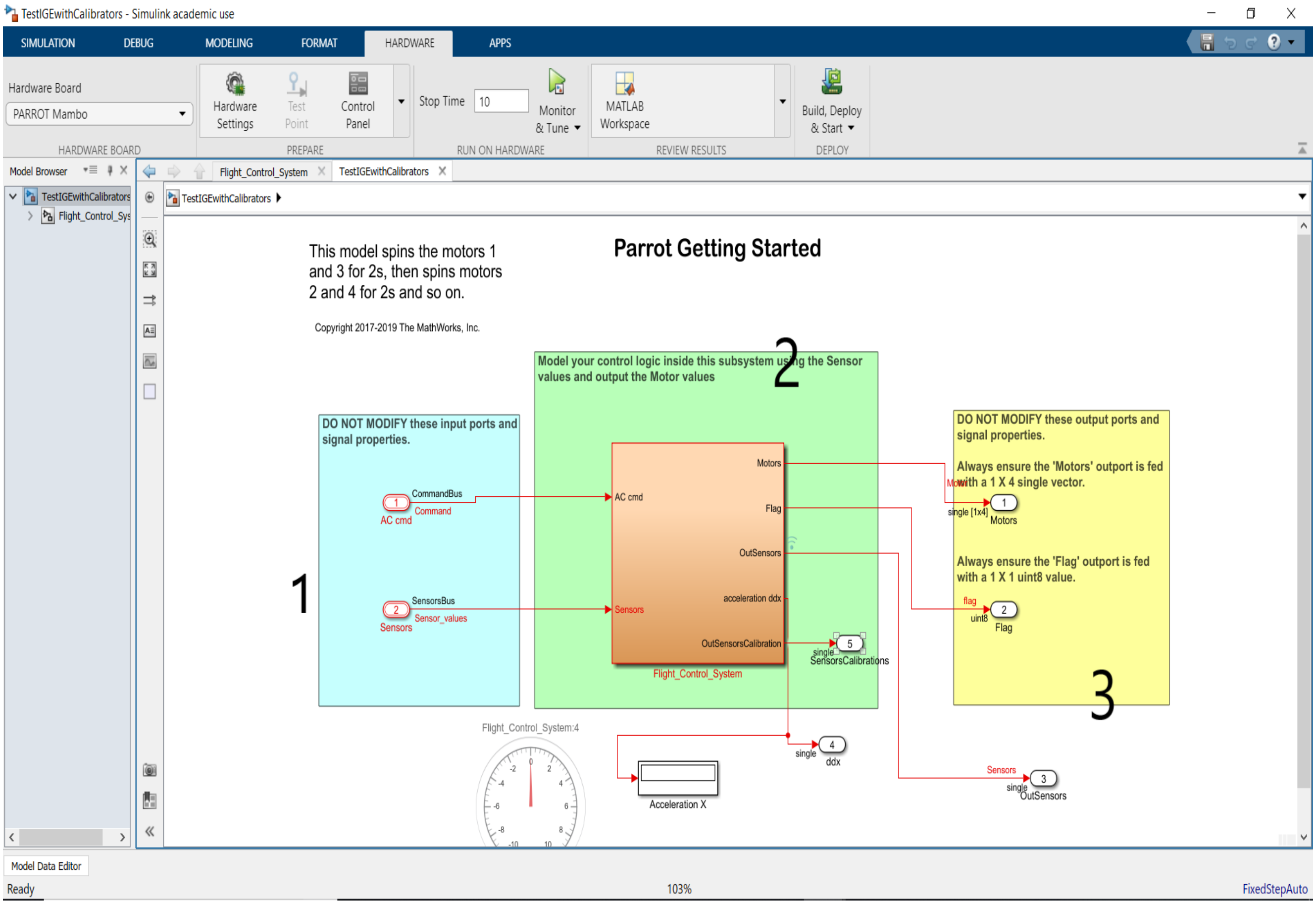

Figure 4.1: Control system design for Parrot Mambo mini drone

Figure 4.2 represents the flight control system, which is the main sub system from which we record the sensor values. In this flight control system, the 'Sensors' input port is divided into 'VisionSensors', 'HALSensors', and 'SensorCalibration' using bus selector block. 'HALSensors' contains all the sensor signal values from accelerometer, gyroscope, pressure sensor, ultrasonic sensor.

And further HALSensor is divided into five types of arrays as shown in Figure 4.3. Each array of HALSensor contains sensor values, which are obtained from accelerometer, gyroscope, pressure sensor, ultrasonic sensor.

- Array <HAL acc SI> contains acceleration of drone in x, y, z coordinates.
- Array <HAL gyro SI> contains angular velocity of the drone from x, y, z axes.
- Array <HAL pressure SI> contains pressure values of the drone.

- And the array <HAL ultrasound SI> contains altitude values of the drone.

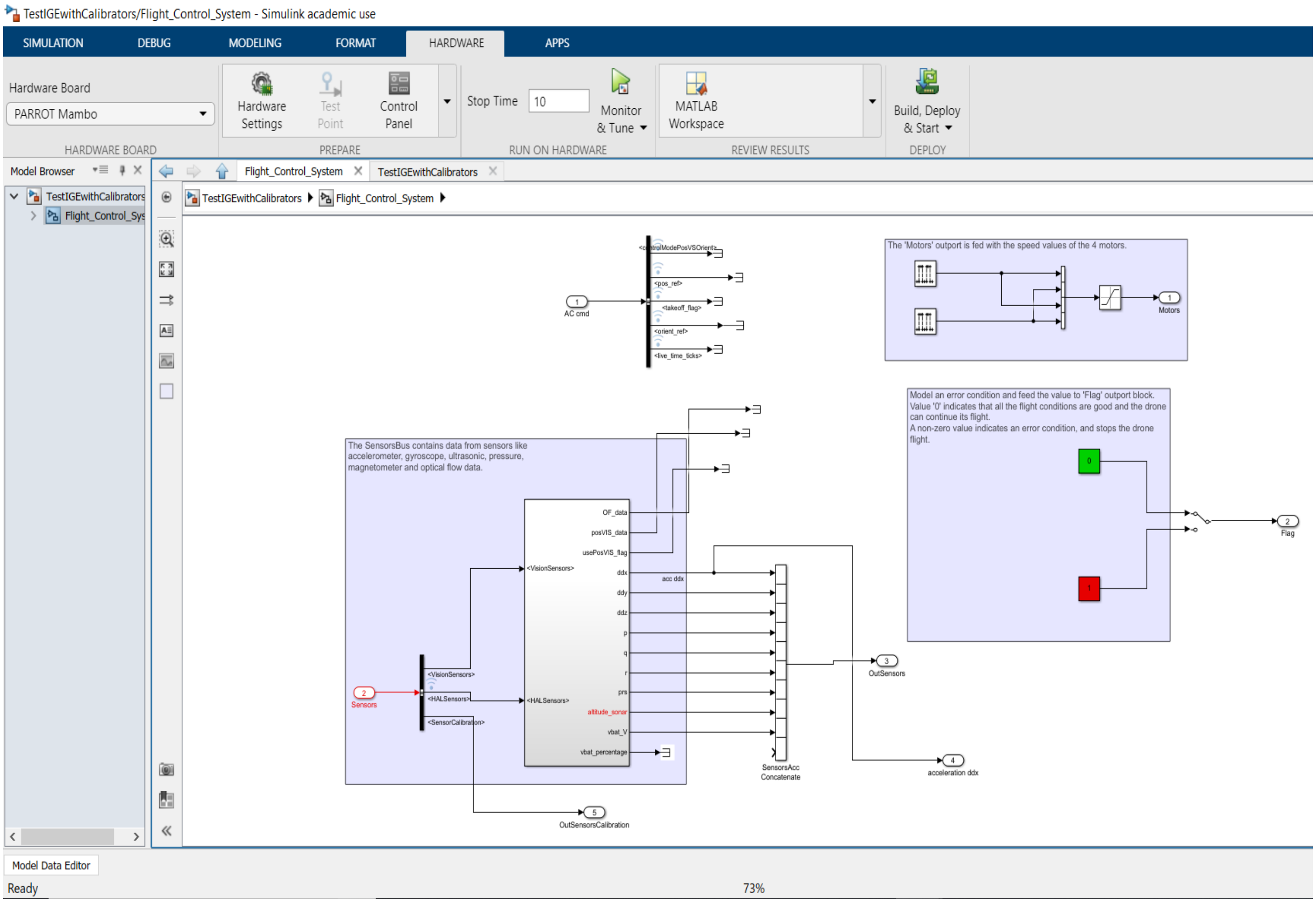

Figure 4.2: Flight control system

As our project is about estimation of altitude of the drone using ultrasonic sensor and the pressure sensor, we record the values from arrays <HAL ultrasound SI> and <HAL pressure SI>. We obtain the values of ultrasonic sensor and pressure sensor from the ports 11 and 10 respectively.

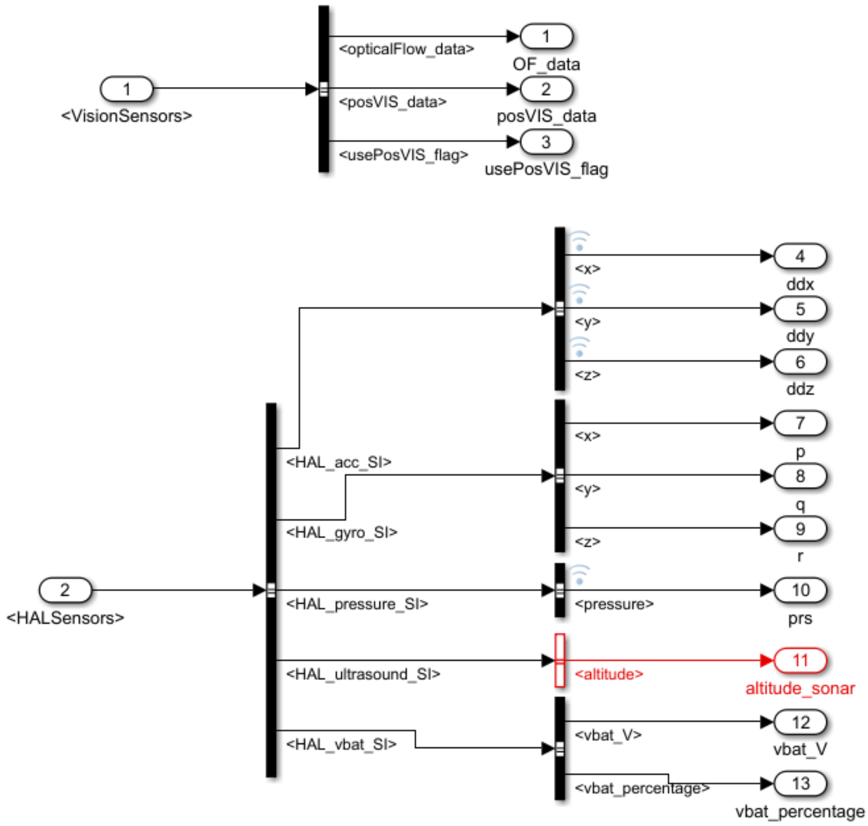

Figure 4.3: HALSensor

From Figure 4.2 port 5 'OutSensorsCalibration' contains all the calibrated values of the sensors like accelerometer, gyroscope, pressure sensor, ultrasonic sensor. Port 1 'Motors' is an output port, which sends signals to the four rotors of the drone. When the system is ready for use, deploy model. Now this model will be loaded into the drone and is ready for simulation. The MAT file containing the recorded values obtained from the sensor of the drone can be downloaded after the flight time. So using these MAT files we obtained plots which are used to study the sensor characteristics of the drone.

Chapter 5

Results

This chapter includes the plots of altitude and pressure values obtained from ultrasonic sensor and barometric pressure sensor. We recorded the values of the altitude and pressure values of the drone for 1 minute. From these recorded values we calculated mean and variance of altitudes and pressures to compare and estimate the altitude of the drone. We plotted the values of altitude and pressure at several setups such as

- When drone is placed on the ground
- When drone is 1 meter above the ground
- When an obstacle placed 60 cm below the drone and the drone is 1 meter above the ground
- When an obstacle placed 90 cm below the drone and the drone is 1.3 meter above the ground

5.1 Drone is placed on the ground

We placed the drone on the ground and recorded altitude, pressure signals of the drone.

Figure 5.1 represents the altitude values d of the drone obtained from ultrasonic sensor for 60 seconds. When the drone is placed on the ground, the mean value estimated from the signal acquired from the sensor is 0.43847 m. We calculated mean and variance of the altitude d of the drone using equations 3.4 and 3.5, where X is the distance d between the drone and the ground.

μ_d_ground $= 0.438$ m
σ^2_d_ground $= 0.00004$ m

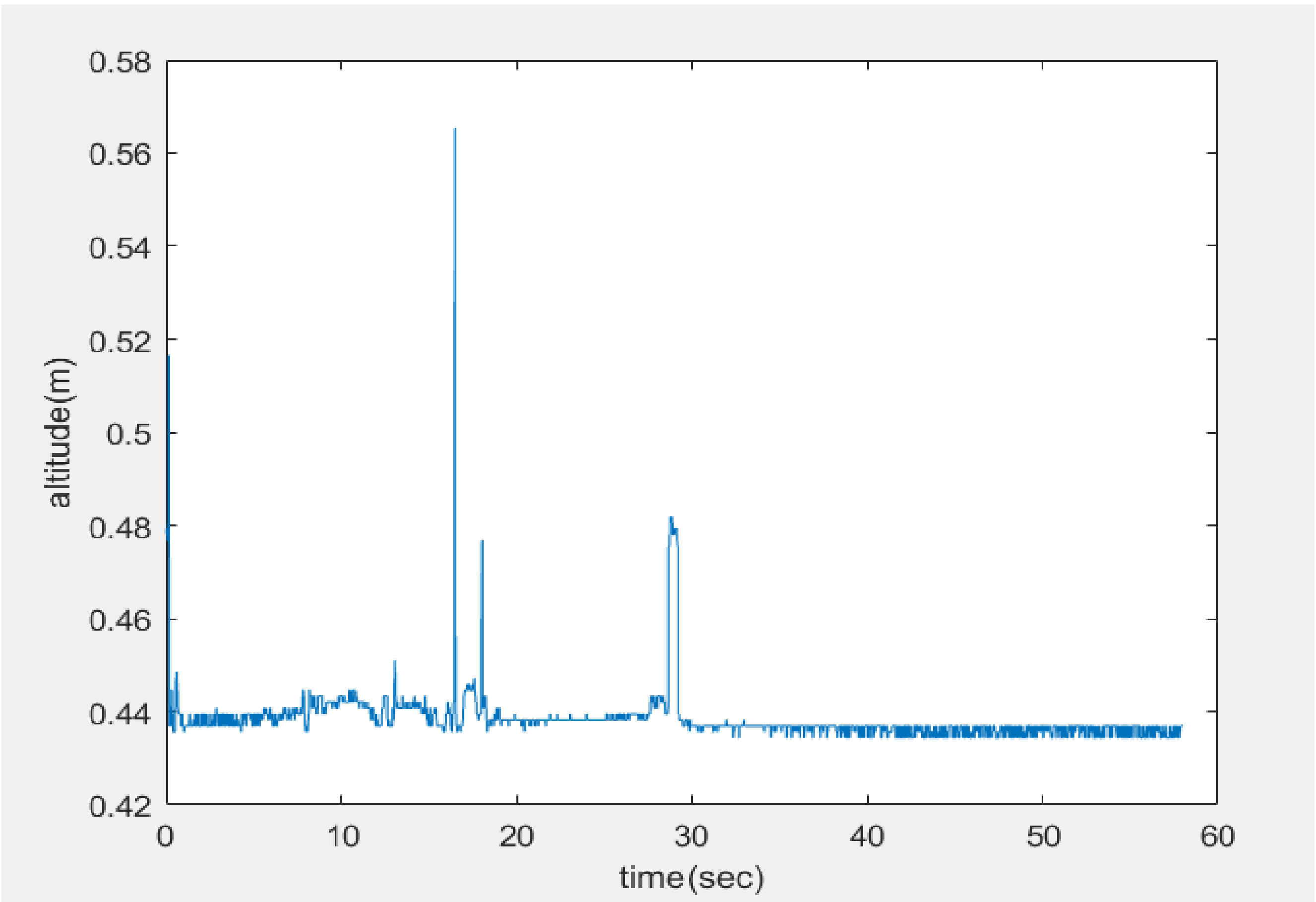

Figure 5.1: Drone placed on the ground

The calibrated value obtained from the ultrasonic sensor of the Parrot Mambo mini drone is `d_ground_calib` = 0.444 m. Generally, all the ultrasonic sensors have its range to work efficiently, i.e, all the ultrasonic sensors works at some ranges only. Outside these ranges, the ultrasonic sensor shows some error values as we see now. For example, ultrasonic sensor 'HC SR-04' has a range of 2 cm to 10 meters at which the sensor works efficiently [15].

From Figure 5.1 it is observed that the minimum value that ultrasonic sensor of the drone can show is 0.43 m. When the drone is placed on the ground it is showing an error of 0.438 m.

With Parrot Mambo mini drone placed on the floor we obtained pressure values P from barometric air pressure (BAP) sensor. Using these recorded pressure values, we calculated the mean and variance of BAP. The recorded plots were shown in Figure 5.2. We considered this mean value as the reference pressure P0 to calculate the altitude of the drone h from the pressure values P according to equation 3.3.

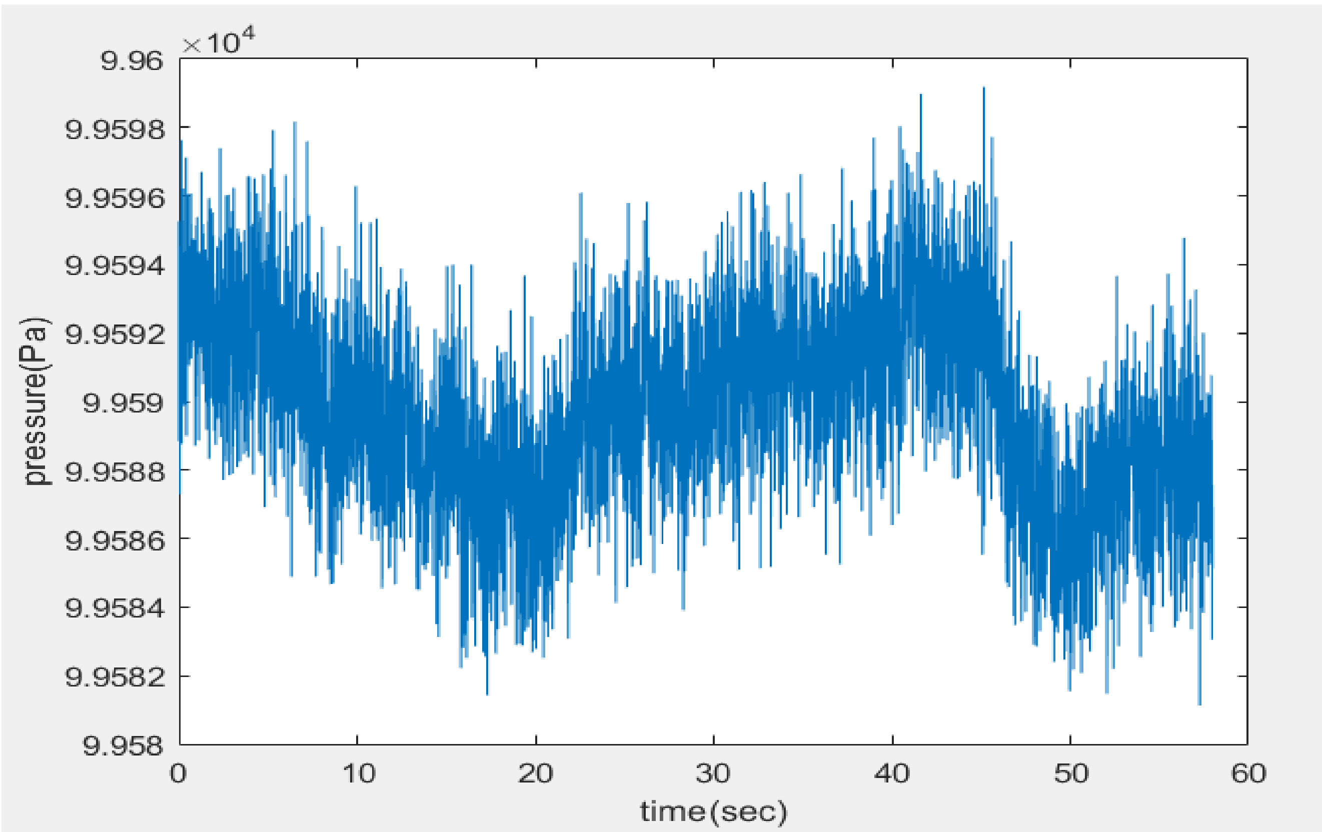

Figure 5.2: Pressure of the drone when drone is on the ground

We calculated mean and variance of the air pressure P of the drone as shown in Figure 5.2,

μ_`P0` = 99589.774 Pa,

σ^2_`P0` = 8.069 Pa,

Calibrated sensor value, when drone is on the ground P0 = 99593.555 Pa.

5.2 Drone is 1 meter above the ground

The setup where Parrot Mambo mini drone is 1 meter above the ground, is shown in Figure 5.3.

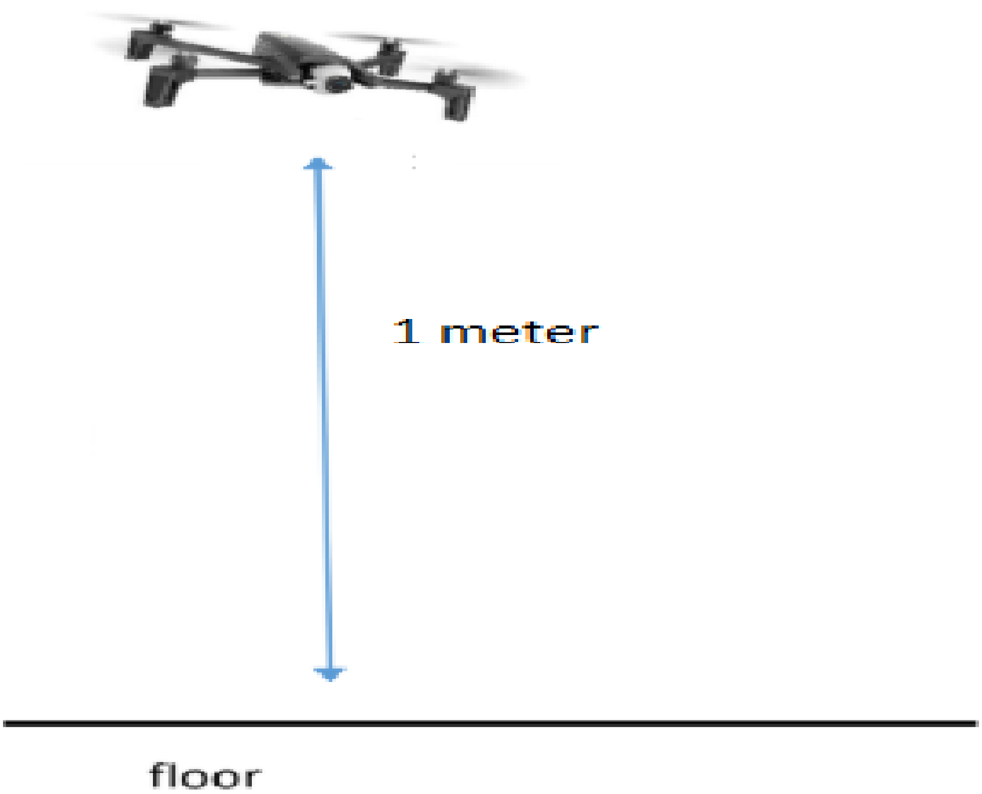

Figure 5.3: Drone is 1 meter above the ground

The blue colour plot in Figure 5.4 shows the altitude values, when the drone is 1 meter above the ground. We can clearly see the difference between the two plots (when the drone is placed on the ground and when it is 1 meter above the floor) from the picture as shown in Figure 5.4

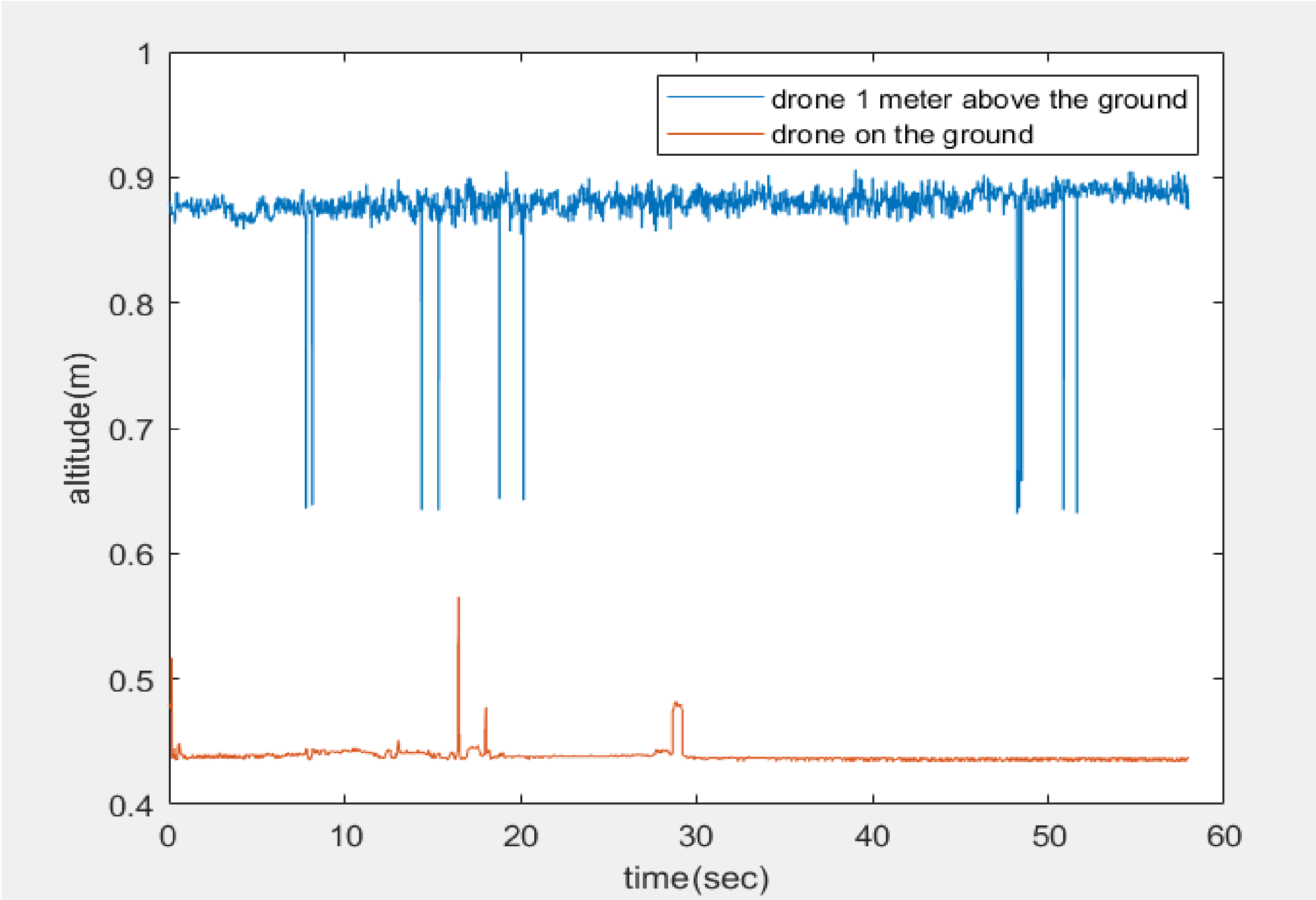

Figure 5.4: Comparison between altitudes, when drone is on the ground and the drone is 1 m above the ground

From the above observations, we calculated the mean and variance corresponding to the altitude values obtained from the ultrasonic sensor.

μ_`d_1m` = 0.878 m,
σ^2_`d_1m` = 0.0005 m,
`d_1m_calib` = 0.926 m.

From the above plot, we can notice the difference between theoretical and practical values. Here, the mean value experimental value μ`_d_1m` = 0.87 m, while theoretically it should be equal to 1 m.

From the above experiment which we made by placing the drone 1 meter above the floor, we got the corresponding pressure values from the pressure sensor. Through these observation, we calculated again the mean and variance of the pressure values that we recorded from the barometric pressure sensor. The plots were shown in Figure 5.5

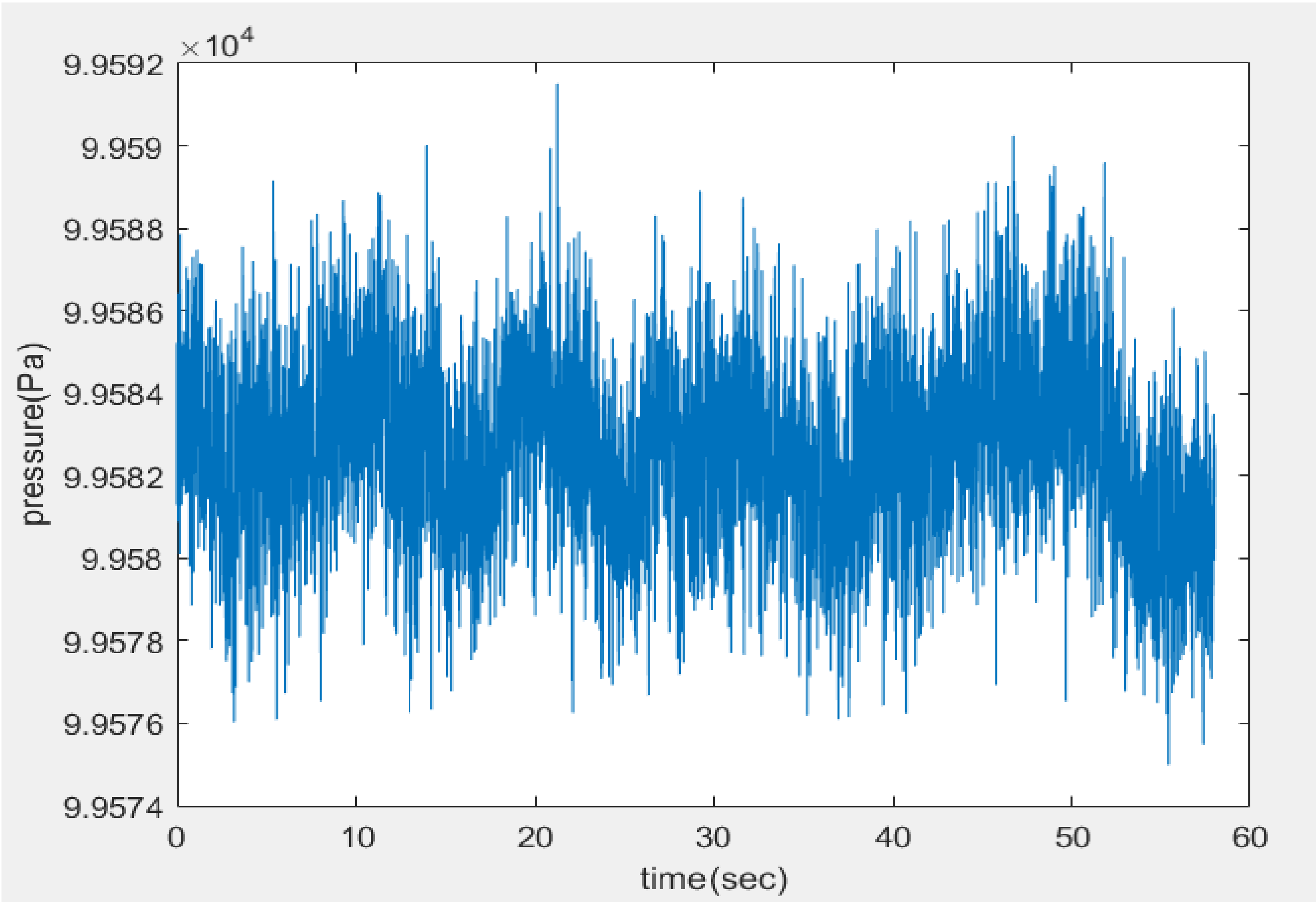

Figure 5.5: Drone is 1 meter above the floor (pressure)

The mean and variance of the pressure values calculated from the above plot are stated as below:
μ`_P_1m` = 99582.59 Pa,
σ^2`_P_1m` = 5.428 Pa,
Calibrated sensor value, when drone is 1 m above the ground = 99584.992 Pa.

Using equation 3.3, we calculated the altitude at instantaneous pressure P which we noticed during the experiment (when the drone is 1 meter above the floor) from the barometric pressure sensor. The mean and variance are calculated from the instantaneous altitude values.
From the equation 3.3,

- P0 (reference pressure) = Calibrated pressure sensor value, when drone is on the floor = 99593.555 Pa.

- P = instantaneous pressure values obtained at each interval.

We considered calibrated pressure sensor (when drone is on the floor) as the reference pressure P0 and calculated the altitude h at every instant. From these instantaneous altitude h, we calculated mean and variance using equations 3.4 and 3.5 respectively.

μ_h_1m = 0.960 m,
σ^2_h_1m = 0.041 m.

Here, when we compare the mean (μ_d) which we got from the ultrasonic sensor and the mean (μ_h) of the altitude that we calculated from the BAP sensor, we can see the difference in the values. The mean (μ_h = 0.960) calculated from pressure values is greater than the mean value from ultrasonic sensor (μ_d = 0.878).

5.3 An obstacle placed below the drone

5.3.1 An obstacle placed 60 cm below the drone, the drone is 1 m above the floor

The ultrasonic observations are recorded in the experiment when the drone is 60 cm below the drone and the drone is 1 meter above the floor as shown in Figure 5.6.

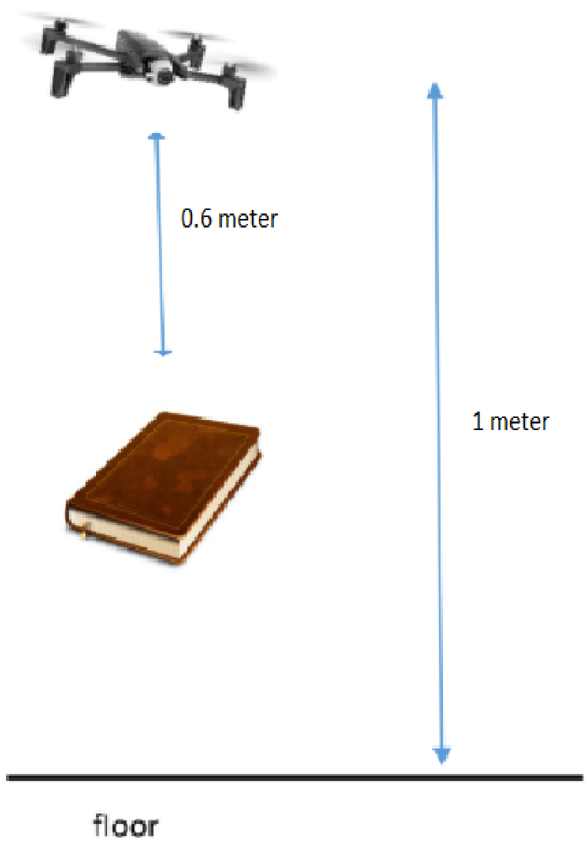

Figure 5.6: An obstacle is placed 60 cm below the drone

The plot in Figure 5.7 represents the altitude characteristics of the drone when the drone is 1 meter above the floor having an obstacle below it.

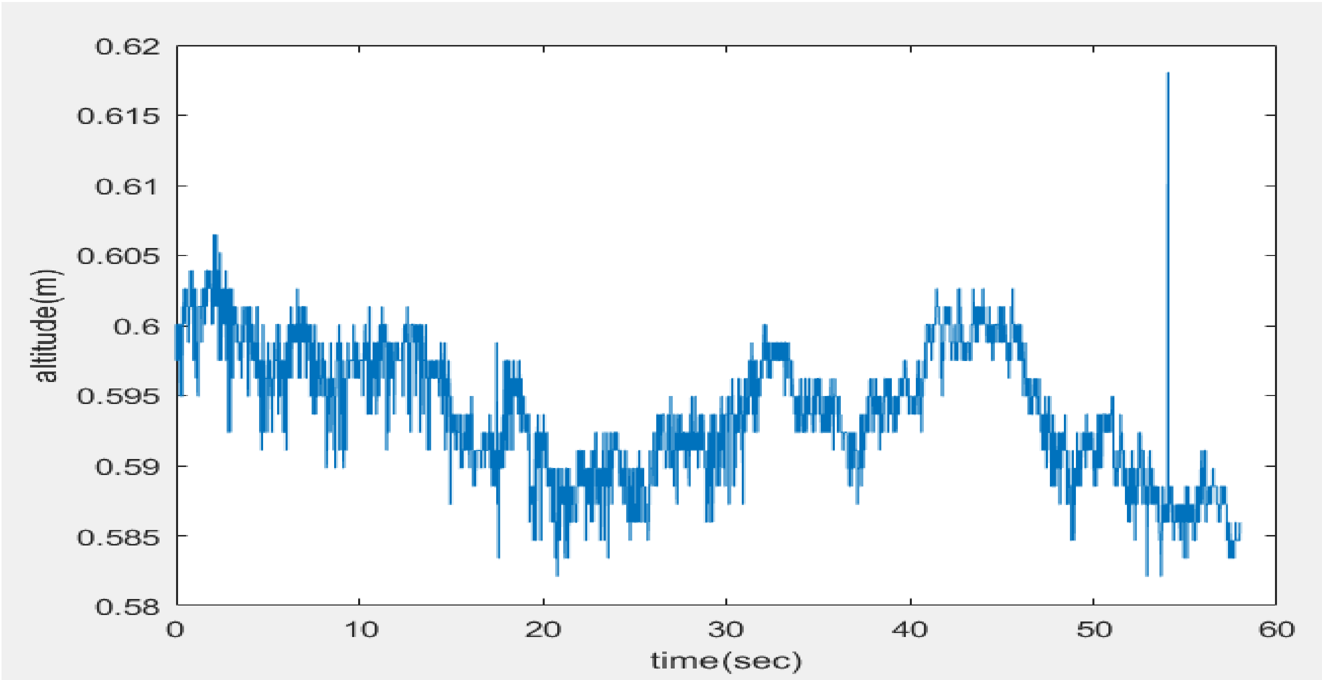

Figure 5.7: An obstacle placed 60 cm below the drone (altitude)

Mean and variance are calculated, using the formula for mean 3.4 and formula for variance 3.5 as stated above from the observed ultrasonic values. The values are stated below in the bullet description.

μ`_d_obstacle(60cm)` = 0.593 m,
σ^2`_d_obstacle(60cm)` = 2.266 m,
`d_obstacle(60cm)_calib` = 0.597 m.

Here, the mean that we got from the ultrasonic sensor, is very close to the theoretical value. As we should get 0.6 meter when the drone is 60 cm above from the obstacle.

The pressure sensor values are also recorded from the experiment (when the object is placed above 60 cm from the drone). The corresponding mean and variance are calculated from the values that are recorded from barometric pressure sensor. The plot is shown below in Figure 5.8.

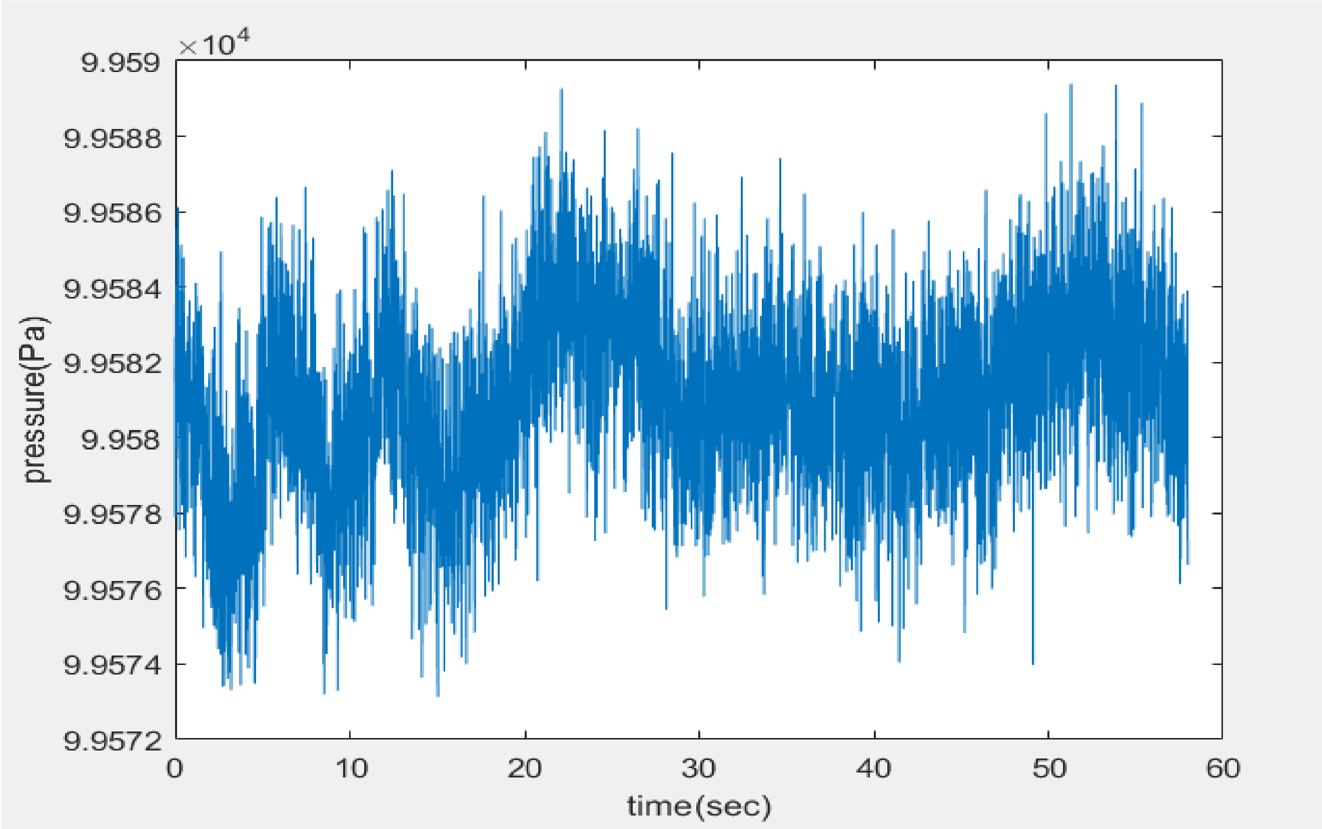

Figure 5.8: An obstacle is placed 60 cm below the drone (pressure)

The mean and variance are calculated from the barometric pressure sensor and stated below,

μ`_P_obstacle(60cm)` = 99581.05 Pa,
σ^2`_P_obstacle(60cm)` = 6.26262 Pa,
`P_obstacle(60cm)_calib` = 99581.547 Pa.

Using the equation 3.3, we calculated the altitude at instantaneous pressure which we noticed during the experiment(when the object is at 60 cm below the drone) from the barometric pressure sensor. The mean and variance are calculated from the instantaneous altitude values.

From the equation 3.3,

- P0 (reference pressure) = calibrated pressure sensor value, when drone is on the floor = 99593.555 Pa as it was described in Section 5.1.
- P = instantaneous pressure values obtained in this setup.

We considered calibrated pressure sensor (when drone is on the floor) as the reference pressure value and calculated the altitude values at every instant. From these instantaneous altitude values, we calculated mean and variance using equations 3.4 and 3.5 respectively.

μ`_h_obstacle(60cm)` = 1.094 m,
σ^2`_h_obstacle(60cm)` = 0.048 m.

We understood from the above values, that the pressure sensor values are independent of the object placed below the drone whereas the ultrasonic sensor values vary with the object distance to the ground. The mean that we got in the experiment (when the object is placed 60 cm below the drone) is much more similar to the mean value of the experiment (when the drone is 1 meter above the floor). That means that the pressure sensor is useful for estimating the attitude but not for the obstacle avoidance directly, unless the height of the obstacle is known in advance.

5.3.2 An obstacle is placed 90 cm below the drone, the drone is 1.3 m above the floor

This experiment is made by placing the drone above the floor in the height of 130 cm and the object is placed in between the drone and floor with 90 cm below the drone and 40 cm above the floor as shown in Figure 5.9.

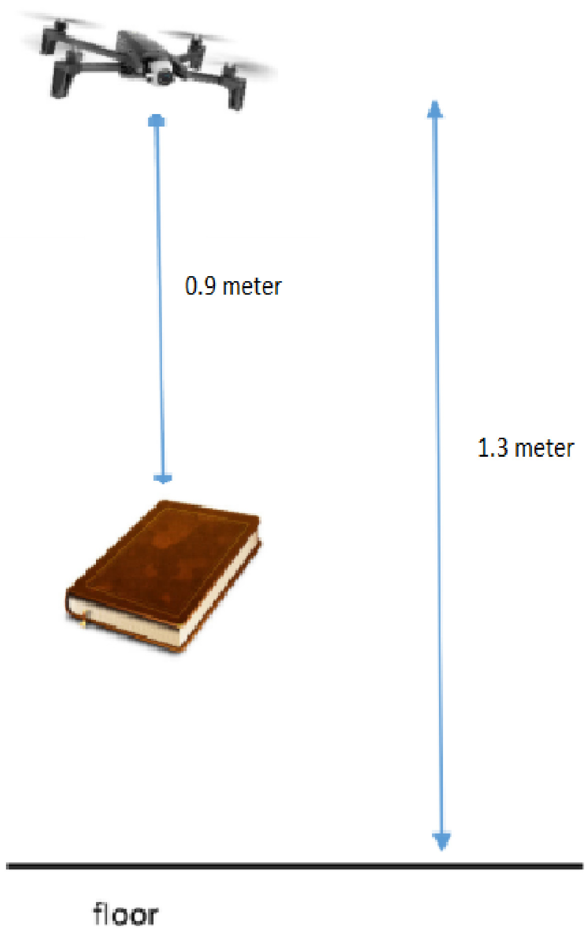

Figure 5.9: An obstacle is placed 90 cm below the drone

The ultrasonic values are recorded for the experiment and plotted as seen in Figure 5.10.

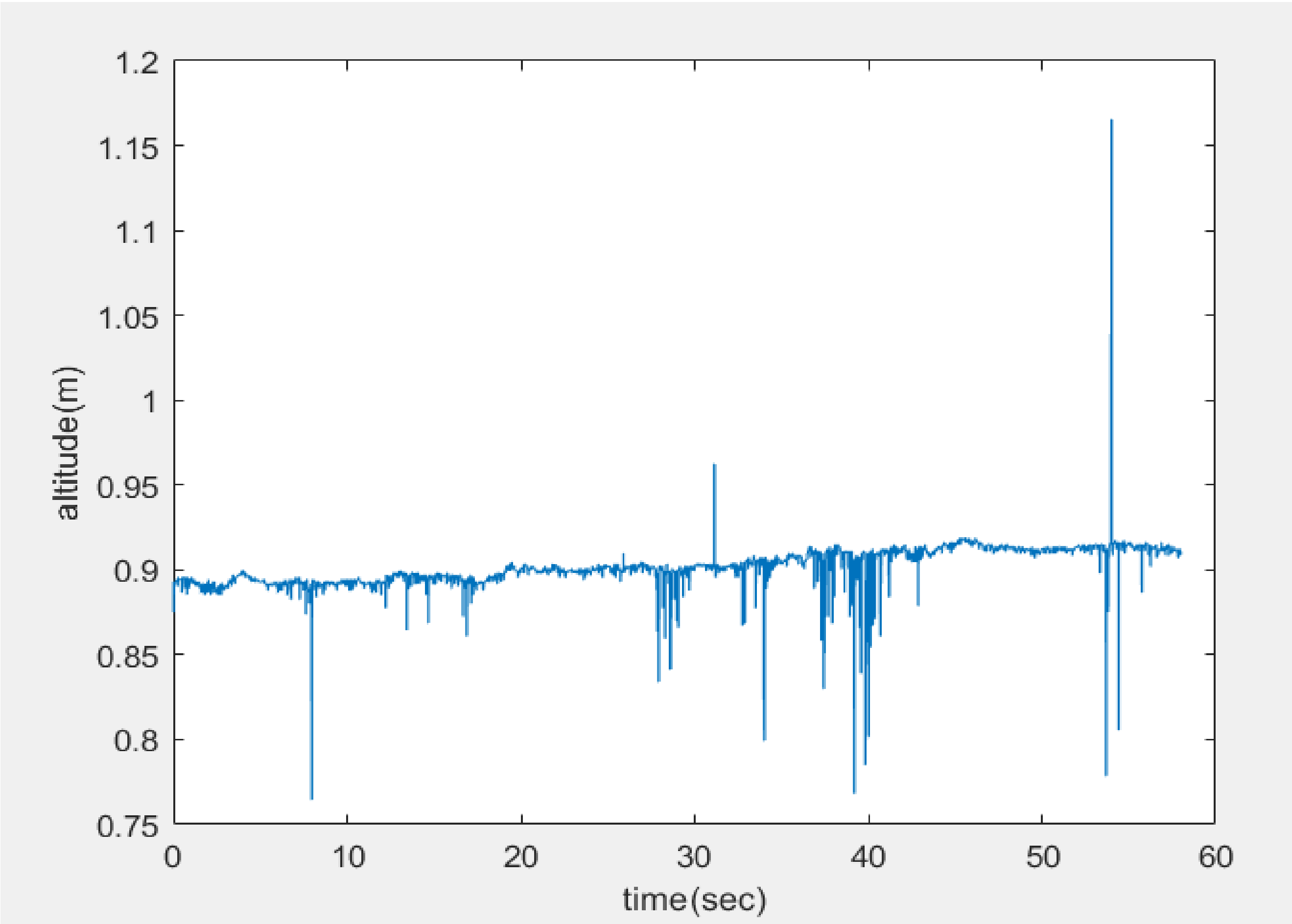

Figure 5.10: An obstacle is placed 90 cm below the drone (altitude)

The mean and variance that corresponding to the altitude values are calculated using the mean and variance equations. The mean and variance values are stated below :

μ`_d_obstacle(90cm)` = 0.901 m,
σ^2`_d_obstacle(90cm)` = 0.0002 m,
`d_obstacle(90cm)_calib` = 0.891 m.

The mean value that calculated from the altitude are close to the theoretical ones as it should be 0.9 cm.

Here, the pressure sensor values are also recorded to estimate altitude of the drone from these values. The corresponding mean and variance are calculated from the values that are recorded from barometric pressure sensor. The plot were shown in Figure 5.11 below.

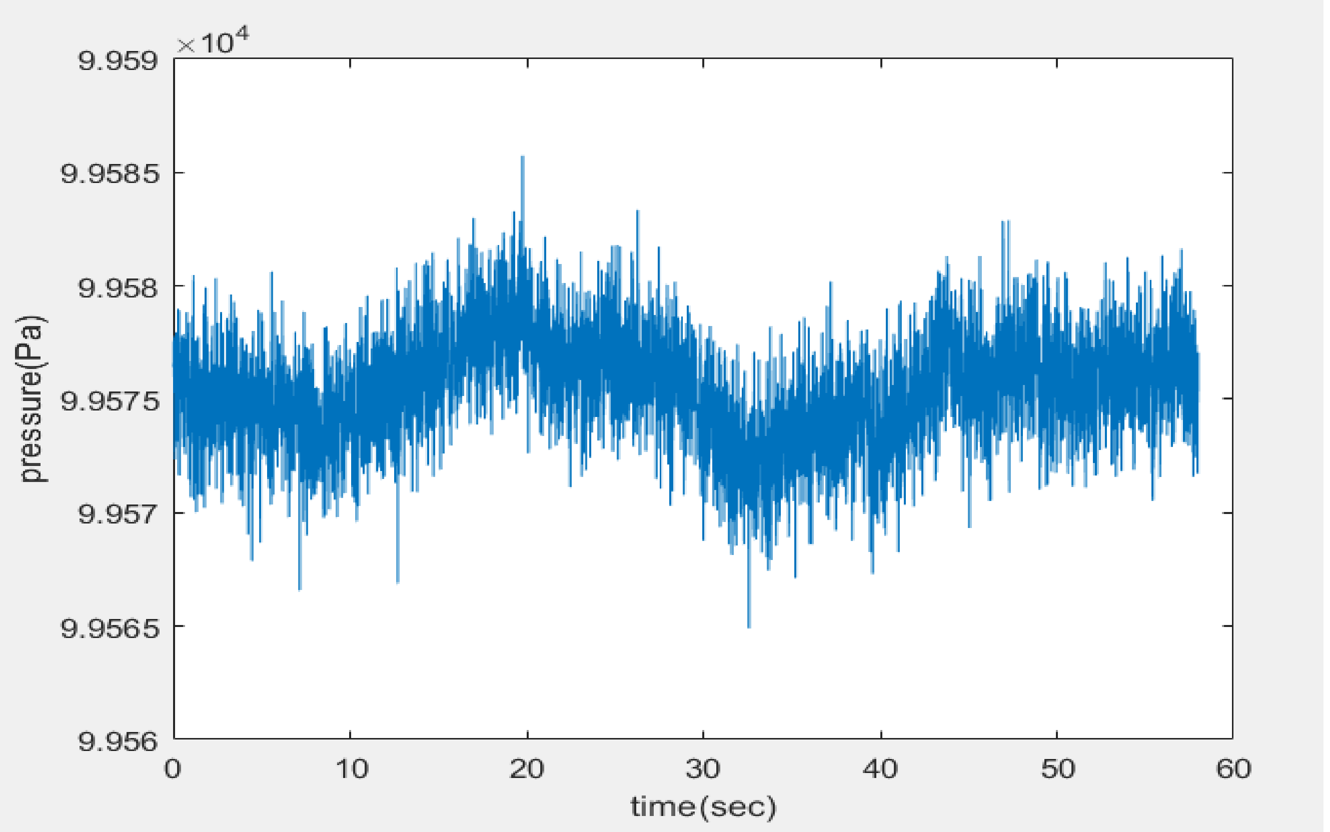

Figure 5.11: An obstacle is placed 90 cm below the drone (pressure)

The mean and variance are calculated from the barometric pressure sensor and stated below,

μ`_P_obstacle(90cm)` = 99575.48 Pa,
σ^2`_P_obstacle(90cm)` = 6.402156 Pa,
`P_obstacle(90cm)_calib` = 99575.867 Pa.

Here, the reference pressure is taken as P0 = 99590.658 Pa as the air pressure changes due to many factors. We calculated the mean and variance of the altitude, from the observations, we got through the pressure sensor using the mean and variance equations.

μ`_h_obstacle(90cm)` = 1.329 m,
σ^2`_h_obstacle(90cm)` = 0.049 m.

The above mean value is similar to that of when drone is placed 1.3 m above the floor. As already stated above, now we can very strongly confirm that pressure values from barometric pressure sensor are independent of obstacle placed between the drone and the floor.

We tabulated all the pressure and altitude values obtained from the four setups experimented above.

Drone	Distance to obstacle	Pressure P, Pa		Altitude h from P, m		Altitude from ultrasonic sensor d, m	
		μ	σ^2	μ	σ^2	μ	σ^2
On the ground	x	99589.7	8.069	x	x	0.438	0.00004
1 m air	x	99882.5	5.428	0.960	0.041	0.878	0.00051
1 m air	0.6 m	99581	6.262	1.094	0.048	0.593	2.26655
1.3 m air	0.9 m	99575.4	6.402	1.329	0.049	0.901	0.00022

From the results above,

- Relative error of ultrasonic sensor and BAP sensor are calculated to estimate which sensor is more accurate.

  Relative error in % = (|true value - estimated value|/true value) * 100%

Drone	Relative error in %	
	Ultrasonic sensor	BAP sensor
0.6 m	1.16 %	x
0.9 m	0.1 %	x
1 m	12.2 %	4 %
1.3 m	x	2.23 %

- From the above table, we can observe that the maximum values of relative errors of both ultrasonic sensor and the BAP sensor are small, i.e the altitude values from the ultrasonic sensor and BAP sensor are accurate.
- However, when the drone is 1 m above the ground and there is no obstacle placed, the ultrasonic sensor is showing a relative error of 12.2% which is an exceptional case.
- When an obstacle placed below the drone at a distance of 0.6 m and 0.9 m, the ultrasonic sensor is showing the values of distance from the obstacle not from the ground. In the presence of obstacle, the ultrasonic sensor detects the obstacle but we cannot estimate the altitude of the drone from the ground.

- We can clearly observe that, regardless of obstacle presence, the BAP sensor shows the altitude of the drone from the ground. For example, when the drone is 1 m above the ground without any obstacle, the altitude calculated from the BAP sensor is 0.96 m and when an obstacle is placed 60 cm below the drone, the altitude calculated from the BAP sensor is 1.09 m.

- From the observations above, to estimate the obstacle the ultrasonic sensor is more useful and to estimate the altitude of the drone from the ground regardless of obstacle presence the BAP sensor is more useful.

Chapter 6

Conclusions and Future Work

6.1 Conclusion

We had studied the working of sensors present inside the drone and their characteristics, their behaviour at different conditions and lengths. We identified the difference between the ultrasonic and BAP sensor values. Here are conclusions of our study:

- To estimate the altitude of the drone, the ultrasonic sensor and the Barometric Air Pressure (BAP) sensor can be used.
- The altitude values from the ultrasonic and BAP sensors are close to the original altitudes.
- Ultrasonic sensor of the drone is more useful to detect the obstacles, i.e we can use the ultrasonic sensor of the drone for obstacle detection or obstacle avoidance application.
- The main advantage of BAP sensor in estimating altitude of the drone is that, using BAP sensor we can estimate the altitude regardless of obstacle presence.

From the above conclusions, we can state that both the ultrasonic and barometric pressure sensor has equal importance in estimating the altitude of the drone in relative to the condition the drone has placed.

6.2 Future work

The future scope of our project will be making the drone to fly up and down based upon the object placed below the drone. The drone's position will be varied according to the object's position. If the obstacle is raised by a certain length from the ground, then the drone also should fly up to the length which the book is raised. In the same way, if the drone's position is changed to certain length below from initial ground position, then the drone should fly down corresponding to the drone's position.

Bibliography

[1] Types of drones - explore the different types of UAV's, Electronic Circuits and Diagrams-Electronic Projects and Design. Library Catalog: www.circuitstoday.com Section: Drones, [Online]. Available: http://www.circuitstoday.com/types-of-drones (visited on 04/17/2020).

[2] W. Liang, "Attitude estimation of quadcopter through extended kalman filter," p. 42,Available:http://preserve.lehigh.edu/etd/2685

[3] (Jun. 2015). Rise of mini-drones | proceedings of the 2015 workshop on privacy-aware mobile computing. Archive Location: world Library Catalog:PAMCO '15:Proceedings of the 2015 Workshop on Privacy-Aware Mobile ComputingJune 2015 Pages 7–12https://doi.org/10.1145/2757302.2757303. (visited on 04/03/2020).

[4] P. Lu and Q. Geng, "Real-time simulation system for UAV based on matlab/simulink," in *2011 IEEE 2nd International Conference on Computing, Control and Industrial Engineering*, vol. 1, Aug. 2011, pp. 399–404. DOI: 10.1109/CCIENG.2011.6008043.

[5] Altitude sensor fusion, Tim Delbrügger. Library Catalog: timdelbruegger.wordpress.com, [Online]. Available: https://timdelbruegger.wordpress.com/2016/01/05/altitude-sensor-fusion/ (visited on 06/08/2020).

[6] D. L. Kulhavy etal . Accuracy assessment on drone measured heights at different height levels, [Online]. Available: https://scholarworks.sfasu.edu/cgi/viewcontent.cgi?article=1005&context=soar.

[7] Welcome to ROSA p |, [Online]. Available: https://rosap.ntl.bts.gov/view/dot/36276 (visited on 06/30/2020).

[8] A. Cherian, J. Andersh, V. Morellas, N. Papanikolopoulos, and B. Mettler, "Autonomous altitude estimation of a UAV using a single onboard camera," in *2009 IEEE/RSJ International Conference on Intelligent Robots and Systems*, ISSN: 2153-0866, Oct. 2009, pp. 3900–3905. DOI: 10.1109/IROS.2009.5354307.

[9] Simulink support package for parrot minidrones. Library Cat-alog: in.mathworks.com, [Online]. Available: https://in.mathworks.com/matlabcentral/fileexchange/63318-simulink-support-package-for-parrot-minidrones (visited on 06/09/2020).

[10] M. R. Kaplan, A. Eraslan, A. Beke, and T. Kumbasar, "Altitude and position control of parrot mambo minidrone with PID and fuzzy PID controllers," in *2019 11th International Conference on Electrical and Elec-tronics Engineering (ELECO)*, Nov. 2019, pp. 785–789. DOI: 10.23919/ELECO47770.2019.8990445.

[11] A. Carullo and M. Parvis, "An ultrasonic sensor for distance measurement in automotive applications," *IEEE Sensors Journal*, vol. 1, no. 2, p. 143, 2001, ISSN: 1530-437X, 1558-1748. DOI: 10.1109/JSEN.2001.936931. [Online]. Available: http://ieeexplore.ieee.org/document/936931/ (visited on 06/08/2020).

[12] HOW DO DRONES WORK? PART 11 - PRESSURE SENSORS | LinkedIn, [Online]. Available: https://www.linkedin.com/pulse/how-do-drones-work-part-11-pressure-sensors-tiziano-fiorenzani/ (visited on 06/08/2020).

[13] What sensors do drones use? 3D Insider. Library Cata-log: 3dinsider.com, [Online]. Available: https://3dinsider.com/drone-sensors/ (visited on 06/08/2020).

[14] Temperature influence on differential barometric altitude measurements - Dimosthenis E. Bolanakis ; Konstantinos T. Kotsis ; Theodore Laopoulos 2015 IEEE 8th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS) Year: 2015 | Volume: 1,[Online]. Available: https://ieeexplore-ieee-org.miman.bib.bth.se/document/7340711 (visited on 06/08/2020).

[15] S. Adarsh, S. M. Kaleemuddin, D. Bose, and K. I. Ramachandran, "Performance comparison of infrared and ultrasonic sensors for obstacles of different materials in vehicle/ robot navigation applications," *IOP Conference Series: Materials Science and Engineering*, vol. 149, p. 012 141, Sep. 2016, ISSN: 1757-8981, 1757-899X. DOI: 10.1088/1757-899X/149/1/012141. [Online]. Available: https://iopscience.iop.org/article/10.1088/1757-899X/149/1/012141 (visited on 06/08/2020).