Visual Control and Tracking of Autonomous Quad-Copter Using Camera

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THESIS

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dedicated to my beloved mother and father for their ongoing love and support ...

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SUMMARY

The objective of this work is to design,model,control, and experimentally study low-cost autonomous UAV which can fly indoors along with onboard computation and line tracking system for educational purpose. The system is expected to steer the quadcopter to follow a track on ground smoothly without using any GPS signals. The main aim was to design and implement a nonlinear, path following system which should involve a low-cost/low-power platform, should be simple to use, safe and easy to implement with minimal need of prerequisites. The closed-loop system is designed to make the system more stable and track the path smoothly as compared to the manual drones. Adding to the advantages,the autonomous mechanism converts the under-actuated quad-copter into an over-actuated robot which provides us with full control of the state-space. Also, the research has been done to create dynamics of quadcopter and implement it in the mechanism so as to achieve the target, stability and make the quadcopter immune to any external noise. Also provided is the control system for line detection which is capable of detecting the orientation and the average position of the lines captured by a down-facing camera interfaced to UAV. The design of altitude control algorithm using four down-ward facing ultrasonic sensors is created to provide extra stability and hovering mechanism to the quadcopter and prevent the drone from drifting and to reduce the drifting issues related to the flight controller.

CHAPTER 1

INTRODUCTION

1.1 Engineering Design Criteria

The development of this project was restricted and guided by the engineering design constraints and criteria, which are provided as below:

- Safety
- Cost
- Simplicity
- Portability
- Robustness
- Repeatability
- Commercial Viability

1.1.1 Safety

As we know a quadcopter is potentially dangerous to the researchers and property, all measures have been taken to make sure the risk is minimized in every aspect. The quadcopter has to be tested in a closed environment (in our case we used a drone netting cage) after every modification is made to it. It should be capable of switching in to manual mode and perform a safe landing whenever required an idea of a fail-safe safety system is in progress. Safety is of a great significance in this project and should be maintained throughout all the steps of the project.

1.1.2 Cost

Electrical and Computer department provided the project funding for this research . Overall funding was limited to approximately $3000 to fit within the educational scope of the project. Therefore prior to any purchasing, adequate research and planning had to be done in order to successfully complete the project objective with the limited amount of funds.

1.1.3 Simplicity

The drone should be easy in implementation, handling and operation so that the autonomous UAV will be able to control by a beginner without any kind of experience or training. Very less calibration or technical setup procedures should be needed with a single input device that can fully operate the system. There should also be feedback provided by the system to the operator so that the autonomous behavior of the UAV's is easy to understand and transparent.

1.1.4 Flexible

The drone should have a good control and small setup, without any obligations of a lengthy setup. There should not be a need for special environment preparation or any prior knowledge of the environment. The sensing mechanism and the processing of the data should be done on the drone itself, in order to guarantee maximum portability. The system must not be dependent on an additional ground control mechanisms like ground station hardware for the efficient operation of the drone.

1.1.5 Stability

The system must be stable environmentally and should be robust.It should be able to operate in various range of environments successfully.The characteristic and nature should not affect performance.

1.1.6 Repeatability

The UAV should perform efficiently and the task must be repeatable and efficient, with a great rate of success.The system should be efficient without any constraint with the pattern of the movement or targets nature.The system should be invulnerable to any kind of changes in the environment and should be consistent in actual scenarios.

1.1.7 Commercial Viability

Although the system is based on research for educational purpose and doesn't have any kind of market attachments it is necessary to consider the commercial practicality of the project and its applications. This should increase the cognizance of the UAV's abilities and should also lead to further discussions and collaborations.

1.2 Approaches

The objective of the project to automate the capabilities of the drone are provided below:

- Research, purchase and assemble the UAV
- Identifying the steps to operate the UAV autonomously
- Interface the cameras and sensors to the assembled UAV
- Implement line sensing and altitude stabilization algorithm
- Implementing the closed loop system by providing a feedback using PID algorithm
- Create a gimbal system for testing the UAV in a closed netting enclosure
- Evaluate the success of the developed system

To achieve the desired goal set for this thesis, a control algorithm based on the analysis of mathematical equations of the dynamic motion model is created using Kinetis design studio on the ARM-based freedom KL25Z controller. The simulation is done in order to sense the camera values and provide the output to the micro-controller which has a PID control algorithm along with the automatic start-up sequence of the quad-copter. The altitude stability is achieved with the use of 4 different ultrasonic sensors whose output can be used as the threshold for the altitude of the quad-copter. The design of 3D structures were implemented for the design of different 3D structures and for the fabrication of the components using Solid-works 3D designing platform. Several attempts were made to create the perfect low weight and sturdy structure design. A different set of tests were done in order to check the efficiency of the flight platform and stability in varying conditions. The validation of the PID control algorithm and the attitude locking algorithm is carried out with these flight tests.

1.3 Contribution

The objective of the thesis is to design, control, fabrication and experimentally study low-cost autonomous UAV which can fly indoors along with onboard computation and line tracking system. The contribution is as follows:

- Design and assembly of low-cost quad-copter system suitable for the automation.
- Design of architecture for the autonomous quad-copter with attitude stability along with visual control.
- Design of algorithm for visual control using line sensing camera.
- Design of ultrasonic sensor based altitude control system and PID contol algorithm for the improved stability and robustness to the hovering mechanism.
- Created function for autonomous Flight Calibration and autonomous flight start unit.
- Design and fabrication of components and parts in SolidWorks and printed using a 3D printer.
- Validation of designed control techniques have been carried out by the experimental results.

CHAPTER 2

LITERATURE SURVEY

(Aguilar et al., 2017) developed an ”obstacle avoidance system” for micro aerial vehicles using a ”monocular camera”. The system is able to find obstacles based on the database of images from MAV’s. The control law is created in such a way that if there is a match between the compared images, the avoidance algorithm is triggered. The system works on a method which uses perception based on feature points of the images for detecting the obstacle and control law for avoiding obstacles, just based on monocular camera, without using any other sensors. SURF (Speeded-up Robust Features) feature point detector is used for fast processing of the obstacles.The algorithm works on comparing feature points between two images. SURF is selected in this proposal because of its less computational cost without lowering the robustness. The process of obstacle avoidance used in this is defined into three parts: 1. ”System Identification” 2. ”Controller design” 3.”Obstacle avoidance”. Experimental results were based on the comparison between autonomous algorithm and teleoperations of two different persons with varying experience levels using the same UAV.

(Gupte et al., 2012) in this paper, a detailed survey has been done on quadrotor system starting from the basic stricture design, mechanism of flying, control system and dynamic modeling and different vision systems that are used in the unmanned aerial vehicles. It states that quadrotor accurately and efficiently perform tasks that are risky for humans to perform. It has VTOL (Vertical Takeoff and Landing) ability with maneuverability advantage beacuse of its dynamic nature. The most important advantage of quadcopter over helicopter is the mode of fixed-rotor propulsion. Depending on the throttle provided to each rotor we can change the roll, yaw, and pitch of the quadcopter. The movement mechanism is further based on two different types of configuration: ‘X ‘and ‘+’. The ‘X’-configuration is the most stable of all the configurations. Various control structures are used in the dynamic modeling of the system such as the most basic PID control to more complex control such as using backstepping or neural networks. Nowadays the controller logic is also created so that it can be used in a ”multi-agent environment”, where quadrotors can predict each other’s location based on the information provided. The other important aspect to be considered for autonomous control of the quadcopter is the sensors used. The different types of sensors found on the quadcopter are IMU sensor, barometer, magnetometer, GPS, infrared sensors, range finder, camera and many more. Each of these sensors has a specific contribution in providing increased stability and autonomy to the quadcopter. Various Visual based robot control techniques are used such as ”Image-based visual servo (IBVS)” and ”Position based visual servo (PBVS)”. Blob detection techniques are used in most algorithms for tracking usinng cameras off-board. Onboard single or multiple monocular cameras can be used for tracking applications.

For the robot navigation system SLAM (Simultaneous localization and mapping) techniques are popular. Due to the unique abilities of the UAV’s they have been used in many different commercial applications such as ”military, emergency response, border patrolling, and surveillance”. The improvement in various technologies has provided various tips in the improvement of design and computing power. These technologies have improved the field of navigation and stability and so the research is never-ending in this field.

(Prathamesh et al., 2014) developed autonomous quadcopter which can carry out obstacle detection and Collision avoidance using low cost ultrasonic sensors. The SR05 ultrasonic sensors are used because of its low price, high range of measurement and easy communication using I2C interface.12 different ultrasonic sensors are used to cover 360 degree circle range. Three sensors are connected on each arm which provides better results. The data from the sensors can be used in processing pipelines that will be able to recognize obstacles from all angles in the surroundings. Arduino controller is used to process the data and provide signals to the ESC's in order to control the quadcopter. The paper provides an introduction to the quadcopter stabilization and navigation. The angular velocities of the rotors are adjusted to control the quadcopter. ID algorithm is applied in order to calculate the output values and provide the commands to the motors based on the input values received from the transmitter and sensors. The paper also provides a brief information on the concept of flight mechanism. The number of redundant ultrasonic sensors are increased to increase the detection resolution and sensor data reliability. Even though the number of sensors increases, the resolution and redundancy is increased. The collision avoidance module divides the area around quadcopter into three different zones:

- Far or safe zone
- Close zone
- Dangerous zone

When in the dangerous zone the state 3 is activated which will control the distance to the obstacle based on PID controller. One major issue that needs to be considered is the noise and error generated from the ultrasonic sensor interference. Hence there is always a tradeoff between sample time and accuracy. The other problem faced is the rotation of quadcopter change the ultrasonic measurements. Hence the angular rate from gyroscope is used to detect the rotation of quadcopter and let go the incorrect readings from ultrasonic sensors. Hence as per the algorithm provided the quadcopter stabilizes itself and avoid obstacles using the sensor arrays integrated to it .The system can detect obstacle and avoids them, it is also capable of holding its position based on the data from ultrasonic sensors.

(Timothy et al., 2005) In the paper mentions the ”vision-based obstacle detection for small autonomous aircraft”. In this, the obstacles are detected using sky segmentation method which divides the sky into two regions namely two regions , ”sky and non-sky” where non-sky regions are nothing but the obstacles. The experiment was verified by performing hardware in loop simulation (HIL) and also implementing it on small low weight remote controlled plane.The obstacle considered during the testing is an inflatable balloon. The two most important steps in this detection feature are Sky segmentation and Horizon detection. The horizon is found out by dividing the binary image of the sky into the sky and non-sky regions. Further implementation of OpenCV using Hough transform is used on borders to detect the horizon. The controller designed for the control of the aircraft was a simple lateral controller modeled by standard unicycle model.

(Samir et al., 2004) has mentioned in his paper the research done on design and control of indoor micro quadcopter. Due to recent research on the high-density power storage elements along with the miniature actuators and MEMS sensors, it has been possible to create miniaturized versions of autonomous flying robots which are highly used nowadays in military and civilian applications. They have also provided a piece of brief information on the comparison between helicopters and other flying principles such as VTOL (Vertical Take Off and Landing). They have provided information on the dynamic modeling, design, and control for indoor autonomous VTOL system. Controller design was implemented for carrying out experiments in real time. The controller was designed in a way to control the vehicle orientation while keeping the height fixed by the test bench.

(Susilo et al., 2014) has described in the paper about the auto level control system of V-tail quadcopter. The system uses orientation control implementation by PID control, the feedback to the control is used from the data output from the nine degrees of freedom MARG (Magnetic, Angular rate, and gravity sensors) sensors. Auto level control is developed by using the Attitude and Heading Reference system (AHRS). The AHRS is a navigation system which is capable of providing information related to orientation to the platform. In order for improved performance UAV should have the ability to correct itself even after the noise alters the position and orientation. Also, the orientation of the propellers is changed so as to provide roll and yaw effects. Further, the design of the quadcopter along with the specifications of electronic hardware and control system implementation is described in the paper. Performance testing is carried out for calculating the thrust and orientation of the estimation filter. Finally, the result shows that the steady-state error is approximately equal to zero and the error for the roll and pitch angles are less than 1 degree.

(Wei et al., 2006) the paper has focused on hovering control of the drone autonomously and guidance for a micro flying robot which will be used in natural disasters. The paper has also focused on the concept of Automatic Takeoff and Landing Control for Wireless XRB helicopters. In this research three-dimensional coordinates are calculated using a ”CCD camera” so as to identify a square shaped marker. Computer controlled camera is used to expand the observation range. Modeling and control are performed on the robot and also on helicopter. The research is based on modeling and $H\infty$ control of micro flying robot. $H\infty$ controller is used for better performance as interference is generated for multi-axis control. Experiment is carried out on the autonomous flight in order to observe the position of micro- flying robot and the XRB. Success was achieved in the autonomous hovering and control of micro-flying robot. Future research would include the obstacle avoidance and group control.

(Markus et al., 2009) in the paper has provided the information about the cost-effective and easy to use design of quadcopter, in which the quadcopter movement is controlled by taking feedback from IMU sensors. Various markers have been designed and used for improving the visibility and also the robustness under various disturbances using image-based pose estimation. A closed feedback loop system is used and demonstrated successfully in the paper. Experimental evaluation of pose estimation based on images was conducted and created using the positioning-table. The paper also includes information on the pose reconstruction and tracking of the quadcopter using the camera system using the 3-D reconstruction of the position of marker. Finally, a performance evaluation was done based on processing time, delays and pose accuracy. Hence an efficient method for tracking the drone or objects with markers is presented successfully.

(Sefidgari, 2013) in the paper has described the design of quadcopter using image processing for body detection and tracking in real time providing a PID control algorithm for controlling the quadcopter based on the variations detected. The process needs feature extraction and edge detection for the process.PID controller is created which is improved by the use of a genetic algorithm. The system design includes a CMOS camera along with a wireless sensor module and implemented on AVR microcontroller in real time.Various algorithms are used for human detection in image processing like HOG, LBP, EOH, edge detection, stereo vision, and monocular vision. The geometric algorithm is applied to the controller to detect humans. PID was implemented for controlling the altitude of quadcopter along with module consisting of ”human body detector” and decision-making. Neural Fuzzy genetic algorithm was used in order for altitude stabilization of quadcopter.

(Bora and Erdinç, 2007) described in the paper a model with four rotors along with ”Vertical take-off and landing (VTOL)” for UAV. The control architecture is created and explained which includes vision-based control. The dynamical model of the system also consists of the gyroscope which leads to gyroscopic effects.The controlling of these gyroscopic effects are considered to be the source of future works.PD controller was developed to control the pitch and roll which further control the thrust of the quadcopter. The design also controls Yaw angle of the quadrotor. The result based on the simulation of the controller in Simulink for the the controller parameters were achieved.A vision-based control system was designed and developed which can focus on the pattern on the ground using an onboard camera and hover on that pattern at the desired altitude.

(Kada and Ghazzawi, 2011) describes the design and structure characteristics for a robust PID controller of systems with higher order. This is done to increase the PID controller performance and make it more robust.The design analysis is done on the design of unmanned aerial vehicles based on pitch and axis autopilot design. It also describes the disadvantage of lower-order systems which lack robustness against a large system parameter uncertainties.The best solution provided is the cascading of controllers that link the output of one PID unit to the input of others. Such controllers can be used for more complex missions.A mathematical based framework is used in order to design PID controllers which are more robust for a class of higher order systems. The simulations for LTI systems show that with the described control strategy an impressive performance and robustness in the time domain can be obtained. The deadbeat controller can carry out tracking tasks within the limitations of actuators. The framework provides an efficient and robust way for real-time parameter tuning for the PID controller.

(Gabriel et al., 2007) described in the paper about the flight dynamics and control of the quadrotor helicopter.The work presented to address the problems faced when deviating from the hover flight system.The test also investigates the aerodynamics effects as they are related to the quadcopter flight. The system contains STARMAC 2 quadrotor which was designed and built to carry a computer and different payloads UAV projects along with Atmel microprocessor. The sensors used are ”Microstrain 3DM-GX1 inertial measurement unit (IMU)”, ultrasonic rangefinder and Novatel Superstar 2 GPS receiver. There are certain effects that result from translational or vertical velocity components which sometimes cause variations in attitude control.Various tests have been implemented on the developed quadrotor system. The tests show there is coupling between velocity and attitude dynamics of the aircraft. Many controllers such as LQR –derived and PD attitude controllers are used, which sometimes lead to loss of performance for both attitude and position control. The tests also reveal that we need to take into account aerodynamics inflight or else the control performance can get affected. Good vehicle design can also eliminate or diminish this kind of effects. The tests reveal that these control and models are not sufficient for tracking of trajectory to be accurate in environments which are uncontrolled.

(Felipe et al., 2003)] has provided a design concept of a ”micro-coaxial rotorcraft” with the use of custom manufacturing methods and various commercial components. A small scale co-axial rotorcraft called MICOR (Micro-Coaxial Rotorcraft) is developed to gain the advantage of rotary wing flight and best suited for hovering which weighs approximately 100 gm. The vehicle should be able to investigate the target and sending back the information to the operator. Different concepts were compared to select the best configuration for the vehicle. The co-axial configuration is used as it is compact and provides stable anti-torque capabilities. In order to control the vertical velocity, the total thrust is varied by adjusting the motors rotational speeds.The experimental results show that drag in profile makes upto 45 %

of the losses as compared to 30 % in helicopters. The aerodynamic performance was yielding poor FM of 42 % for some set of twisted blades. Also flying time was reached at a high of 3 minutes with the use of 430 mAh, 3-V LiMnO2 batteries. Future scope includes the aerodynamic performance improvement and reduction of undesired detrimental effects of viscous drag at low Reynolds number.

(Claudio Vianna Junior et al., 2013) has provided the different stages of dynamic modeling, identification and also the UAV control using PID controller in order to create a quadrotor to capture images and videos at low cost. Mathematical modeling of ESC, motor, propeller along with the modeling of the complete structure was achieved in the identification process. In order for stabilization and control of the structure, a PID controller is used.The results obtained were related to the pitch and roil movement only which shows that they are related very closely to reality because of the range of rotational speeds. Some of the components were not used and considered in the identification stage, which will be taken into account in the future. When the velocities of the motors are increased simultaneously there is some non-linearity developed in the system. Tuning of the controller is done using pole placement method along with simulations in MATLAB. The problem is solved by using adaptive control, where the PID works along with the Fuzzy controller and would adjust the coefficients of PID based on the current speed of the motors. Future scope includes using fusion techniques to improve the quality of the angle measurements of the model and increase the control of UAV based on latitude, longitude, and altitude.

(Metni et al., 2005) in the paper described control law to monitor structures of bridges, based on ”computer vision for quasi-stationary flight”. The control law is defined to make the UAV track the trajectory which is created with the help of a prerecorded pictures.The Euclidean hymnographers are taken out using three different views: 1. ”Current image” 2. ”Corresponding image” 2. ”Unique reference image”.Also, the homography matrix is implemented from a visual data using ”back stepping” technique and ”adaptive nonlinear tracking control law” which provides efficient target tracking and depth estimation, which is the desired distance of the target from the camera. The simulation was done to estimate the success of the proposed control and estimation law. The result shows control design gains used are: ”k1 = 2.5, k2 = 1.2, k3 = 2.0, k4 = 2.5, gamma1 = 1/400, gamma2 = 1/80”. For the estimation of unknown constant parameter created from the extraction of pose parameter from homography, an adaptive update law was created and presented along with simulations. The future work in this is related to the work on nonlinear state observers.

CHAPTER 3

BACKGROUND

Unmanned Air Vehicles trace their origin back to the aerial torpedoes almost 95 years ago. In order to provide strike and exploration services to the battlefield commanders during the wars, the military services tested different sensors, missions, and munitions (Krossblade, 2019). The first known to construct a quadrotor were two brothers named ”Louis and Jacques Bréguet”, working for ”Professor C. Richet”, named the quadcopter as ”Bréguet Richet Gyroplane No. 1 Breguet-Richet-1907”. (Figure 1) The figure shows the quadcopter ready for its first manned flight with double layered propellers.

Later on, two new structural designs were made and experiments were carried out on the same. The first, by ”Georges de Bothezat and Ivan Jerome in 1922”, created a rotorcraft with six blades and the rotors were attached at every truss structure end in an X-shape (Figure 2).

The other structure, Figure 3, designed by ”Étienne Œ hmichen in 1924”, and various records were created, one of whch was for the first helicopter flight travelled a kilometer (Syed and Wail, 2010).

The Israeli and U.S military were the first to recognize the potential of using unmanned aerial vehicles during wars.Advances in miniaturization, powerful processors and cheaper sensors have led to an increase in the research and investment in these machines. In recent decades there has been an extensive increase in the usage of UAV’s in military and civil missions’. Even various universities nowadays have motivated the creation of innovative vehicles that can take-off and land vertically (VTOL). Applications such as rescue and search operations, sensing, and aerial surveillance led to the advancements in these fields.UAVs have been referred to by many names mainly RPV (remotely piloted vehicles), drone, pilot-

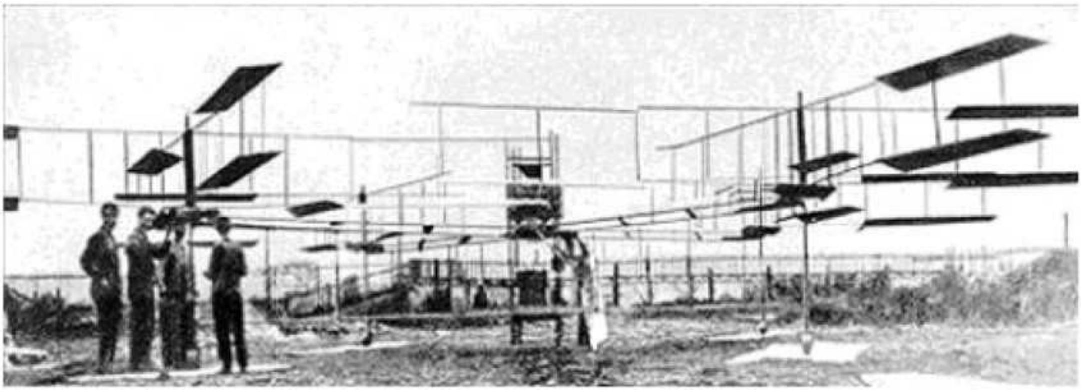


Figure 1: ”Bréguet Richet Gyroplane No.1 Rumerman (2002)”

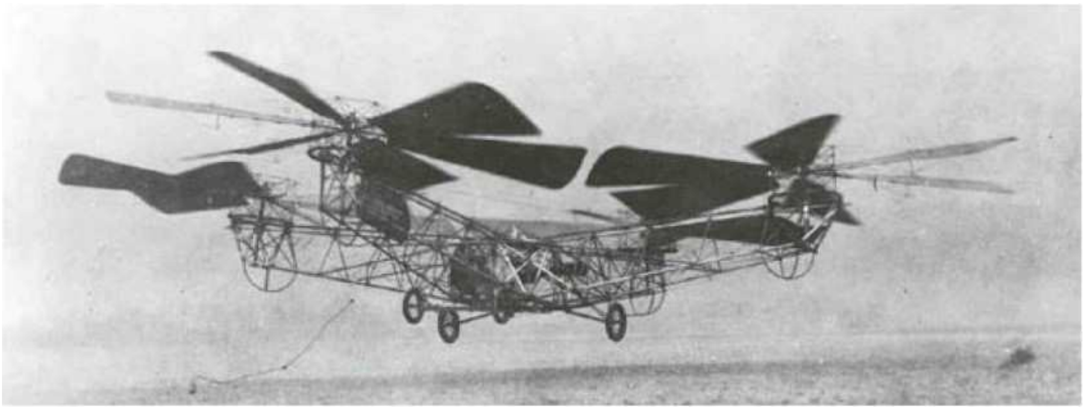


Figure 2: ”Quadrotor designed by George De Bothezat, February 21, 1923 Rumerman (2002)”

less aircraft, robot plane. Also, they are named by the Department of Defense as powered aerial vehicles without any human operator.Due to the smaller size and the type of propulsion system used the system is more readily stable and steady as compared to the manned aerial vehicles. The miniaturization led to the

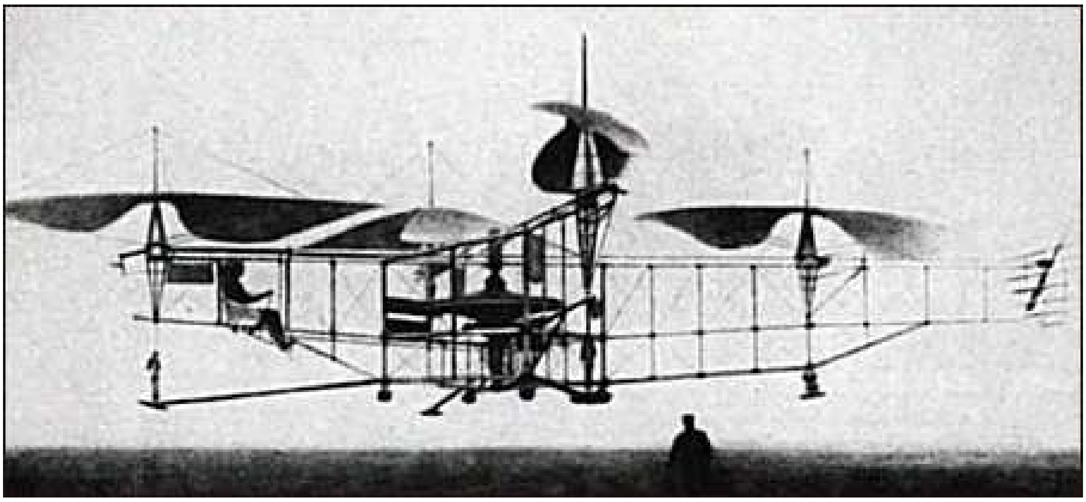


Figure 3: ”Œ hmichen quadrotor designed in 1924 Rumerman (2002)”

creation of smaller UAV’s or micro UAV, which weigh less than a kilogram.The quadrotor helicopter is considered the most versatile and stable and can carry out tasks that are very difficult for humans.Many more applications have been developed recently such as a miniaturized version of UAVs that can travel in a group and can be deployed for finding out survivors without risking the human life in the collapsed buildings. It can also be used as flying photographers if equipped with cameras, which can provide aerial based photography and videos of sports events (contributors, 2019).

The quadcopter can be classified as rotorcraft in comparison with the fixed-wing aircraft, as the lift provided to quadcopter is generated from a set of two rotors with vertically oriented propellers. They use two pairs of identical fixed pitch propellers. The motors can change the thrust or torque of the quadcopter based on the variation of the speed of the motors. The quad copters differ from two motor helicopters which use rotors that can change the pitch of blades dynamically as they rotate around the hub. The two rotors in helicopters are arranged in the same plane which provides upward thrust and force. They are arranged in such a way that one rotor provides the push and the other rotor which is fixed horizontally is used to check the torque provided by the primary rotor. Many experiments were implemented by the early designers as the design of using a single main rotor with a tail rotor so as to counterbalance the torque due to the single main rotor was complex, inefficient. A swash plate was needed in order to vary the approach of principle multirotor which controls the blade pitch which further connects to the helicopter flight controls. But some of the issues were seen such as increasing the development costs would also increase the unpredictability .10- 15 % of the power from the engine is consumed by the tail rotor of the single rotor helicopter, even then the lift and forward thrust created by it is not sufficient. The system also needed large rotor blades 4 or 5 m or longer which are really heavy as compared to the smaller ones used nowadays. The swash plate is used to provide more degrees of opportunity to the helicopter but the same can be gained by using two more additional rotors. Also, earlier prototypes of quadrotors faced performance issues and required too much pilot workload because of poor-stability and limited control. The quadcopters used to have the engine located in the center of the fuselage, driving four rotors using belts and shafts. The shafts and belts used to be heavy with the possibility of breakage, also all the motors were slightly different from each other which made the quadcopter unstable. The quadcopters have to be constantly stabilized, which increased the need for computers and electronics in the system. The reducing expenses of chips and electronics have made control of quadcopter achievable for applications such as military, business, and academic purposes.

Quadcopter control is a really complicated task and difficult to achieve.The under-actuated controls of a quadcopter with six degrees of freedom controlled with just 4 inputs makes them difficult to control.

The combination of transnational and rotational motion makes it possible to achieve the six degrees of freedom. Also the helicopters have very little friction as compared to the ground vehicles while flying in order to deter it from moving and remain stable. Different simplified quadcopter models have been presented to control the dynamics and design the controllers. The qualities of quadcopter such as vertical takeoff and landing, staying perfectly still in the air and traveling in any direction at any time, unlike other fixed-wing aircraft enables it to operate even in extremely constrained spaces and even makes them suitable for stationary observation.

In order to maneuver the modern UAV's use a wide range of sensors like inertial measurement unit (IMU) which measures aircrafts orientation and acceleration, GPS based navigation is also used for autonomously navigating in a known environment or to make it stay at one position without drifting away. When flying the drone in an unknown environment or indoors where GPS signal is barely available we have to use alternative localization methods. There are various different sensors available which can be used for the same. The ultrasonic distance sensors are cheap and can be used for applications like attitude hold, where they detect the distance to the closest object in a particular direction. There are various Laser range scanners available which provide full depth image but are extremely costly and large in size. Also, optical cameras are really popular nowadays and are one of the ways to accumulate and provide a huge amount of information. Along with large data collection, they are also cheap and lightweight which are very suitable for micro aerial vehicles. But the challenging task is dealing with such amount of large visual data, which increases the complexity and also requires a large amount of computational capacity. The only limitation of using the optical camera is the lack of depth of information as the only two-dimensional projection of the field is observed.

CHAPTER 4

COMPONENT SELECTION AND MULTIROTOR ASSEMBLY

4.1 Multirotor component selection

The aim of my thesis was to do specific research , design and create algorithm for a drone that should work suitably for my further research. In order for me to aim completely on the autonomy of the quadcopter, readily available and a hardware with easy implementation was selected so as to achieve an architecture with the capability of controlling the flight manually with very minimum technical work required.

4.1.1 Multirotor component selection Criteria

There were many constraints in the component selection criteria which also restrained the use of many components and also the selection process. These are:

- Suitability of modification for automation of the drone
- Modular design
- Availability of the stock
- Support and warranty
- Simplicity
- Rate of adoption and existing base of user

4.1.2 Commercial System Research

Research was done to explore systems that are commercially available and robust, which would allow for more focus on the autonomy of the project .The following different systems were considered in the case study :

- DJI f450
- DJI F550
- Parrot AR Drone 2.0
- ZMR 250
- QAV 450
- Dragan Flyer X4
- Dragan Flyer X8

The above analysis was done without any funding limitations so as to get an impartial knowledge of the market.But some of these systems were too expensive which also limited the research. Along with that, the systems like Parrot AR Drone and ZMR 250 were not suitable for any modification for the automation process. Depending on these factors the system based on DJI drone, namely DJI450 and DJI550 were the most pertinent in the considered systems. DJI F450 have four rotor configuration while DJI F550 had six rotor configuration and was slightly larger. The DJI F450 was selected as it was more stable and less heavy as compared to DJI F550. The requirement of payload capacity for this project was less, due to which the quadcopter was selected.

Figure 4: Flame Wheel ARF kit - DJI F450

4.1.3 Component Research

The most important thing that must be apt for modifications so as to automate the system was the flight controller. Initially different open source flight controllers were taken into consideration along with the recommended flight controller of DJI F450 so as to modify the operating code to make sure that the UAV operates adequately in autonomous mode. The research was done on many different kinds of flight controllers

- Arducopter
- Openpilot
- Pixhawk
- Mikrokopter
- KKmulticopter

- Multiwii
- DJI Naza M lite

After examining the components described above I found out that the NAZA M- Lite was simple to implemnet with good stability and attitude control performance whereas the open-source were difficult in implemenation for an amateur. Hence the simplicity in interfacing overshadowed the advantages of open-source firmware. Also, it was taken into account that the NAZA flight controllers are professionally configured and thoroughly tested, which was another reason that the commerial closed source flight controllers were taken into account and considered safe. By using the NAZA M LITE it was ensured that the drone would be stabilized and reliable at all times.Also, a fail-safe system can be incoporated to get the control back in manual mode.DJI NAZA M Lite also includes safety features such as a battery monitoring system that provides battery level and whenever the battery level goes below-provided threshold the UAV slowly descends and lands if necessary (DJI, 2013). Also if there is a communication loss and the transmitter is lost or interrupted, the drone will automatically return to the site of launch and land automatically (DJI, 2013). These features make the system safe and reduces risks of controlling UAV. All other UAV components were then selected to match the configuration of the drone and the flight controller.

4.2 Hardware

The unmanned aerial vehicle was developed using various components and hardware such as NAZA-M LITE flight controller, DJI brushless DC motor, electronic speed controller (ESC), Line sensing camera, Ultrasonic sensors, RC remote and receiver and Li-Po battery. For tracking and detection of the path from the quadcopter camera, ARM based FRDM board along with the software Kinetis Design studio was used for processing of the output obtained from the quadcopter camera.

4.2.1 Flight Controller - NAZA-M LITE

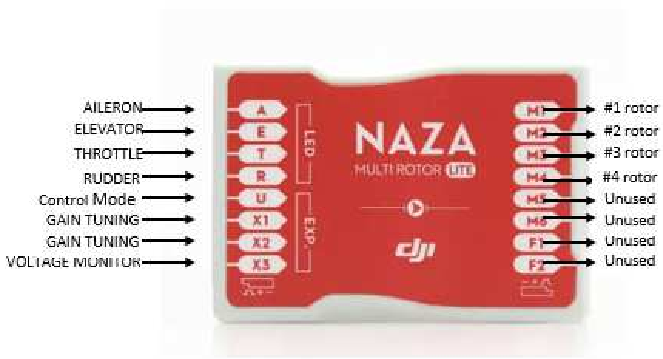


Figure 5: flight controller board (NAZA-M LITE)

NAZA-M LITE flight controller as shown in Figure 5 is the central controlling unit of the quadcopter (NAZA-M, 2013). The main goal of the flight controller is make the quad copter stable during flight. It takes the signal from the gyroscope (for measuring orientation) combined into the board and sends the signal to the processor. Further, it sends the signal to "electronic speed controllers (ESC's)" so as to control the direction and speed of motors. The pins on the input side of the board are connected to the RC receiver and output pins of the board are connected to the brushless DC motor using ESC's. This board can control, modify and adjust the roll, pitch and yaw angle. Rotation from front to back axis is the roll, the pitch is rotation around the side to side axis and yaw angle is the change or rotation around the vertical axis as shown in Figure 6. By changing the throttle, yaw and pitch it can control the speed of individual rotors as shown in Figure 7.

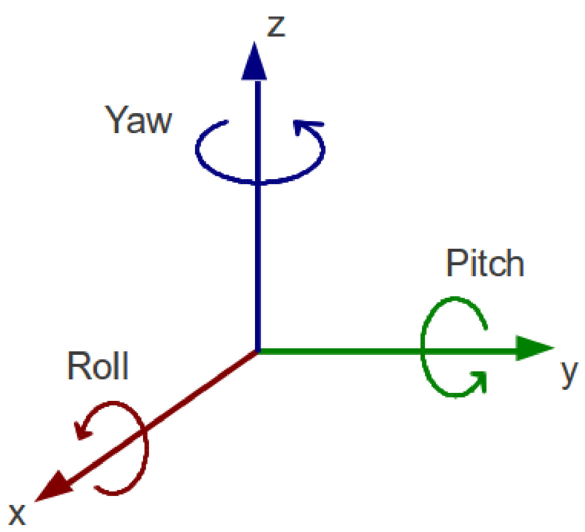


Figure 6: Roll, Pitch and Yaw angle

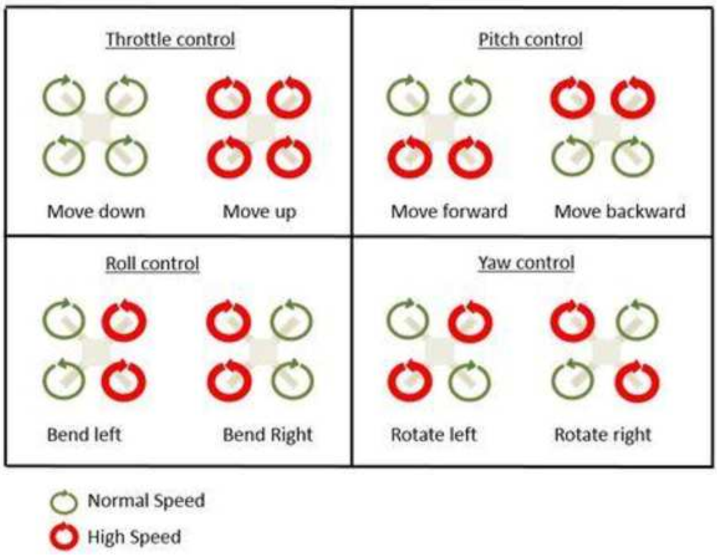


Figure 7: Quadcopter Motion mechanism

4.2.2 Out-runner Brushless DC motors

These are the motors basically used in RC helicopter, quadcopters and hexacopters.Just like the motors used in CD-ROM the outer shell of the motor spins around the winding in the motors. The rotor is the rotating part of the motors and stator is the stationary part. The brushless DC controller excites the stationary winding. There are more than 1 windings in the motor and the current is passed through the 4 nonadjacent windings and the gathering is rotated electronically based on the rotor position input. The brushless motor is constructed in a similar way as a stepper motor is constructed. But as compared to a stepper, a brushless motor usally produces continuous rotation. The advantages of a brushless motor

Figure 8: DJI f450 2312E BLDC motors

as compared to brushed motors are high power-weight ratio, higher speed, and electronic control. The motors used in this project are the DJI F450 2312E 960kv BLDC motors (Figure 8) (DJI, 2015a).

4.2.3 Electronic Speed Controllers

The electronic speed controller is a circuit that is used to control the speed and direction of the out-runner BLDC motors. It is used to convert the voltage down to 5v for the RC receiver. It also accepts the PWM signal so as to vary the speed of the rotor. As the width of the pulse of the PWM signal changes, the motor speed also varies. As shown in Figure 12, the three black wires are connected to the out-runner motor. Two wires black and white are connected to the Li-Po battery and the small twisted

Figure 9: DJI f450 430 LITE ESC

pair wires are connected to the NAZA-M LITE flight controller board. It has a maximum continuous current rating of 30A and PWM input signal level is compatible at 3.3v/5v(Figure 9) (DJI, 2015b).

4.2.4 Propellers

The propellers used in the project are Z-Blade 9450 propellers from DJI.These are aerodynamically optimized.The propellers spin and the blades are designed in a way as to push the air down.As the rotor pushes down on the air, the air pushes up on the rotor. As the blades rotate faster, there will be greater lift and vice versa. In order for hovering, the net thrust from four of the rotors that provides thrust up must be exactly equal to the force pulling down, namely gravitational force(Figure 10).

Figure 10: DJI Z-Blade 9450 Propellers

4.2.5 Radio Transmitter and Receiver

The RC equipment used consists of a Spektrum 6-Channel 2.4 GHz transmitter operated by the operator from the ground and a receiver is connected to the flight controller (NAZA-M Lite) so as to receive the signal from the transmitter. The transmitter has 4 or 6 or 9 channel depending upon the requirement. In this project, we have used a 6-Ch transmitter. The transmitter sends information by creating a radio signal which is sent to the receiver and the receiver is able to detect the signal after tuning it to a specific frequency. The receiver used was Spektrum AR6600T receiver (Figure 11).

(a) Spektrum DX6 Transmitter

(b) Spektrum AR6600T Receiver

Figure 11: Radio Transmitter and Receiver

Figure 12: LiPo Battery

4.2.6 LiPo Battery

Li-Po Battery is a rechargeable battery with technology on lithium-ion. It has 3 cells, 4 cells or 6 cells in a pouch format. The working is based primarily on intercalation and de-intercalation of lithium ions. This is the source of power to the microcontroller and to the ESC through the flight controller. The Battery used in this project had an input voltage of 11.1 volts, 3 cells, and 30C battery with a capacity of 2200 mAh. The C rating is an indicator of a continuous discharge rate of Li-Po(Figure 12).

4.2.7 Microcontroller

The controller used in this project is ARM-based FRDM-KL25z.This is a replacement for the traditional receiver, which is used along with the transmitter to supply throttle and controls to the quadcopter flight controller. The main objective behind the use of the controller is to replicate and provide the 3.3 V PWM signals to the flight controller just like the receiver by creating PWM signals using a timer and

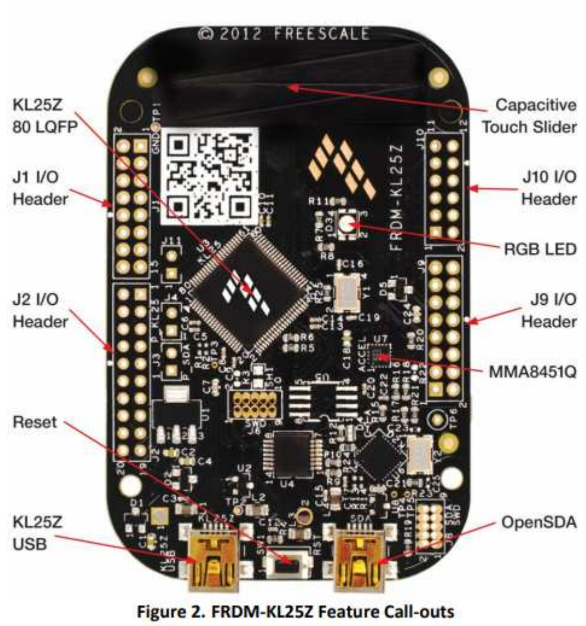


Figure 13: ARM based FRDM – KL25z

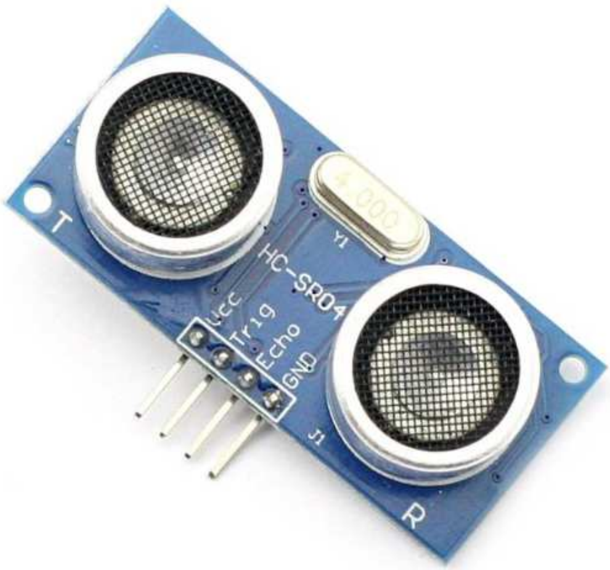
interrupts from the controller.It also performs the basic operation of controlling the quadcopter based on the feedback provided by the cameras and sensors such as ultrasonic sensors which serves the purpose of autonomous attitude stabilization. It also works as an emergency stop system (Failsafe) by cutting off the power to the motors. This is an "ultra-low-cost development platform built on ARM Cortex M0+ processor". The features are "32-bit ARM Cortex-M0+ core - up to 48 MHz operation, one , and two 2-channel Timer /PWM modules, 3-axis accelerometer" (Figure 13) (ARM,)

4.2.8 Camera

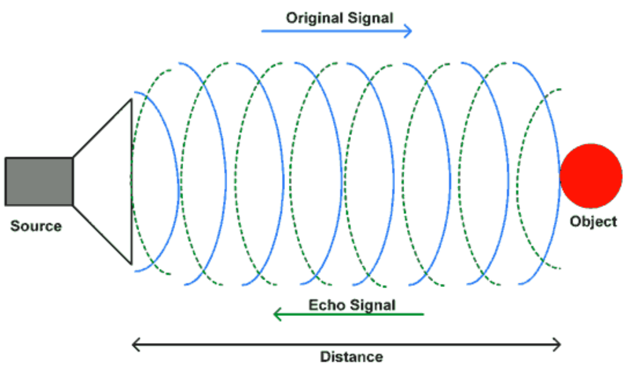
The camera used in this project was a Line sensing 1-D camera called TSL1401Cl. This was chosen as it offers less pixel count as compared to the other types of sensors. The table 1 below shows a

Figure 14: TSL1401 Line sensing camera

comparison between three different types of vision sensors. ”TSL1401CL linear sensor consists of a 128x1 pixel array of a linear image sensor with a focusable lens of 7.9mm. Each of the pixels contains a photodiode, charge amplifier circuitry and an internal pixel data-hold function. The PCB connector of the sensor provides interfacing to the one analog pixel output. This sensor is simple and easy to use. The allowable exposure time for the sensor is between 267 microseconds to 68 milliseconds. Also, the lens of the camera can be adjusted and changed for different resolution” (Figure 14) (TAOS, 2011)



(a) Ultrasonic sensor module HC-SR04



(b) Ultrasonic sensor working principle

Figure 15: Ultrasonic sensor module and its working principle

Vision Sensor	Pixel Count
CM-26N/P CMOS Color Camera Module	(640 x 480)
RMRC-520 520 Line CCD Camera (NTSC)	(768 x 492)
TSL1401CL	(128 x 1)

TABLE I: PIXEL COMPARISON BETWEEN DIFFERENT VISION SENSORS

4.2.9 Ultrasonic Sensors

These are the best to detect distance and level of the object with high reliability. ”The sensor uses a transducer to send and receive ultrasonic pulses that send back information about the proximity of the object. High-frequency sound waves reflect from boundaries to produce distinct echo patterns”. This project uses an HC-SR04 ultrasonic sensor which detects the altitude and output the distance data to an ARM microcontroller. There are 4 pins – Trigger, Echo, VCC, and GND. The trigger signal from the ARM controller is sent in the form of pulses to the sensors. It has ranging accuracy of up to 3 mm.The working current is 15mA with a frequency of 40 Hz.Figure 16 provides the expected TTL operation of the trigger and echo pins of the sensor (Freaks, 2010)

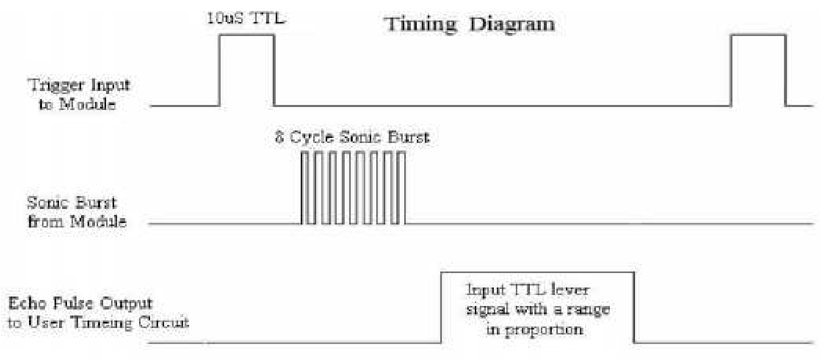


Figure 16: TTL Timing Diagram for HC-SR04 Ultrasonic Sensor

4.3 Multirotor assembly

The assembly and operation was an important part of this project. The manufacturer, DJI provided instructions on how to assemble the kit which comprised of the frame and major components. Once the assembly was done the additional equipment for the autonomous operation was connected and mounted on the drone. All of the onboard equipment gets power from the single Li-Po battery (Lithium- Ion Polymer), this is done to simplify the process of charging and to decrease the possible erratic behavior because of the power failures in individual components. The Flight controller, ARM boards, cameras, and ultrasonic sensors, all are provided with desired voltages through the Power Management Unit. All of the components were connected with double sided tape or zip ties. The flight controller required calibration through the NAZA-M lite software for the exact orientation and a strong adhesive to connect it to the center of the frame. The two-line sensing cameras were connected directly to the 3D printed holders using adhesives facing downwards. The two cameras were attached between the front and the back arms for more stability. While assembling of the quadcopter care was taken to make a distinction between the front and the back side of the quadcopter so that the operator will be responsive to the UAV's orientation while operating it. The fully assembled UAV can be seen in Figure 17

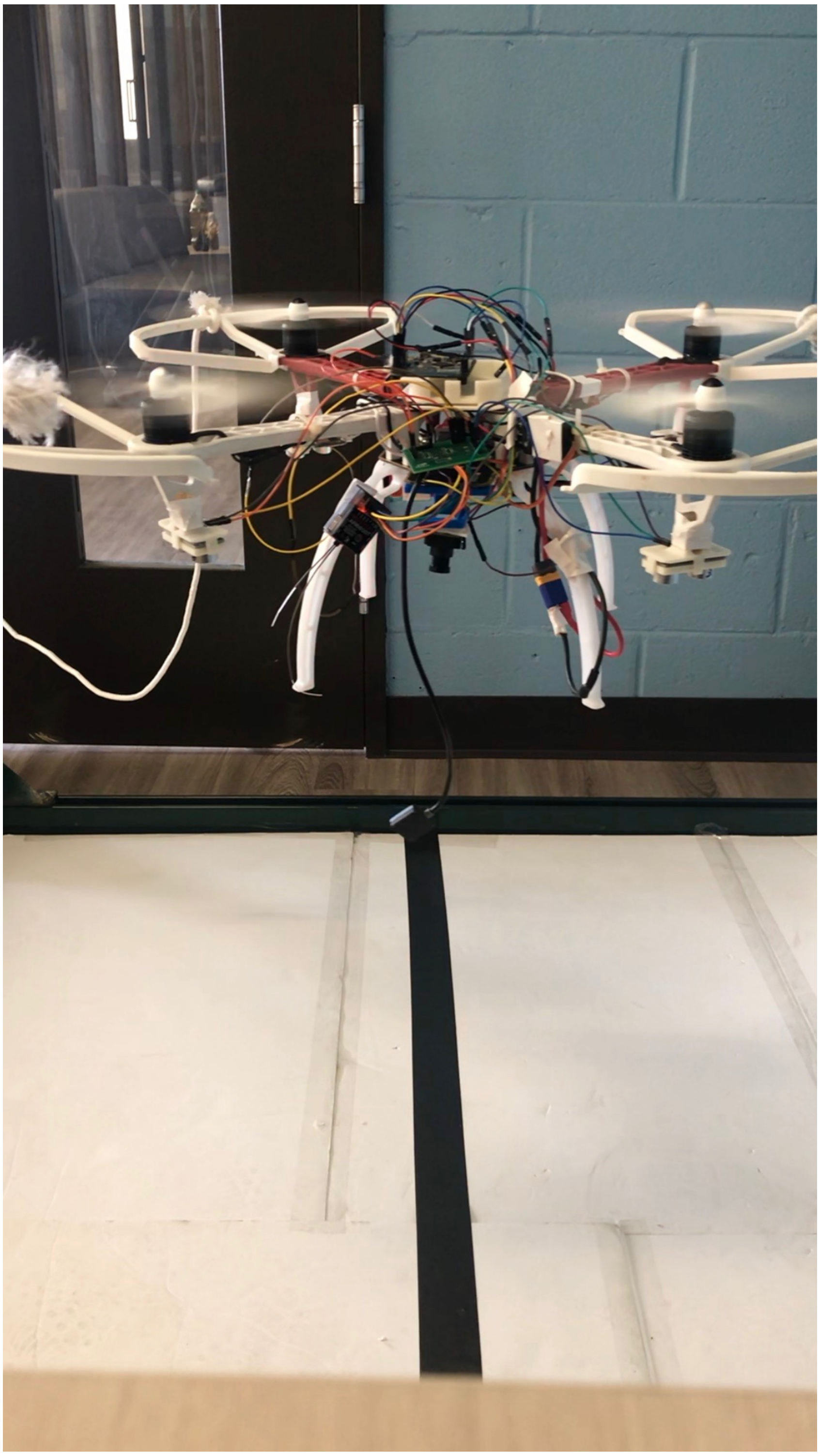


Figure 17: Fully assembled quadcopter

CHAPTER 5

AUTOMATION

The initial stage of the project required assembly, operation and stability control of UAV to stabilize it manually, while most of the research is directed towards automation of UAV.

5.1 Objective

The project includes automation which comprises of visual data processing which is considered to be the primary source of the sensors and the data. The line sensing camera provides a 1-D view of the 3D scanned object or line. This perception provides an understanding of its operation.The simplest autonomy of data processing is using visual control and tracking. Main aim was to design an algorithm that makes the assembled drone, perform autonomous visual tracking using data processing techniques on the system. The main focus in this project is completely on automation using a PID control algorithm technique. My research focuses on tracking of a black line on a white track and an altitude stabilization using ultrasonic sensors, so a provision was made so as to modify the algorithm to vary the PID control loop with a minor modification required.The research is totally based on autonomous stabilization of the quadcopter by restricting the use of the navigation using GPS and stability. To achieve this my focus was on developing a control loop so as to successfully stabilize the drone over the track without any GPS inputs. Also, I will be implementing an attitude stabilization algorithm using ultrasonic sensors to provide more attitude control and overall stability.

5.1.1 Automation Program Environment

The controller used for automation was FRDM KL25Z based on an ARM processor. All autonomous program code was written in the "Kinetis Design Studio". "The Kinetis Design Studio (KDS) is a complimentary integrated development environment for Kinetis MCUs that enables robust editing, compiling and debugging of the designs. Based on free, open-source software including Eclipse, GNU Compiler Collection (GCC), GNU Debugger (GDB), and others, the Kinetis Design Studio IDE offers designers a simple development tool with no code-size limitations. Furthermore, Processor Expert software enables design with its knowledge base and helps create powerful applications with simplicity" (Kinetis, 2019). The code was written in C in order to keep it simple and to create a low-level interaction with inputs and outputs from real-world.Complexity in data processing is reduced with the use of C programming language and the Kinetis design studio software.

5.1.2 control system (Autonomous)

The implementation of the autonomous control system was done by replication of control signals of the receiver provided to the flight controller with the onboard freedom controller. When the system is in manual mode, the DJI NAZA-M lite controller gets the signal from RC receiver kept on-board. In order to replicate the signals provided by the RC receiver to the flight controller, the FRDM board needs to generate PWM signals so as to provide the information to the flight controller on how the drone should maneuver. The complex mechanics and stabilization of flight is handled by the controller. The flight controller further produce PWM signals to the Electronic Speed Controllers (ESCs) to individually control each of the motors.To control the different modes of the drone the idea of emergency stop system is being implemented. Freedom board perfectly replicates the signal which provides indistinguishable

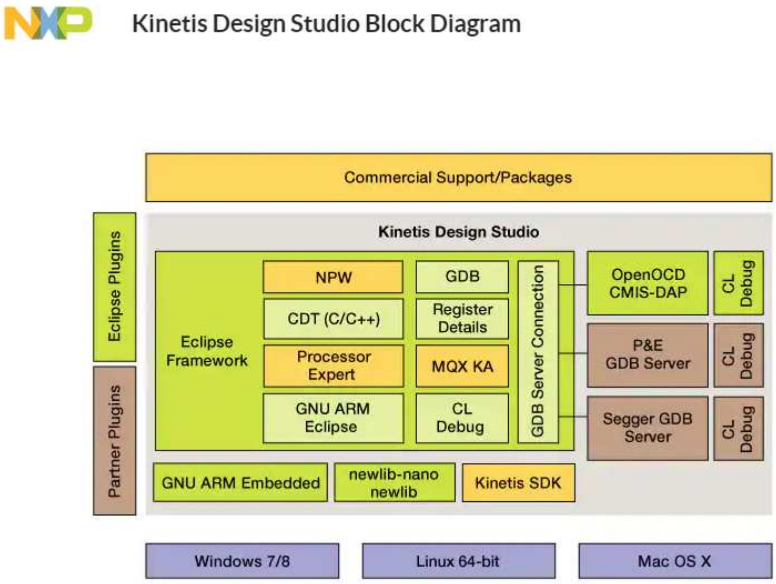


Figure 18: Kinetis Design Studio Block Diagram

control signals. This provides identical performance and capabilities of the drone in manual and autonomous mode with a guarantee that the safety features of the flight controller are active even when UAV is in autonomous mode.

5.1.3 Wiring Diagram

- Manual Mode :

Description: The manual mode wiring diagram is provided in Figure 19. In manual mode, the motors are controlled by the signals provided by the flight controller. The receiver is connected to the flight controller, which is controlled by the RC transmitter unit. The receiver has an inbuilt fail-safe setting which lowers the drone in case of an emergency landing. But the only problem with this fail-safe setting is that it lowers the drone in case of emergency landing but does not turn off the motors. This is the reason why we thought of creating our own kill switch which will take out the power from the motors and will turn off the motors completely.

The receiver has 5 main output control signals: Roll, Pitch, Throttle, Rudder, and control mode input. The sixth one is the AUX input which can be used for tuning purposes. These signals are connected to the NAZA-M lite flight controller. The PWM signals from the receiver are given to the flight controller.The Controller controls the quad-copter based on the PWM signals in three different axes.These signals manipulate the control of the drone. The flight controller has inbuilt inertial sensors which keep track of the stability of the drone. The Output of the flight controller is then provided to the ESC(Electronic Speed Controller). These ESC's converts the output signal from the flight controller into electrical signals which is then provided to the motors. The RPM of the motors varies based on the duty cycle of the PWM signals from the flight controller. The figure shows M1, M2, M3, M4 as output ports connected to the ESCs.The Ports M5 and M6 are unused in this project but can be used to implement hexacopter on the same flight controller. The battery used for this project was a Lithium Polymer battery. The battery is connected to the flight controller using a power management unit, which stabilizes and converts the output of the LiPo battery to a voltage of 4.8 volts to 5.5 volts supported by the flight controller. PMU avoids any kind of voltage or current surge through the flight controller and protects it from damage.

- Autonomous mode :

Description : In autonomous mode, the RC receiver has been replaced by the Freedom controller(Figure 20). The freedom board replicates the signal from the RC receiver and provide it to the flight controller.

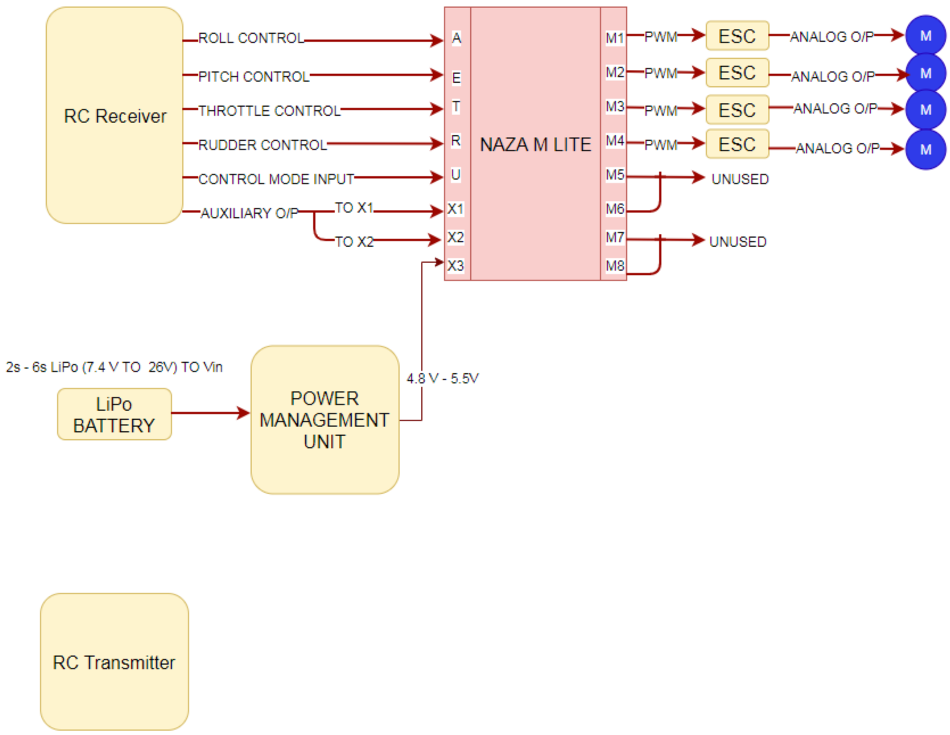


Figure 19: Wiring diagram in manual mode

In order to sense the line, a line sensing camera TSL-1401 (128 X 1)linear array sensor is used. This camera senses the line and provides the output in the analog form through the Analog Output pin. Two cameras are used in a similar way to sense the front and the rear track.The analog output from both the camera is then provided to the ADC(Analog to Digital)pins of the freedom controller. The freedom board then converts the analog signal to digital using analog to digital converter. The digital output is then used in the PID control loop to control the quadcopter. Based on the position of the quadcopter the error value is generated and this error value is added to change the PWM signal. The PWM pulse then controls the RPM of the motors autonomously.Hence based on the string of 1's and 0's the location of the center of the line is identified and calculated.Finally, based on this the PID control loop controls the Pitch, Throttle, Roll, Rudder.The Control mode input is also controlled autonomously based on the duty cycle provided to the pin.

So as to stabilize the altitude of the quadcopter,Ultrasonic sensors are connected to the quadcopter. Four sensors are connected to the four arms of the quadcopter. The multiplexed output from the sensor is provided to the freedom board. The echo output is in an analog form which is then converted to the digital form using ADC(Analog to digital converter).These output values are then used to find out the quadcopter distance from the ground. Therefore, based on the threshold value provided and the PID control loop algorithm created, the quadcopter is controlled autonomously in Z axis.The error value is calculated based on the threshold level provided and the PID control loop uses this error value to stabilize the quadcopter. The output of the control signals is then manipulated based on the error value generated. This change in the duty cycle further changes the RPM of the motors hence controlling the overall stability of the drone in the vertical axis. The rest of the connections and functionalities are kept identical to the manual mode.

5.1.4 Autonomous code activation control switch

The emergency stop system has an autonomous mode activation control switch which is used as a multiplexing device between manual signals from the remote controller and the autonomous FRDM board signals. Along with that, the device plays an important role to switch on or off the flow of the program in autonomous mode. This means whenever the switch is in the autonomous mode program begins and the program can be reset in when it is in air. The fail-safe system in the device acts as an

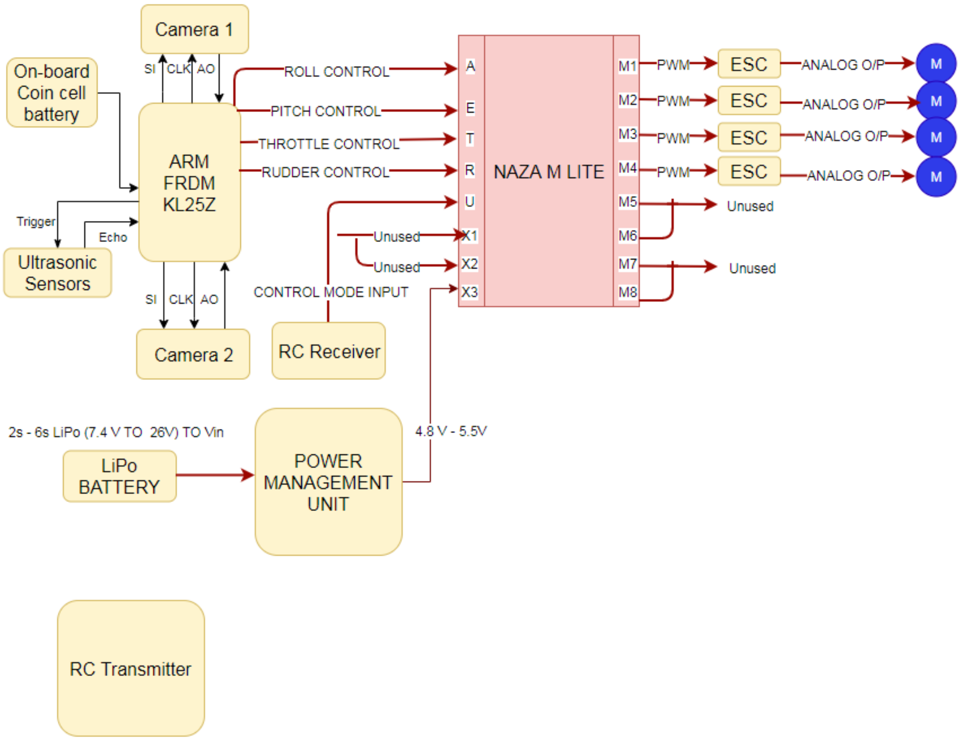


Figure 20: Wiring diagram in autonomous mode

emergency stop mode which will cut the main power from Li-Po battery and flight controllers to kill the motors. The device also keeps the microcontroller online for data collection and debugging. The onboard switches provide an indication of the signals that are controlled by the RC controller and the signals that are still in autonomous mode to provide semi-autonomous operation for debugging and calibration.

5.1.5 Autonomous Program Auto-Start

Autonomous program auto-start is a function created in the Kinetis Design studio, which will auto-start as soon as the freedom board is powered up. Manual start-up of the program every time is a difficult task and creates a complexity in the system. The operator can still achieve the manual control to restart and stop the system by using the switches on the device.

5.1.6 PWM signal generation

As previously stated, the microcontroller should replicate the RC receiver signals provided to the flight controller. The signal from the receiver and the signal replicated by the freedom board provided to the flight controller is in Pulse width modulation form (Polulu, 2011). As the PWM signal from the RC receiver is in the form of Pulses, the signal provided depends on the duty cycle and high pusle duration. The standard RC receiver uses a high pulse of 1 ms duration as the minimum signal, a high pulse duration of 1 ms as a neutral position and a high pulse duration of 2 ms as the maximum as shown in figure 21 (Polulu, 2011).

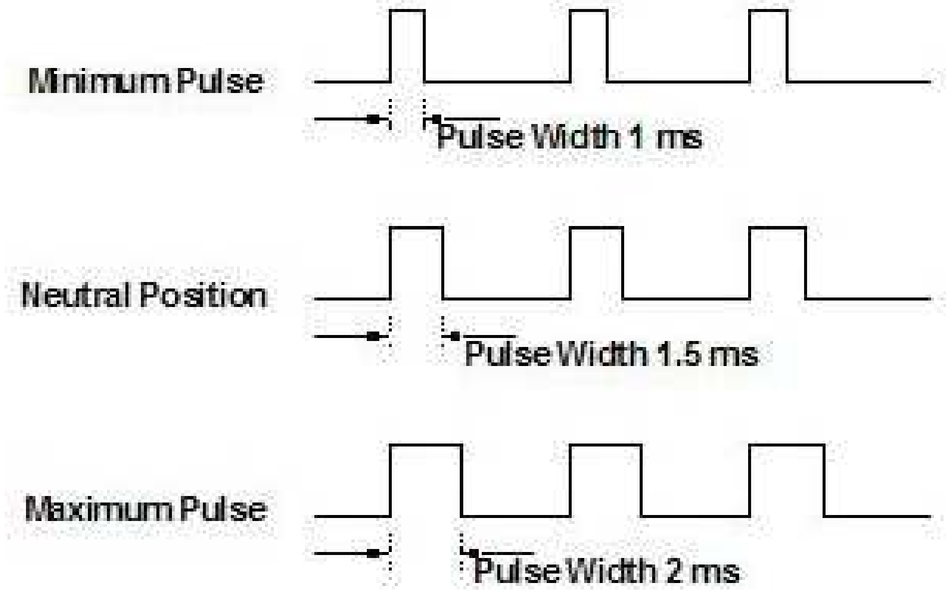


Figure 21: Standard Remote Controlled Pulse Width Modulation

CHAPTER 6

VISION CONTROL AND MOTION APPROACH

A vision system is developed to sense the condition of the track and control the autonomy of the UAV by using TSL1401 Linear Array Sensor with a detection resolution of 128 pixels. The basic idea was to sense the picture using the camera and then send the analog data to the Freescale FRDM KL25Z processor which further determines the PWM pulses to be sent to the flight controller. The coding was done In C and a PID control loop was implemented to control and maneuver the UAV autonomously.

6.1 Image detection using TSL1401 sensor array

As given in (Mohamad et al., 2015) Image detection takes place when the light is reflected from any object or environment and it enters the lens of the camera and hence diverts itself into the sensor. Each pixel is charged based on the light intensity of the light entered through the camera lens. The amount of the charge gained by each pixel depends on the intensity of light and its time of integration (TSL, 2016). The sensor then relays every pixel values one by one until all the pixels are released into the analog output terminal.Further, the values are then converted into digital form, values ranging from 0 to 65536 in the digitized form, hence using the analog to digital converter from the FRDM board. The figure 22 below shows the output of the analog pin of the sensor. As the camera is a 1-D linear array of sensors and it senses a part of the whole image. So as to help with the sensing mechanism of the line, a threshold value had to be set. The threshold value is set such that if the output value exceeds threshold value a 1 was given which indicated a white surface. Whereas the signal output is less than that of the threshold value, it is considered that a camera is detecting a black line and a white surface if a value higher than the threshold is received..

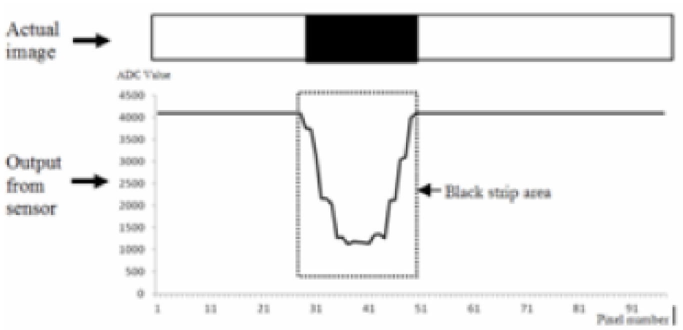


Figure 22: Analog Output from the sensors

6.1.1 Control method using camera

The controlling process of the quadcopter using the camera inputs is shown in the figure 23 . Initially, a line scanning algorithm was implemented which would scan and measure the ADC values from the camera based on the number of clock cycles. The values were then averaged and compared with the threshold value provided. Based on the comparison with the threshold value a string of 1's and 0's was created. Further left and right indexes were calculated depending on the position of the quadcopter as compared to the line. Based on the left and right indexes, the line center was calculated and compared with the desired line center. The error value was calculated based on the comparison with the line center desired. The error value would be nearly equal to zero if the drone position is at the center of the line.If the value is other than zero it would indicate that the position of the drone is not at the center. After getting the error value, the change in the PWM duty cycle of the control signals can be calculated based on the error. The drone is then controlled autonomously based on the feedback loop (Proportional Integral Derivative) created. The movement of the drone depends on the electrical signals received from the ESC's. The ESC's are fed with the PWM signals of varying duty cycle based on the PID control loop. When the drone deviates and goes away from the line center , the speed of the drone should be decreased in order to reduce the value of error. This is implemented by controlling the speed of all the four motors.

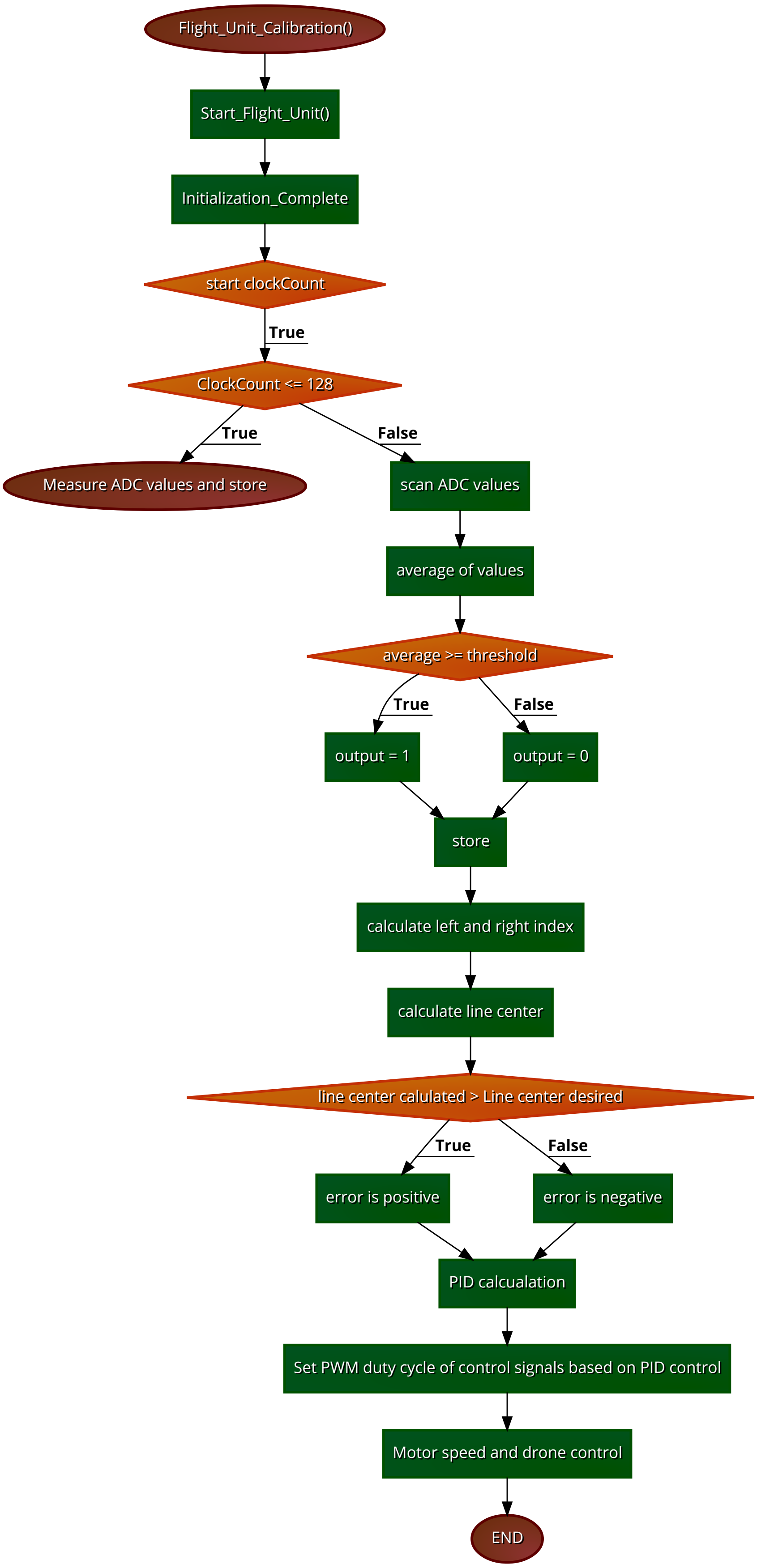


Figure 23: UAV control and line identification process

6.2 Attitude Stabilization control using Ultrasonic sensors

6.2.1 Ultrasonic sensors

The trigger pin of ultrasonic sensors should provide an ultrasonic wave that would travel at a speed of sound. Therefore the distance can be calculated based on

$$distance = \frac{duration * speed}{2} \tag{6.1}$$

6.2.2 Basic principle of working

1. Using PWM, transmit Trigger pulse for at least 10 microseconds high-level signal to HC-SR04 Trig Pin.
2. The module then sends eight pulses of 40 KHz and will detect the rising edge output at Echo pin.
3. When the rising edge captures takes place at the Echo pin, start the timer and wait for a falling edge on the echo pin.
4. As the falling edge is captured at echo pin read the timer count. This time count is the total time required by the sensor to detect an object return back from it.

$$TotalDistance = \frac{343 * Timeofhigh(echo)pulse}{2} \tag{6.2}$$

The speed of the sound is taken to be 343 m/s in this case (depends on temperature and air relative humidity). Sensor holders with four ultrasonic sensors have been mounted on each side arm of the quadcopter. These sensors are connected using multiplexer and decoder so as to reduce the number of connections on the micro controller. Multiplexing the sensors allows us to use just one pin to trigger the pulse and 1 pin for receiving the echo signal from each of the sensors sequentially. The total pins required on the FREEDOM board are just 4:

1. Two pins are Select pins of multiplexer S0 and S1
2. One pin for the trigger
3. One pin for echo

A 4:1 multiplexer is used along with the decoder. Multiplexer used was IDTQS3253 and Decoder was SN74LS139A.

6.2.3 Altitude control using ultrasonic sensors

In order to stabilize the altitude of the quadcopter, I have used four ultrasonic sensors attached on the chassis of the quadcopter in an X configuration. Below is the image of the connection of sensors to freedom board using multiplexer and decoder.The connection of ultrasonic sensors in X configuration is shown in Figure 25(b).

6.2.4 Concept and algorithm of altitude control

Along with the hardware, implementation of the digital PID controller was implemented so as to control the altitude of the quadcopter based on the distance calculated from the echo signals. PID controller sends generated output signal to control the speed of motors. The ultrasonic sensors send the trigger pulses and obtain the echo after reflecting from the ground surface.The pulses are then sent to the freedom board in the form of analog signal. The data is then filtered and used to calculate the distance values, which is then further used to control altitude based on the threshold values provided in

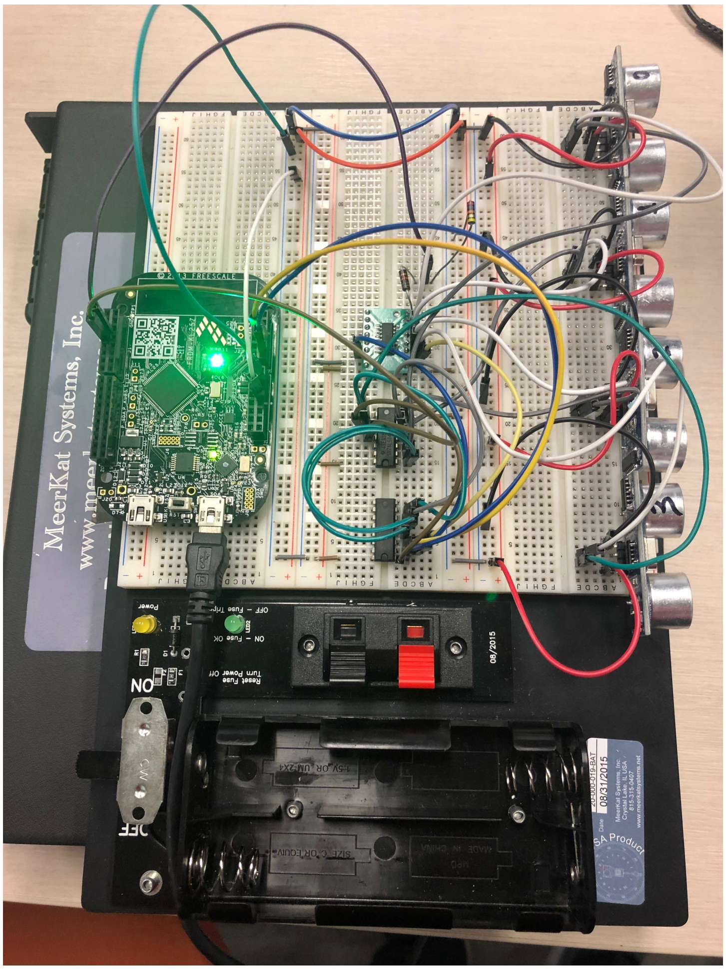


Figure 24: Ultrasonic Sensors connection with freedom board using MUX and decoder

the PID control loop explained further. Four ultrasonic sensors are used to increase detection resolution and provide more stability based on reliable sensor data. Each sensor will provide the distance value whenever it is selected using the select pin of the multiplexer. All the sensors are sequentially selected based on the multiplexer select pins and decoder. The values from all the sensors are sequentially read and averaged. The average distance values are then used in the PID control loop, which will start its work by sending out the correction value to the stabilization board.The normal range for all the control signals is 1000 microseconds to 2000 microseconds and 1500 microseconds is the center or neutral value.But in the project I have used the values in between the range of 1200 microseconds to 1800 microseconds since the quad will be less unstable if the range is less.

The freedom board will continuously gather distance measurements from the array of ultrasonic sensors. When the distance is out of the provided upper and lower threshold values the digital PID controller implemented in the micro controller will provide the PWM pulses to the flight controller so as to control the motors. By changing the duty cycle of PWM signal from the micro-controller the motors can be controlled and thereby controlling the altitude between desired ranges by maneuvering the drone.The system dynamics is changed in order to achieve the desired set value, by changing the motor speed by sending the control signal to the motor..

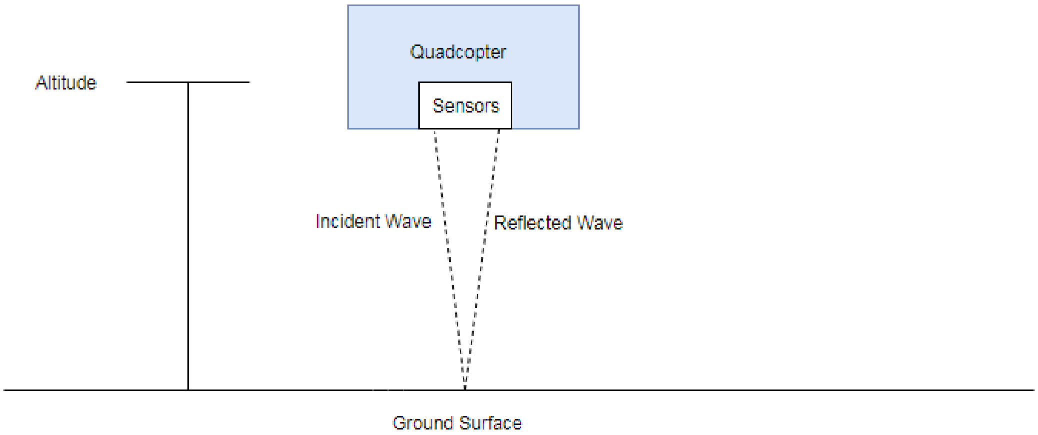
6.2.5 Controller design

A quadcopter stability system was designed initially with a control structure to reach the desired objective of control and attitude stability. The system has inbuilt inertial sensors such as three-axis accelerometer, gyroscopes and barometer. Goal of Attitude stabilization is accomplished by constructing a PID control algorithm to each of the three axis. PID controllers are used in industrial applications because of its simplicity, great performance and we can tune them if we want to generate a specific control system model.

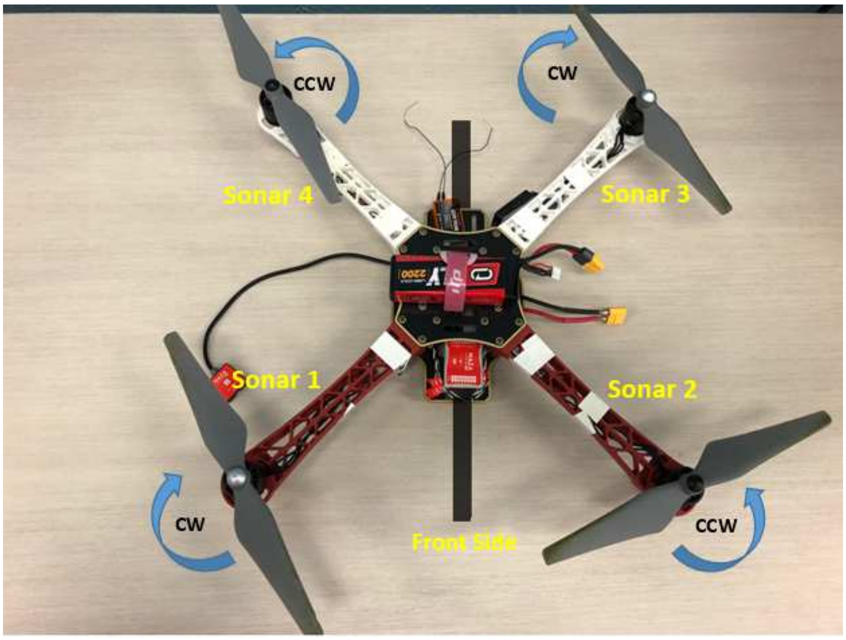
Provided in Figure 26 is the traditional PID control loop .The blocks K_p,K_i,K_d represents the proportional gain, integral gain and derivative gain .The output error is calculated based on the measured error and three controller gains.The blocks 1/s denotes integration and s denotes derivative operations.

The attitude and altitude states are controlled precisely by implementing the control algorithm. The main aim is to make the quadcopter robust and stable and remove any deviations and control the quadcopter signals so as to move it to a new desired position.In order to maintain stability during flight, attitude control is implemented. Speed and position controller design is carried out on the system for performance enhancement.Seperate PID control loop was implemented for each of the four controls, where each controller controller the roll,pitch,yaw axis and also the altitude.

The block diagram in figure 27 shows the implementation of the feedback control loop. In order to change the pitch, the output from controllers modifies the rear and front motors speed.For rolling of the dron the controller should change the speed of left and right motors.Similarly for controlling the Yaw, the controller should change the speed of the diagonal motors.In case of the attitude control, all the motors are modified simultaneously by the controller. When the value is increased, it will ascend and descend if the value is decreased (Ahmed et al., 2016)



(a) Ultrasonic sensing mechanism on quadcopter



(b) Interfacing of ultrasonic sensors to the quadcopter in X configuration

Figure 25: Altitude control

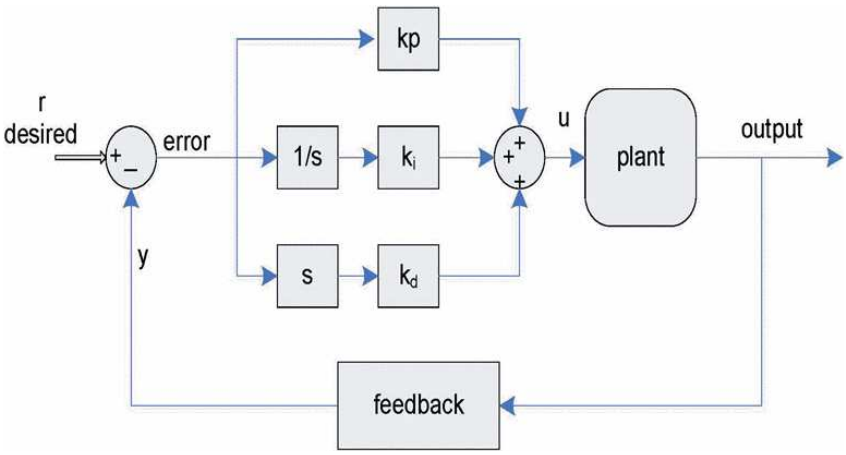


Figure 26: PID Control

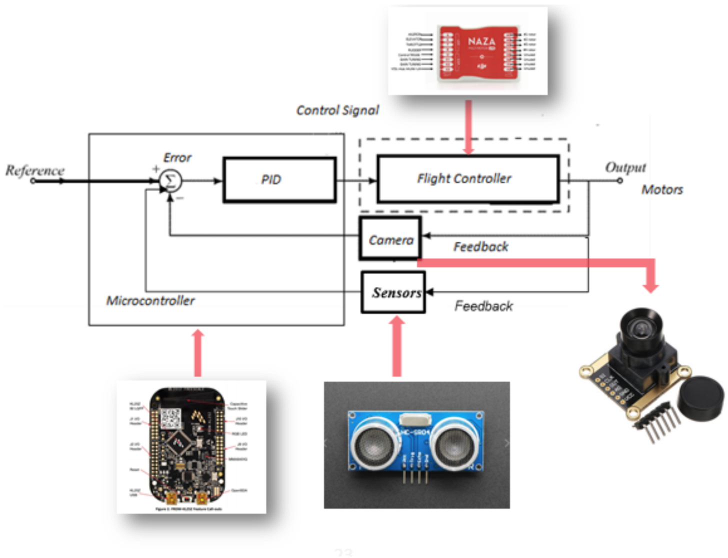


Figure 27: Block diagram of feedback control loop used for automation

CHAPTER 7

RESULTS

7.1 Overview

This section describes the various results based on visual tracking and control of the quadcopter using digital oscilloscopes and kinetis design studio. It also comprises of various figures of output signals of ultrasonic sensors in various scenarios of altitude stability.

7.2 Testing altitude algorithm and Line sensing algorithm

Initially, the circuitry was implemented on a breadboard.Later on, PCB was designed along with the on-board power supply so as to interface the PCB on the quadcopter along with all the sensors. The algorithm for the PID loop was implemented to stabilize the altitude on the freedom board. The testing was done in a closed environment on a gimbal system for safety purposes shown in Figure 28.

7.2.1 MCU Pin assignment and PWM output generation

The ARM processor-based FRDM -KL25Z was used to generate PWM signal. Each pin of the FRDM board was assigned some specific functionality. This FRDM board specifically works as a substitute to the receiver. So each of the control pins provides PWM output and the creation and mapping of these PWM signals in FRDM - KL25Z was an easy task. The configuration was done prior to the creation of the PID control algorithm.The Kinetis Design Studio was used for the development of algorithm and code generation. Find below in the table Pin description of all the pins used for the project.

TABLE II: FRDM KL25Z PIN ASSIGNMENT

Label	Port & Pin no.	Pin description	
1	PTA 1 -(FTM2_CH0)	Clock	Clock signal provided to the camera
2	PTA 2 -(FTM2_CH1)	SI	Serial Input to the camera
3	PTA 13 -(FTM1_CH1)	AO	Analog output of the camera to ADC pin
11	PTC 8 -(FTM0_CH4)	Clock	Clock signal provided to the camera
10	PTC 9 - (FTM0_CH5)	SI	Serial Input to the camera
9	PTA 12 - (FTM1_CH0)	AO	Analog output of the camera to ADC pin
4	PTD0 - (FTM0_CH0)	Roll Control (A)	Roll control input to the flight controller
5	PTD1 - (FTM0_CH1)	Pitch Control (E)	Pitch control input to the flight controller
6	PTD2 - (FTM0_Ch2)	Throttle Control (T)	Throttle input to the flight controller
7	PTD3 - (FTM0_CH3)	Rudder Control (R)	Rudder Control Input to flight controller
8	-	Control input	Control pin of the receiver provides PWM signal to the Control mode switch of flight controller to trigger the fail safe mode
AUX	-	AUX	PWM Auxiliary output pin can be can be connected to X1 or X2 for gain tuning /Gimbal pitch control respectively

Figure 28: Gimbal system

Processor Expert with MCU 10.3 was used for the generation of PWM component.As seen in the figure 29 a PWM signal was generated using the PWM component in the Kinetis design studio. The generated PWM signal was of 10 % duty cycle and the total period was 20 milliseconds.

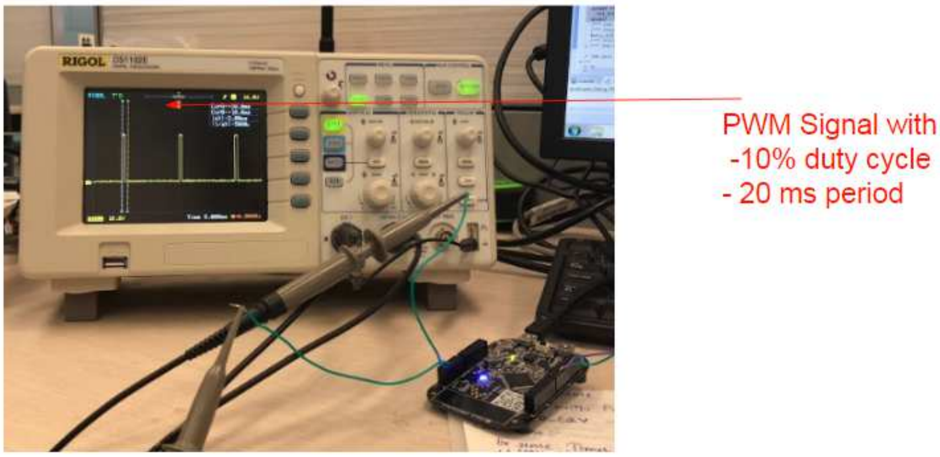


Figure 29: PWM generation in Kinetis Design Studio

The signal output from the manual remote control receiver was measured on an oscilloscope for different range of values from remote controller. The data output is shown in Table 3 and in Figure 30. The duration of cycle measured was 22 milliseconds which is approximately equal to a frequency of $45.45Hz$, the voltage for high pulse cycle was 3 volt and for the low pulse was 0 volt

7.2.2 Line sensing using camera

The figure 31 below provides the signals in the logic analyzer for the SI (serial input) and Clock provided to both the cameras. The SI signal is generated and provided using the BitIO component in the Kinetis Design studio. The clock signal provided to both the cameras are equivalent and the generated clock has a period of 25 microseconds with starting pulse-width of 12.5 microseconds. The Serial Input and clock signals are provided to both the cameras along with the supply and ground. This will generate an output analog signal as shown in the figure 31. The drop in the voltage in the signal is the part where

TABLE III: MEASURED RECEIVER PWM DATA

Signal	High Pulse Duration
High	1.8ms
Medium	1.4ms
Low	1.2ms

the camera detects a black line. The detected voltage drop is then measured and the threshold voltage for both the cameras are measured. The total voltage of the signal is approximately equal to 3.3 volts whereas the threshold for both front and back camera is set to 1.5 volts.The threshold voltage will then be used to generate the bits '0' and '1' which can be used further in the detection and PID control algorithm.

Figure 32 shows the digitally converted output of the analog signal from the Front and back camera during the testing process. 'F' denotes the output from the front camera and 'R' denotes the output from the rear camera.For the sake of convenience, in order to differentiate between the garbage values and the actual output, I denoted white surface as '2' and black surface as '1'.

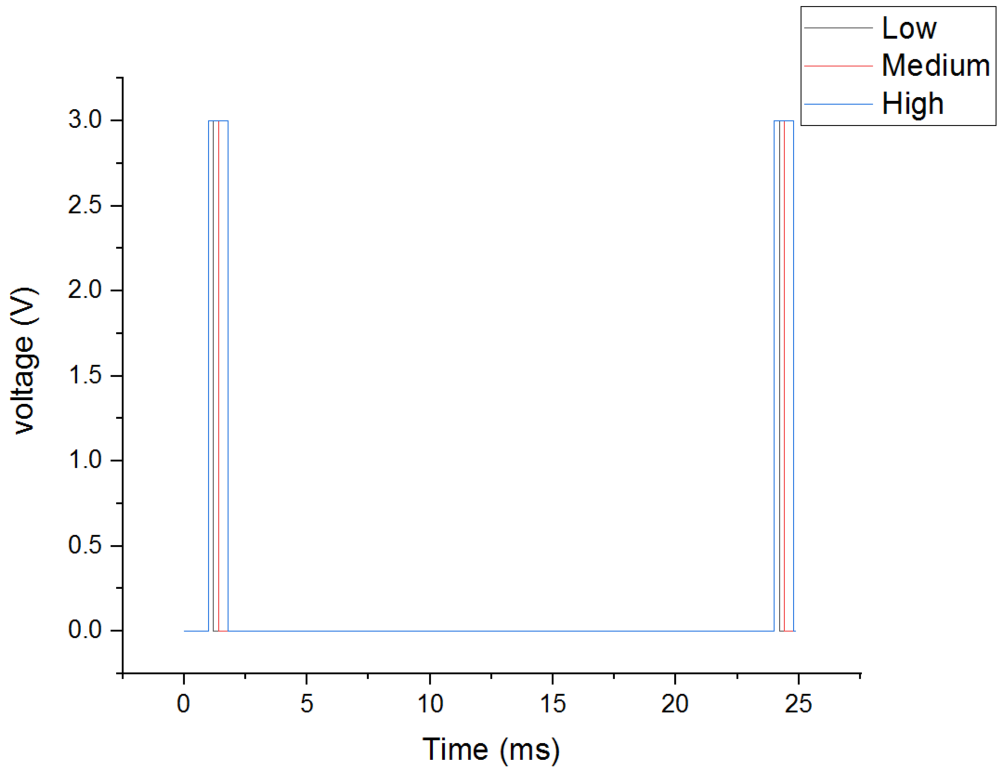


Figure 30: Remote control receiver PWM signal

The figure 33 below shows the analog output of the camera when the quad-copter is at different heights and different position. Figure 33 shows the oscilloscope output of the camera when it is detecting a black line on a white surface. Figure 33(a) shows the output of the camera when the camera is positioned at a height of 7 cm and is detecting a black line on a white surface. When the height of the camera is increased from ground surface to 30 cm the signal changes as shown in figure 33(b). Where the drop in the voltage level at the center is because of the black line, the drop is reduced as the height

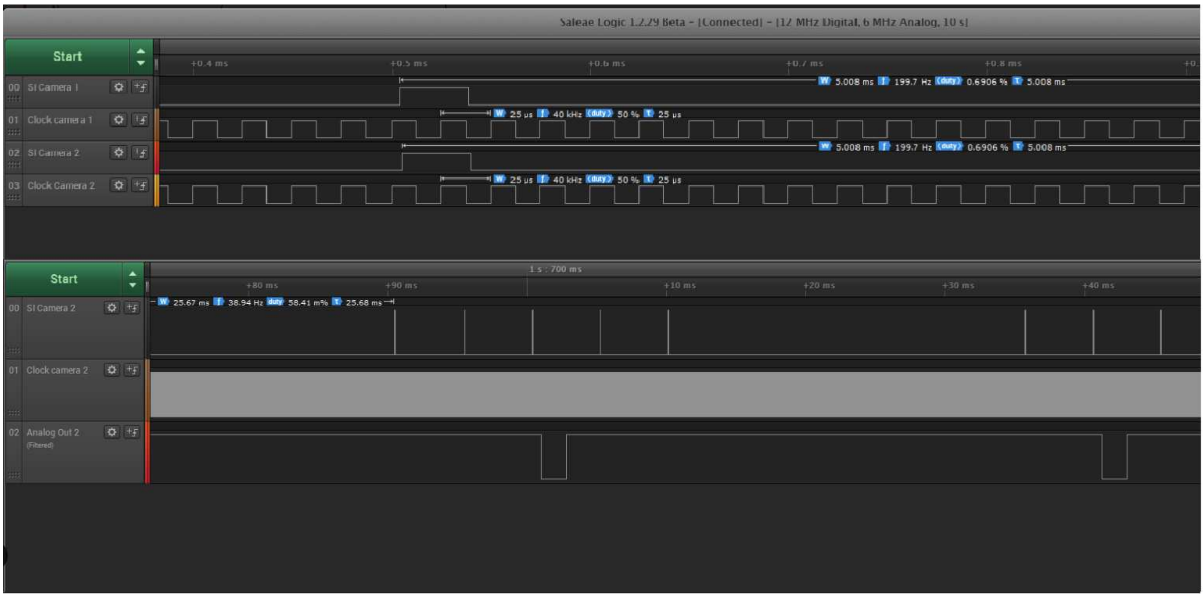


Figure 31: Input signals to the camera and the analog signal output

increases. At the height of 60 cm or more, we cannot differentiate the drop of the voltage level as shown in figure 33(c). Hence the voltage levels of black and white surface provide the same values. Hence at the higher height, the camera cannot differentiate between a black and white surface which makes it difficult for the quad-copter to adjust itself based on the camera values.

Also, the variation in light intensity varies the pixel charge values. If the light is less intense, then the output analog voltage will be of less amplitude, whereas the analog output voltage will increase in amplitude when the light intensity increases.

Also, see the digital output of the camera from different heights, when the camera's "focal length" is kept constant. The graph represents the output of the camera when the camera is positioned at different

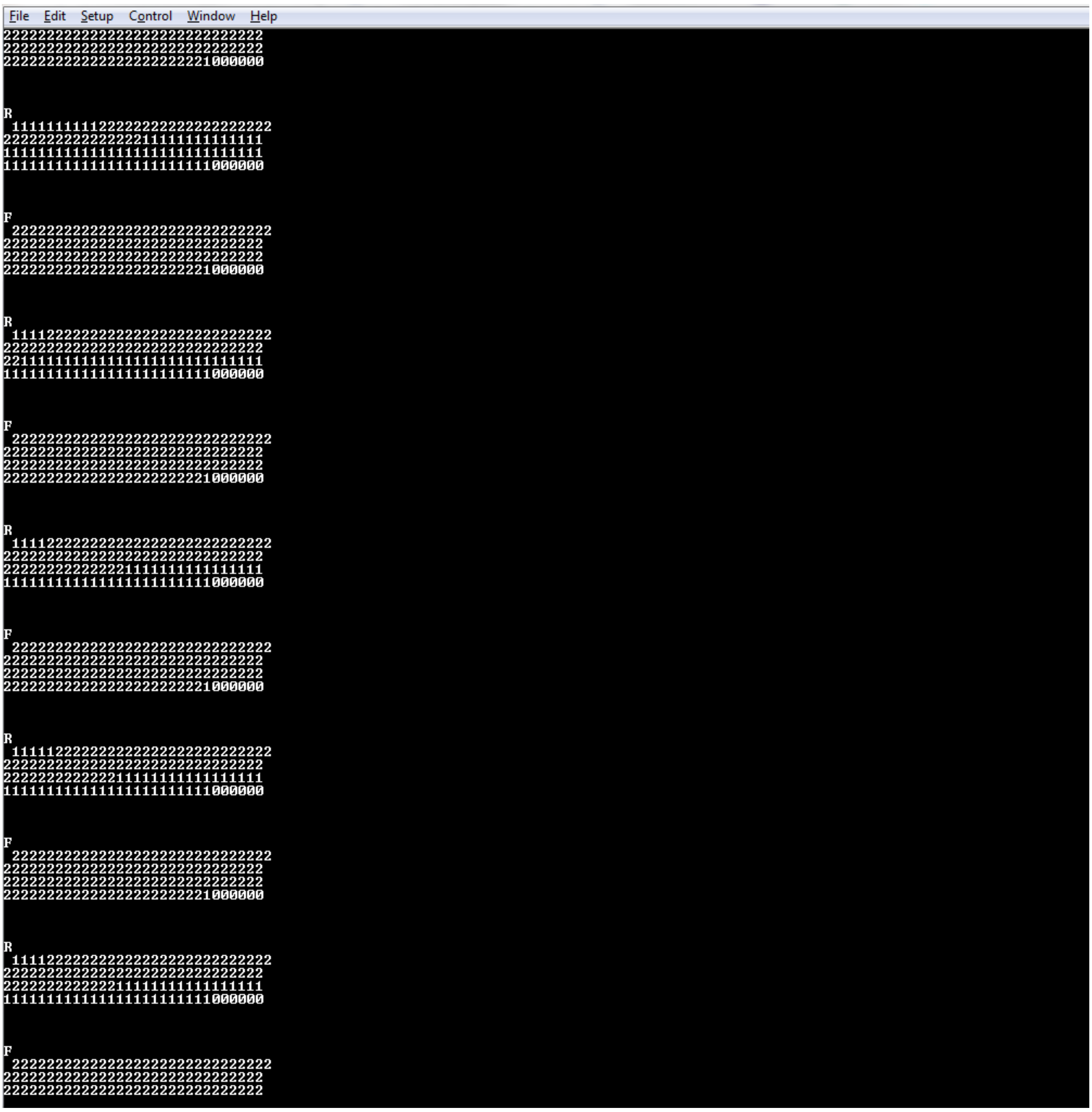


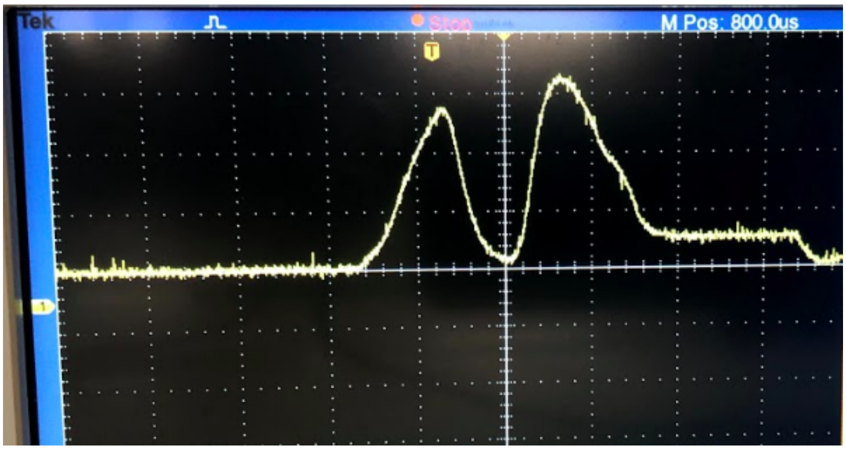
Figure 32: Generated digital output from camera

heights. Figure 34(a) shows the quad-copter positioned at approximately 7cm from the ground and the respective ADC output. The voltage drop when the black line is sensed can be seen in the graph. Similarly, the graphs of the camera output in figure 34(b) and 34(c) shows the output of the camera when the quad-copter is positioned at 30cm and 60 cm respectively. The graph for the camera output from 60 cm shows that the camera loses its vision and provides no differentiation between a black surface and white surface at this height. Also, the output gets noisy due to the vibrations of the quad-copter. The output shown in the graphs in figure 34 is for one complete cycle of the camera(129 clock cycles).

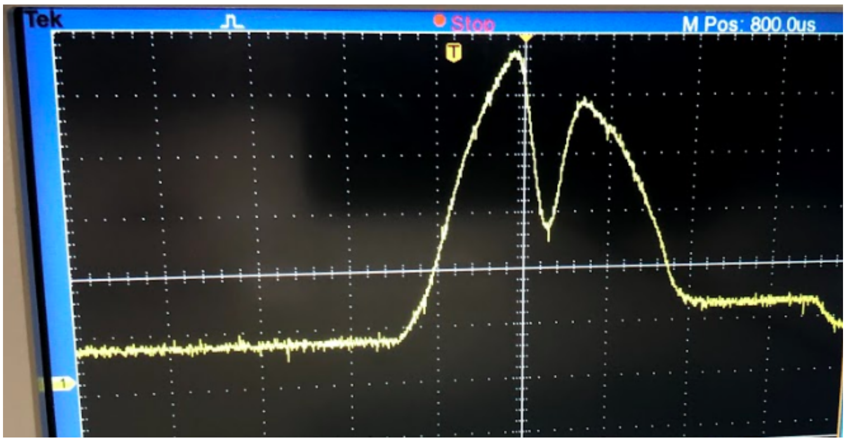
The other figure shows the output of the camera when it changes its position laterally. Figure 35(a) shows the output of the camera when it is centered on the black line. Figure 35(b) provides the camera output when the camera is positioned and aligned to the right of line, hence the sudden drop in the voltage is shifted on the left side. Similarly, figure 35(c)shows the output of the camera when the camera is positioned on the left of the black line, which makes the voltage drop due to the black line shift towards the right. Figure 36 shows the graphs related to the lateral movement and the ADC output of the camera.

As experimentally seen in the graphs, the camera output varies based on the light intensity or illumination. Figure 37(a) and 37(b) shows the output of the camera in light and in no-light conditions at a height of 7 cm. An external light source (LED) was used to increase the light intensity. Hence a solution to make the system more robust and stable is to use a secondary light source, which will increase the amplitude of the analog camera values.

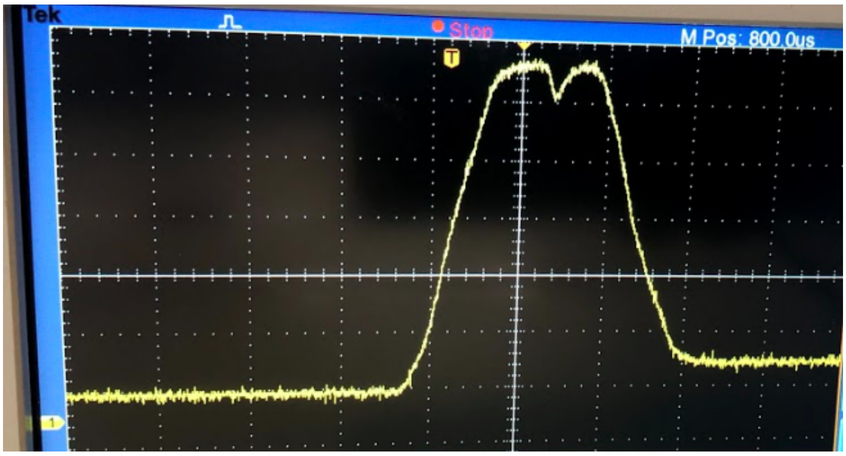
Finally, a test was done to check the output of the camera at the same altitude and same light conditions, but with varying focal length. As the TSL1401 camera has a maximum focal length of 7.9



(a) Analog Ouput when camera is at 7 cm height

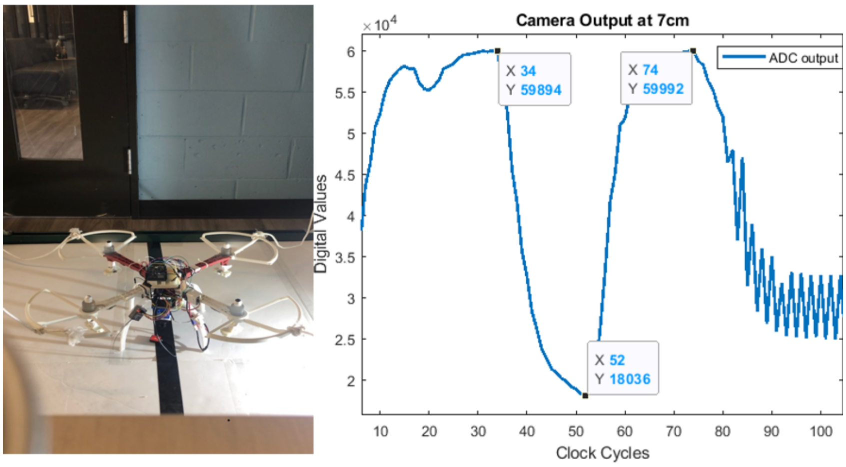


(b) Analog Ouput when camera is at 30 cm height

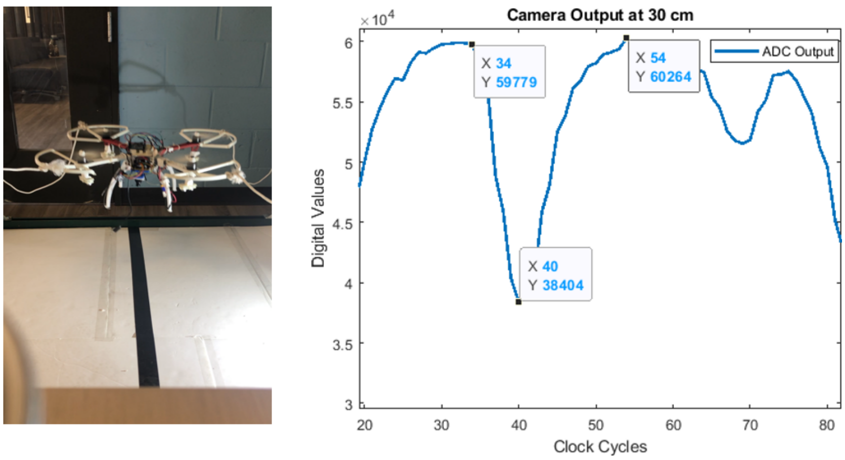


(c) Analog Ouput when camera is at 60 cm height

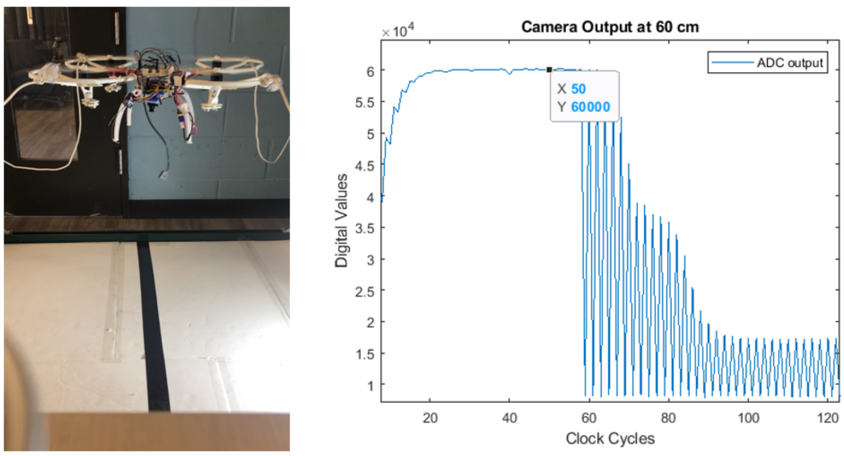
Figure 33: Results of analog camera ouput (vertical change in position) (Scale : 500 mV)



(a) Digital Ouput when camera is at 7 cm height

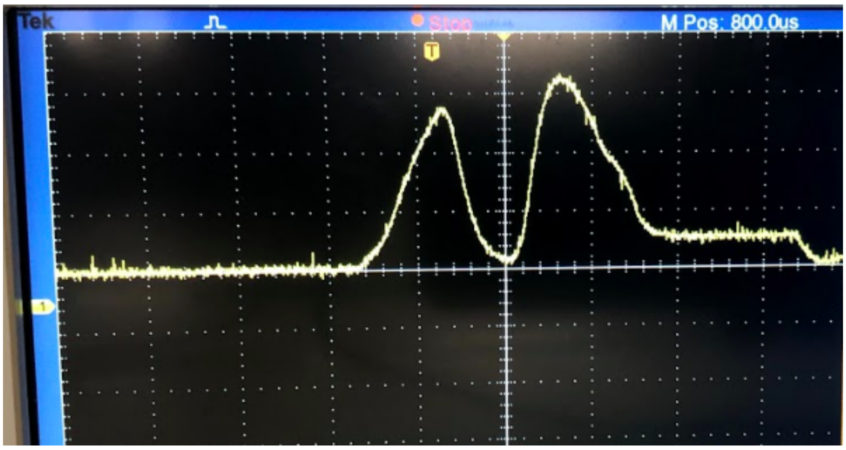


(b) Digital Ouput when camera is at 30 cm height

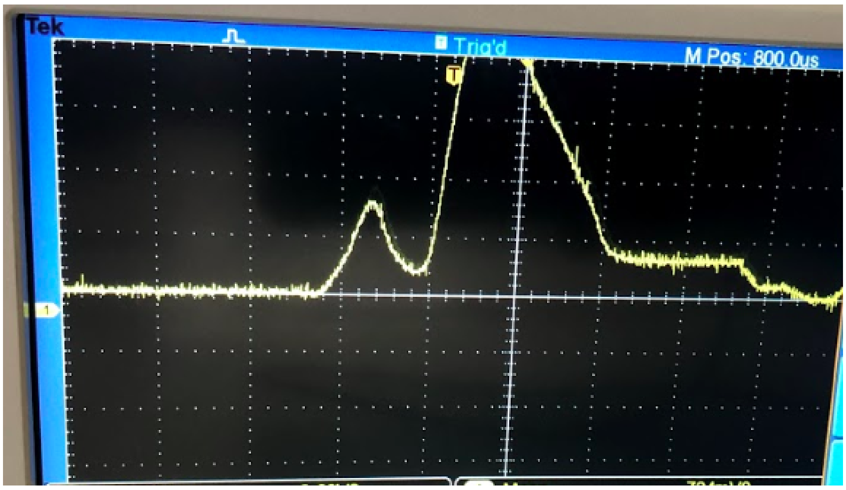


(c) Digital Ouput when camera is at 60 cm height

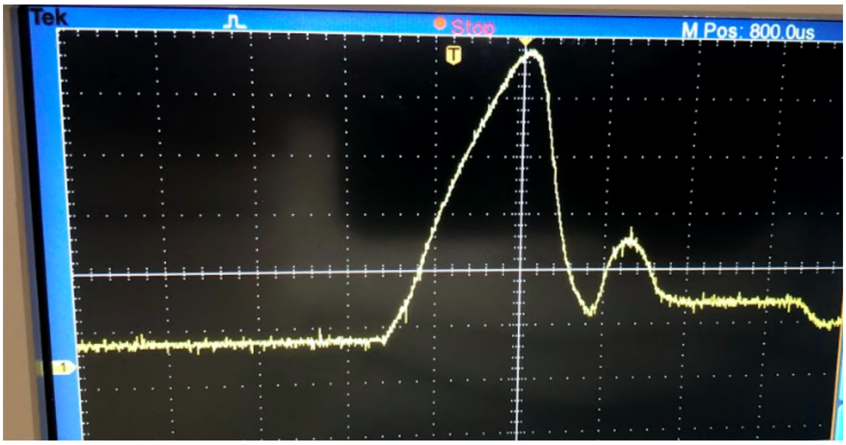
Figure 34: Results of camera ouput (vertical change in position)



(a) Analog Ouput when camera is aligned at center of the black line

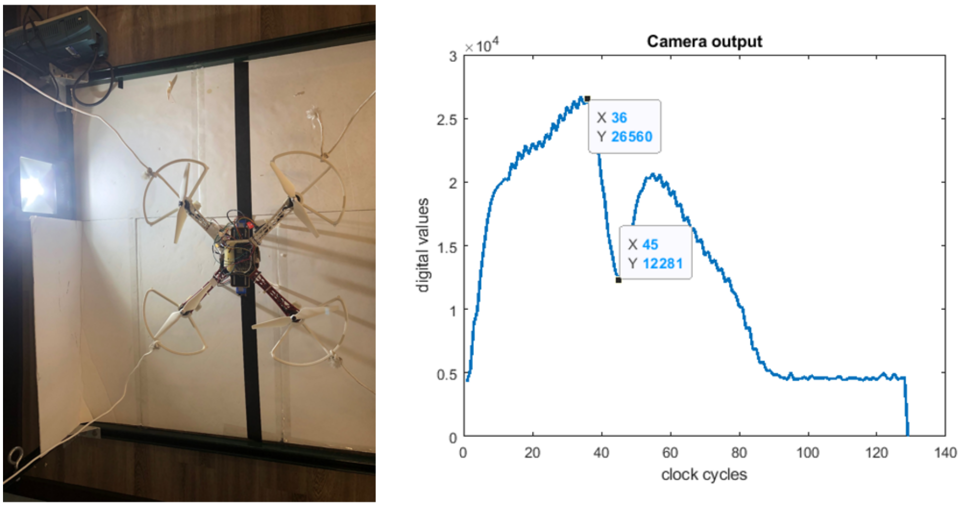


(b) Analog Ouput when camera is aligned at the right of black line

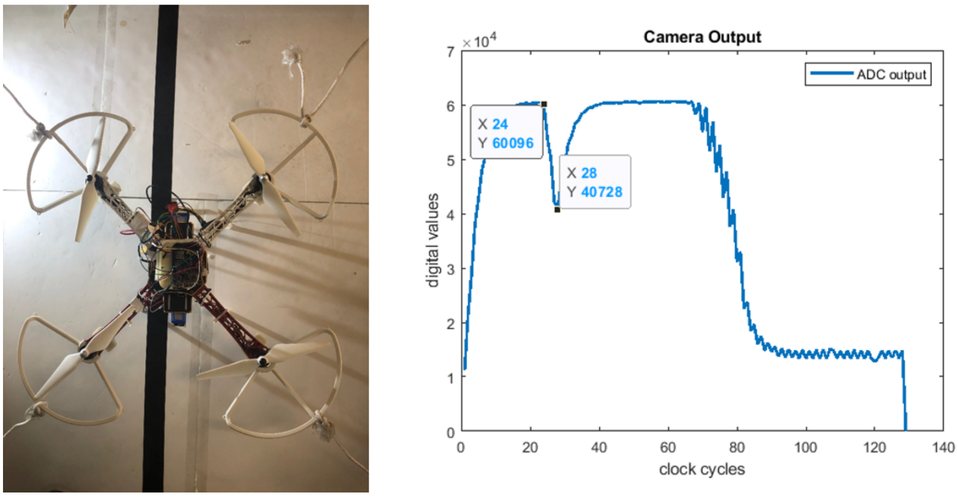


(c) Analog Ouput when camera is aligned at the left of black line

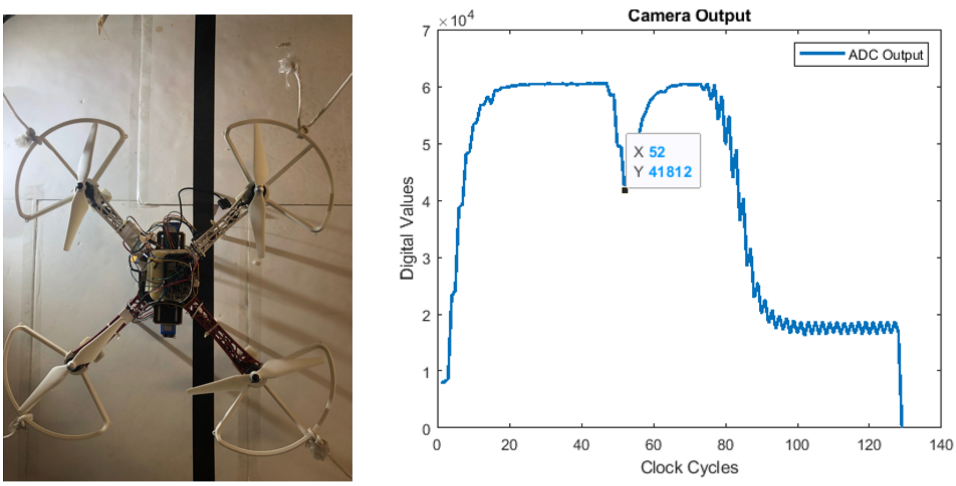
Figure 35: Results of analog camera ouput (lateral change in position)(Scale : 500 mV)



(a) Digital output when camera is aligned at center of the black line

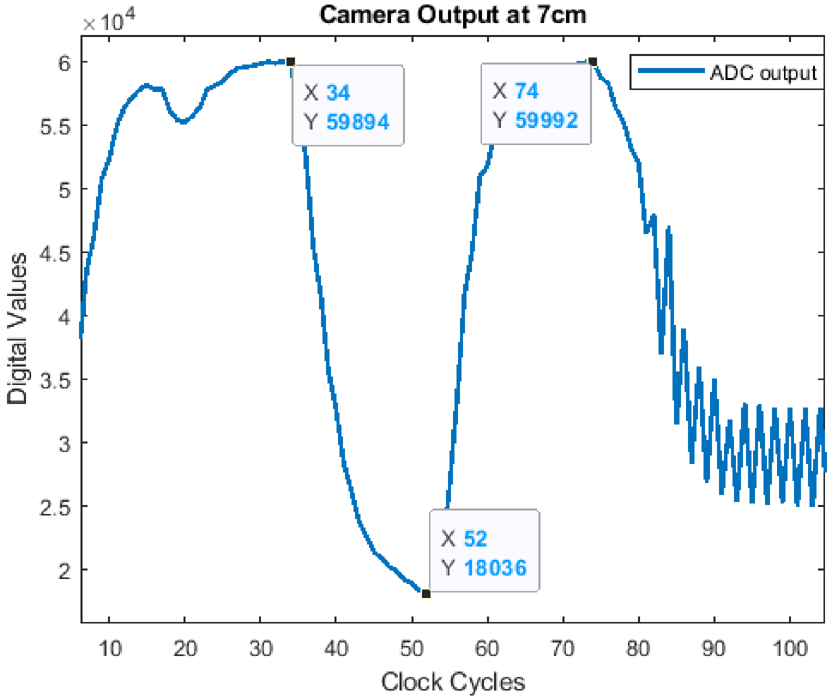


(b) Digital Ouput when camera is aligned at the right of black line

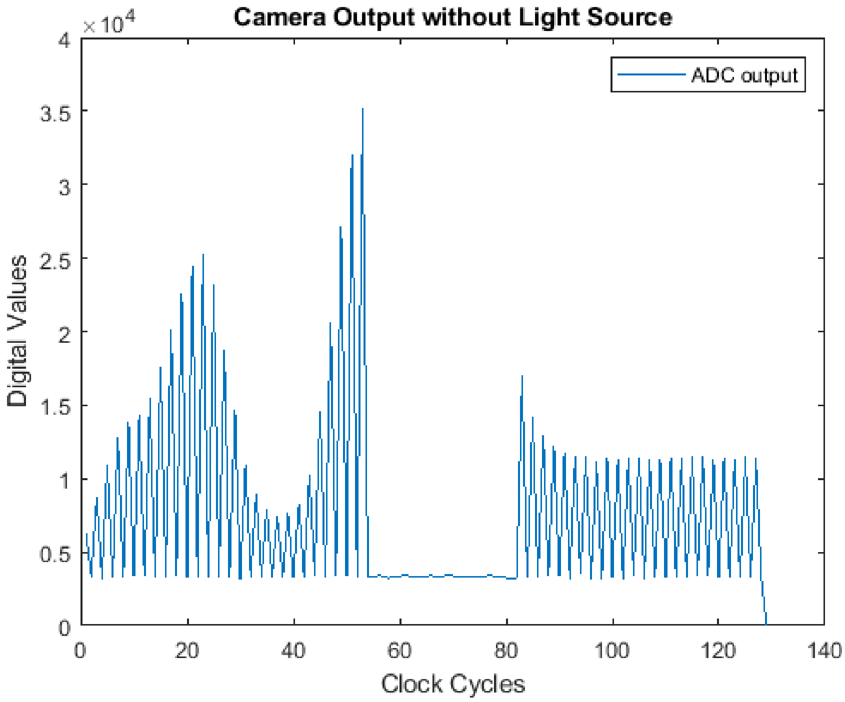


(c) Digital Ouput when camera is aligned at the left of black line

Figure 36: Results of digital camera(lateral change in position)



(a) Digital output when camera is at 7cm with secondary light source



(b) Digital Ouput when camera is at 7cm with no external light source

Figure 37: Results of camera with varying light intensity

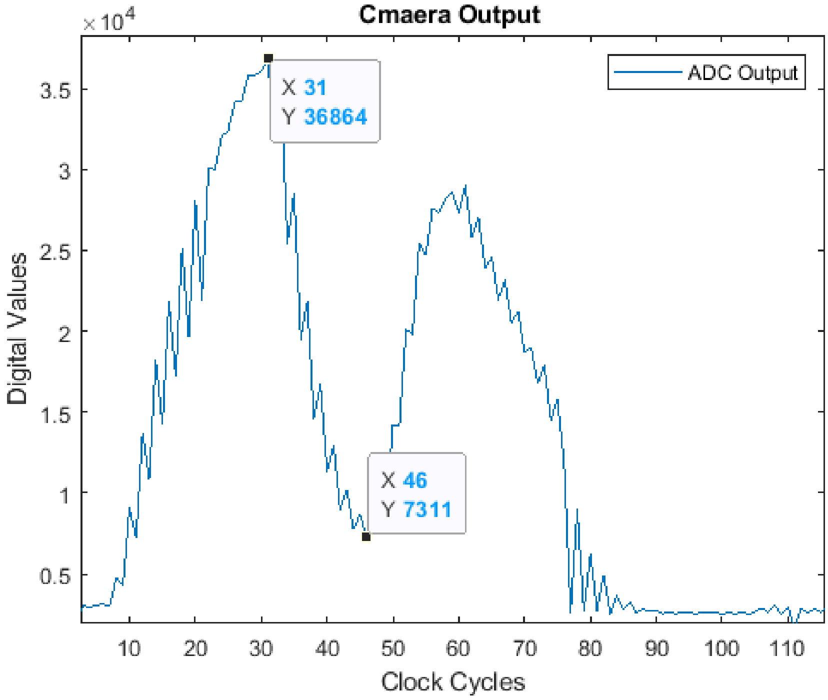
mm, we can check the output of the camera by varying the focal length. As seen in figure 38(a) and 38(b) the voltage drop for the black surface reduces when the focal length is reduced. So if we increase the focus the camera on the line, we can get a good difference between the white and black surface. But as the focus is not auto adjustable it is really difficult to change the focus as the altitude of the drone varies. Hence one solution to get a good output value from the camera is to create a system in order to auto-focus the camera at different heights.

7.2.3 Yaw and roll control using two different cameras

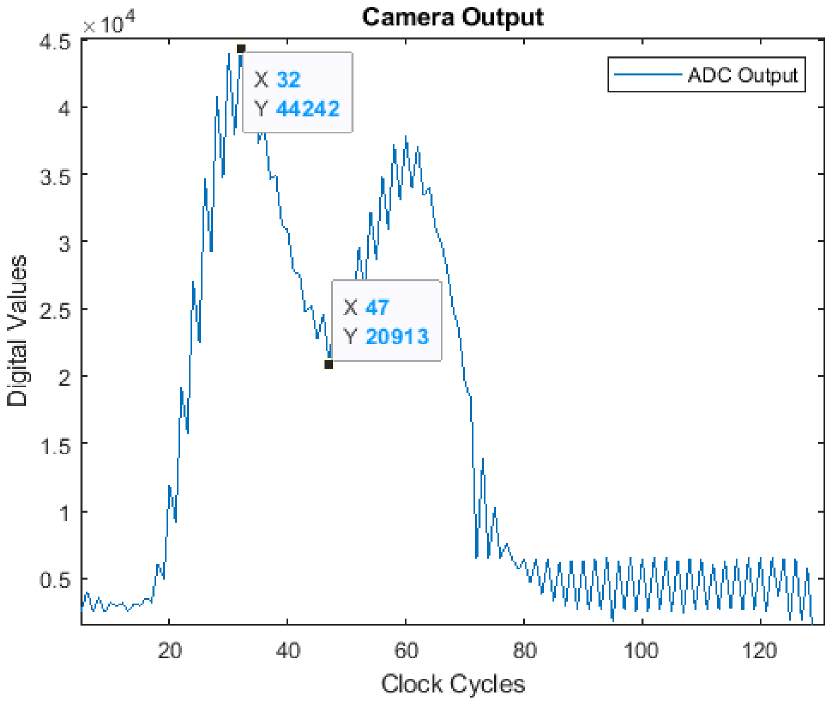
Two different cameras at the front and rear were connected in order to sense the yaw and roll movements of the drone.The image of the drone with two cameras is shown in figure 39. In order to control the yaw and roll motion using the two cameras I am sensing the edges of the line on the track .Based on the error created due to the motion of the drone the line center is calculated.The line center calculated is then compared with the desired center and the cumulative error from both the camera is used to calculate the total tilt and deviation of the drone from the center of the line.As seen in the figure 40 below based on the orientation on the drone the position of the line and the center of the line is calculated and the error is further used to change the PWM duty cycle to move the drone.In order to move the drone in roll axis , the rpm of left two motors and right two motors are modified simultaneously.Whereas for the yaw movement of the drone the diagonal motors have to be modified.

Problems faced :

- **Light Intensity** : The issue was related to the light intensity and the total integration time requirement of the camera. Various methods had to be used to increase the exposure of the camera to the light, like using a secondary white light source to increase the intensity of the light on the camera



(a) Digital output when camera is at 30cm with focal length of 7.9 mm



(b) Digital Ouput when camera is at 30cm with focal length of 1.2 mm

Figure 38: Results of camera with varying focal length

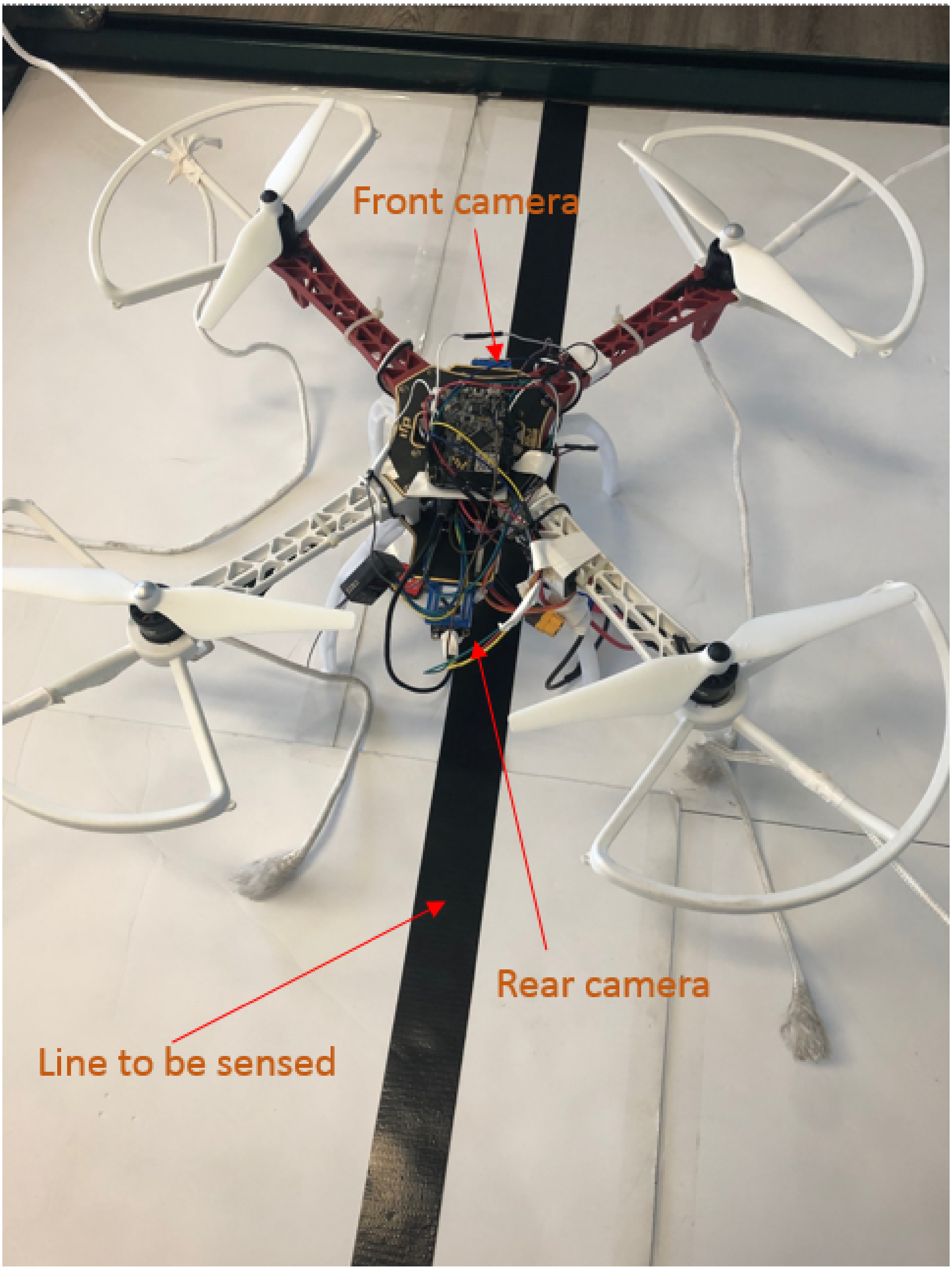


Figure 39: Camera location on the drone

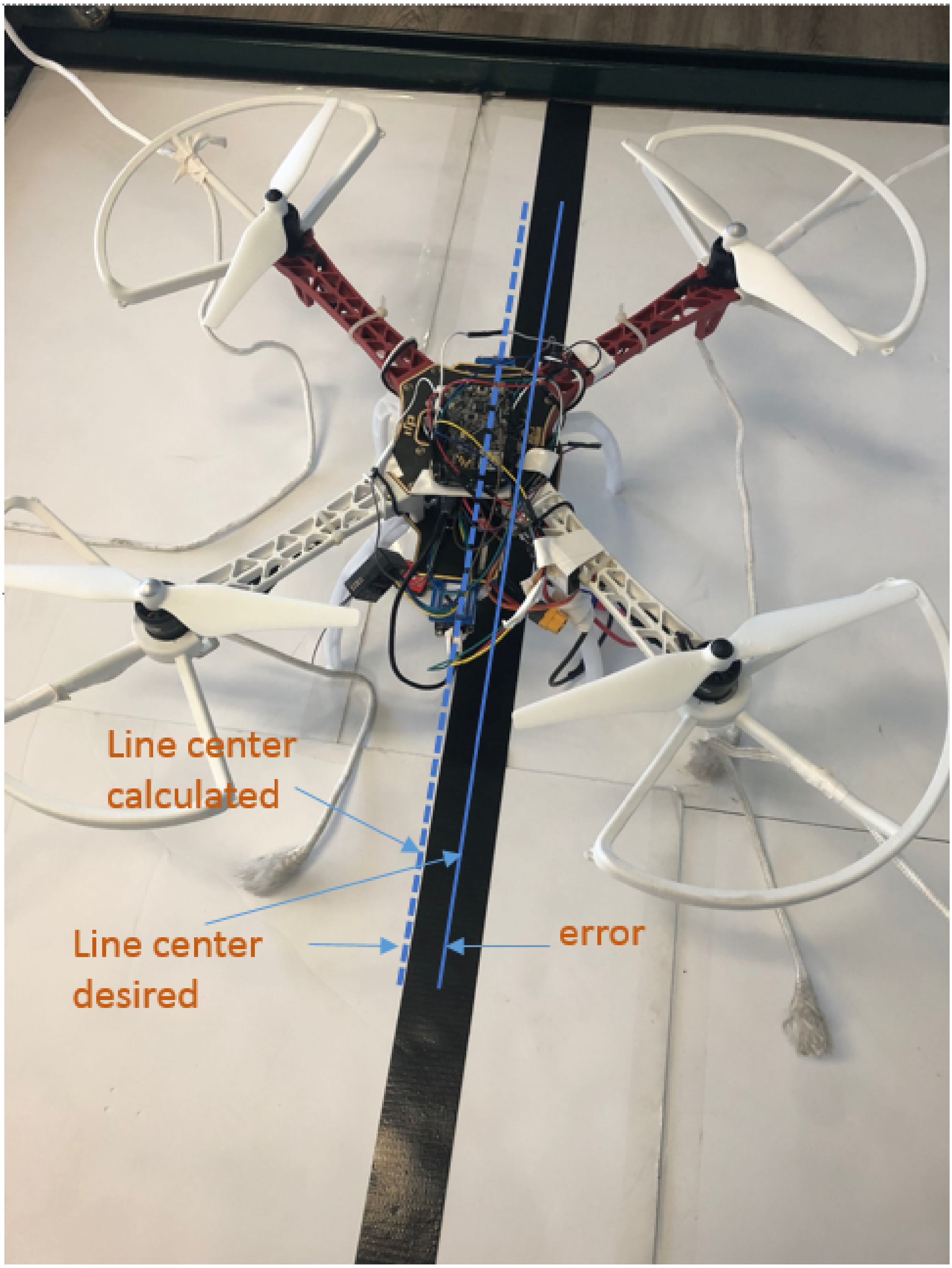


Figure 40: Error calculation for the yaw and roll control

and also to increase the integration time of the camera. Various Tests and tuning of the camera had to be done to get the good analog signal out from the camera. Tuning of the threshold voltage value set was done to get a good digital output from the camera which would make it easier to detect the line center.

- **Altitude of the quad-copter from ground** : As the altitude of quad-copter increases, the amplitude values of analog signal changes and this provides defective digital output in some cases. This happens because the focus of the camera is not auto-adjustable, which made it difficult for me to get the desired output and created problems in the stability of the drone.

- **Low-cost platform** : The other problem which added to the complexity was the stability issues of the DJI DRONE. The flight controller had stability issues and was not stable in even in manual mode and provided drift and back-thrust issues even when controlled using a controller. At lower altitudes the DJI drone made it impossible for me to keep the drone stable, which made it difficult to sense the line.

In order to overcome these issues of instability and line sensing, I decided to go with another stabilization technique which was altitude control technique. This technique was followed in order to stabilize the drone and hold the altitude of the drone at the desired height.

7.2.4 Altitude control

In the experiment, the altitude control test was implemented using down facing ultrasonic sensors connected to the four arms of the quadcopter. The algorithm created was for the standard proportional-integral-derivative controller. The freedom board continuously gathers the distance values from the array of ultrasonic sensors. Initially, the test was done on the breadboard by interfacing the components on the breadboard. The ultrasonic sensors were connected to the freedom board with the use of multiplexer and decoder. The sensors were selected sequentially using multiplexer and the echo signal from each sensor is then stored in a variable in freedom board. The values are then averaged to get a specific distance value. Once the value is calculated it is then compared to the threshold altitude level set.If the distance value is not between the desired value, then the duty cycle of the PWM signal is varied which will maneuver the quadcopter and would stabilize the altitude based on the PID controller designed.

The tests were done for the measurement of distance values using a breadboard.The value of the distance from each of the array of sensors can be seen in the TeraTerm window. The values are then averaged in order to get a gradual change in distance values. The figure 41(a) shows the setup and figure 41(b) the distance values from all the sensors on TeraTerm.

Figure 42 shows the trigger signal provided to the MUX and the output through the final echo signal. The trigger signal is of 10 microseconds whereas the output echo signal is approximately equal to 756 microseconds. The echo output varies based on the distance of the sensor from the obstacle. The minimum distance the sensors can sense is about 3 cm. The multiplexer switches the signal based on the input and the echo signal from that particular sensor is provided to the freedom board.

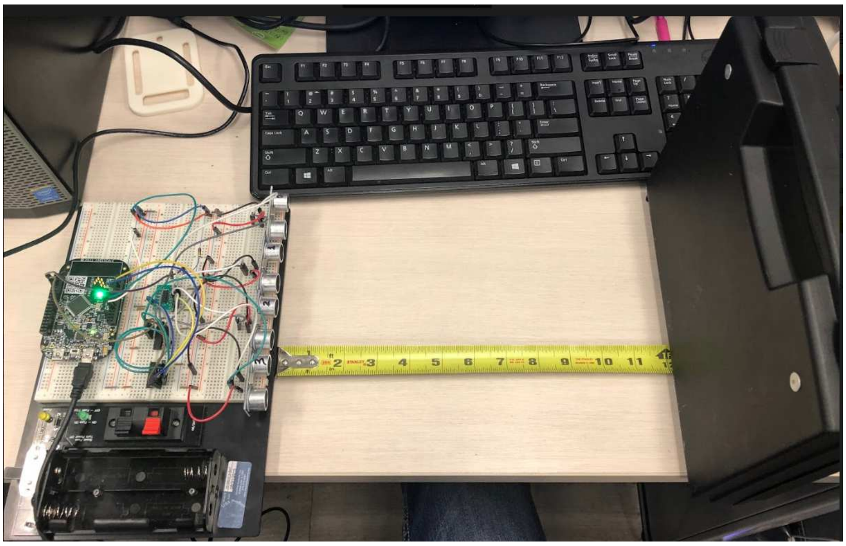
In the experiment, altitude control is achieved using a standard PID controller using the down-pointed ultrasonic sensors. In order to enable an automatic take-off the set-point of the controller is increased gradually until the height is equal to one meter. Similarly, automatic landing is achieved by gradually decreasing the height set-point until the platform is on the ground. The platform takes-off slowly then proceeds to a stable hover at the set-point of 30 cm. After hovering for 15 seconds the system comes down slowly and lands. The test was done for various conditions and heights. The mean altitude during the stable flight was approximately equal to 20 cm with a minimum deviation of 30 mm. The quadcopter hovering with the ultrasonic mechanism and the PID control is shown in figure 43.

The output of the ultrasonic sensors at different heights is shown in figure 44. At an altitude of 30 cm from the ground, the quadcopter hovers and is stable as shown in figure 44(a). The maximum deviation from the setpoint is approximately equal to 2cm. This problem exists due to the delay issues of the ultrasonic sensors. As seen in figure 44(b) we can see that at the lower altitude, that is very close to the surface, the altitude stability is not as stable as that of 30cm. This is also due to the back-thrust issues created by the quadcopter, which adds to the complexity created due to the ultrasonic sensor delay. The deviation from the set-point for this altitude is approximately equal to 5cm.

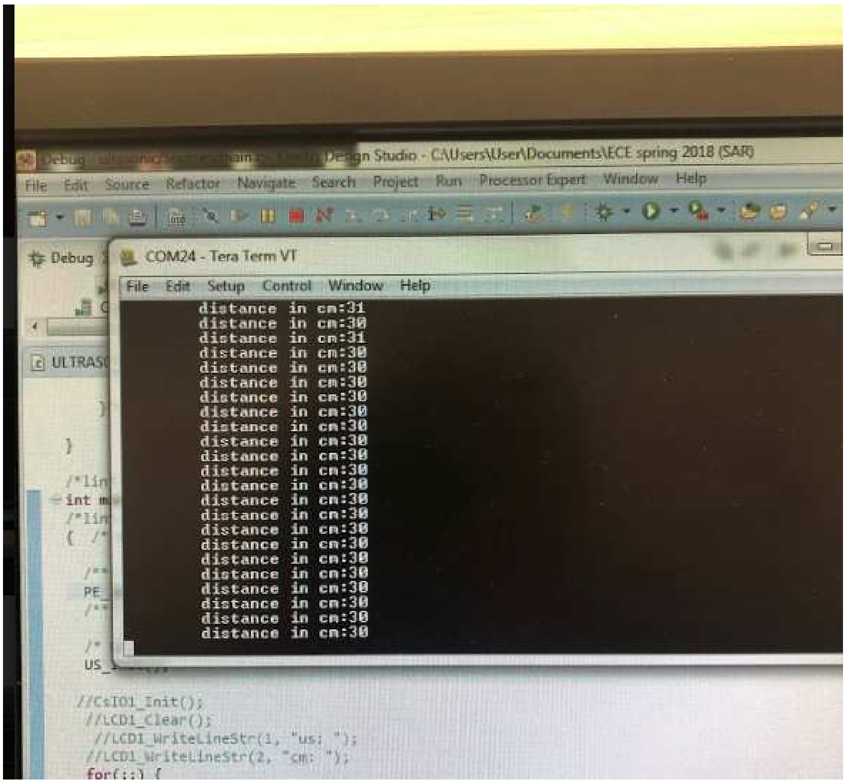
- The only problem with the stability of the drone was due to the delay in the system. The total delay as calculated due to ultrasonic sensors was approximately equal to 1.8 ms.This delay was created due to the delay of 0.45 ms between the trigger and capture of the echo signal.
- Also due to the vibration of the quad-copter at lower altitudes and due to the back-thrust issues, the disturbance in the drone created some disturbance in the hovering.

The solution to these problems would be to use

- Low-cost and efficient 2D LIDAR sensors instead of ultrasonic sensors to reduce the delay problem created due to the ultrasonic sensors. The 2D LIDAR is more robust and works on light instead of the ultrasound signal.Therefore the system would be really faster and would react immediately to the changes.



(a) Setup for calculating the distance (includes Ultrasonic sensors connected to freedom board)



(b) Result of the sensors on TeraTerm

Figure 41: Altitude control

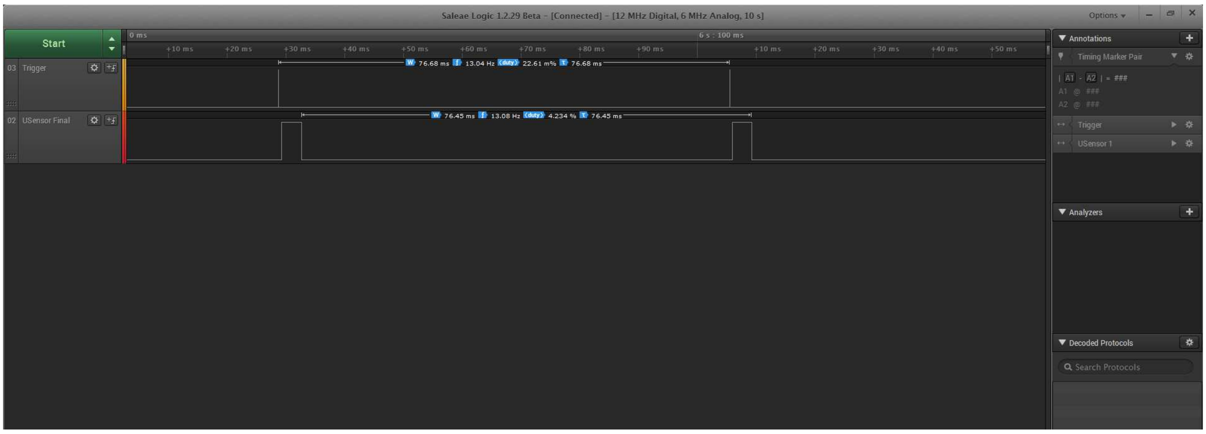


Figure 42: Trigger and output of the final echo signal

- We also need to use drones with less stability issues and an open source flight controller with good inertial sensors and less back-thrust issues.

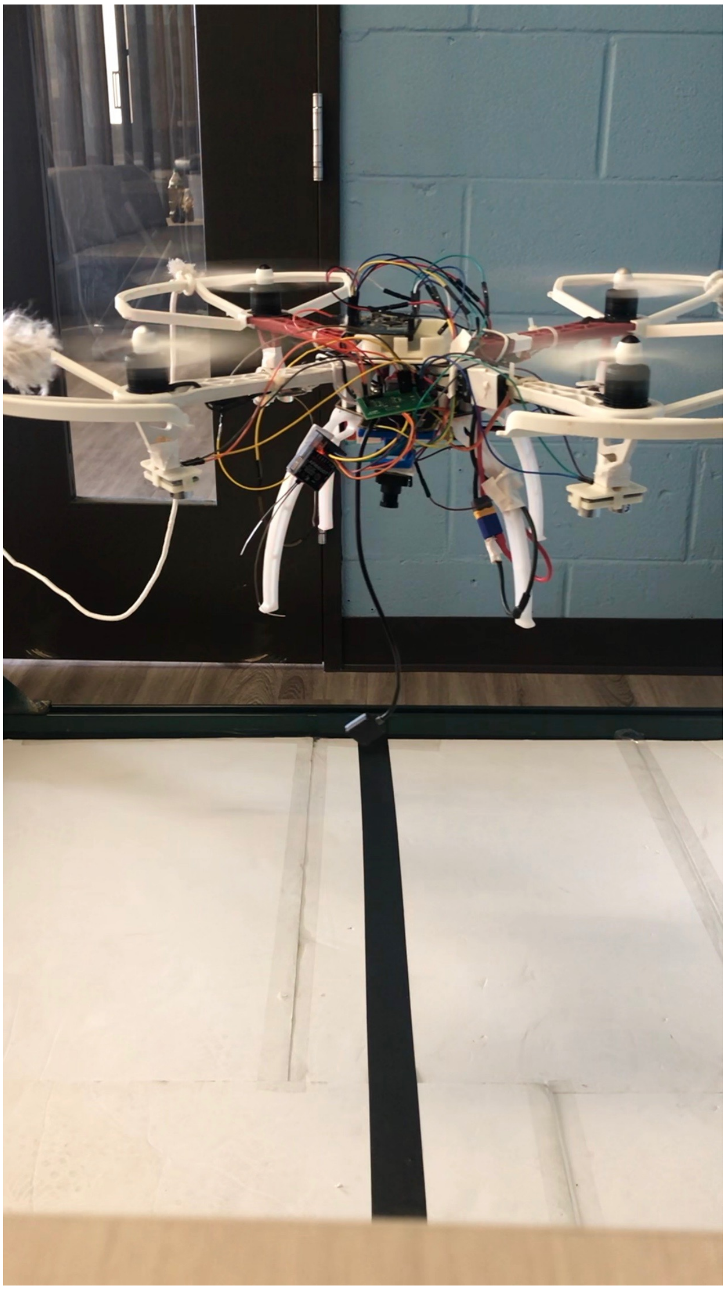
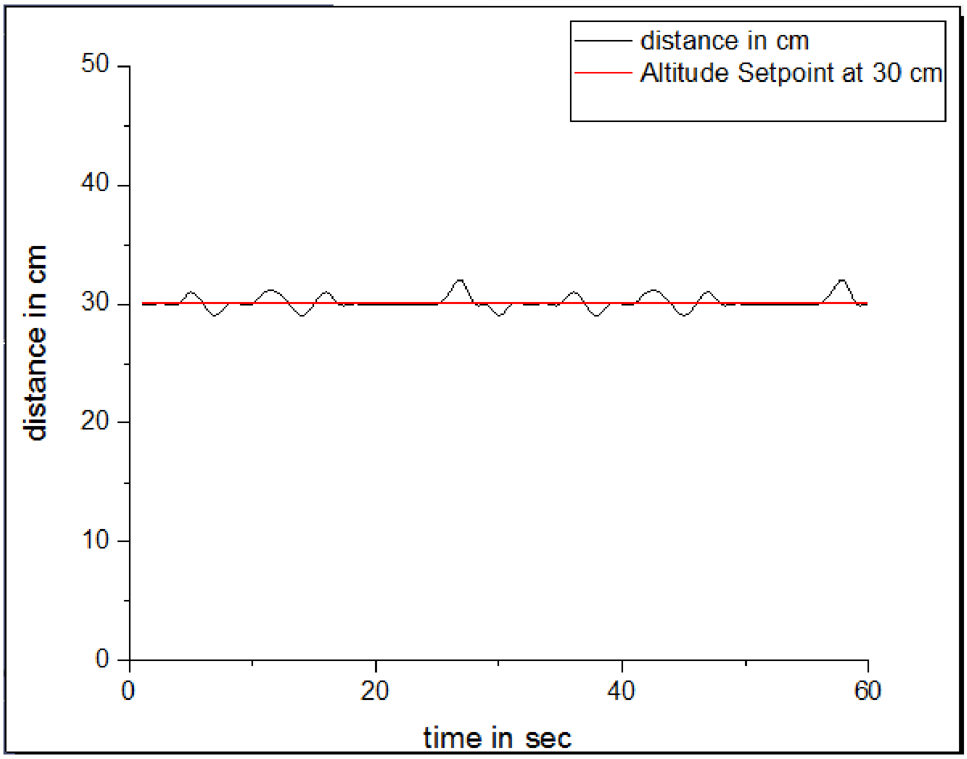
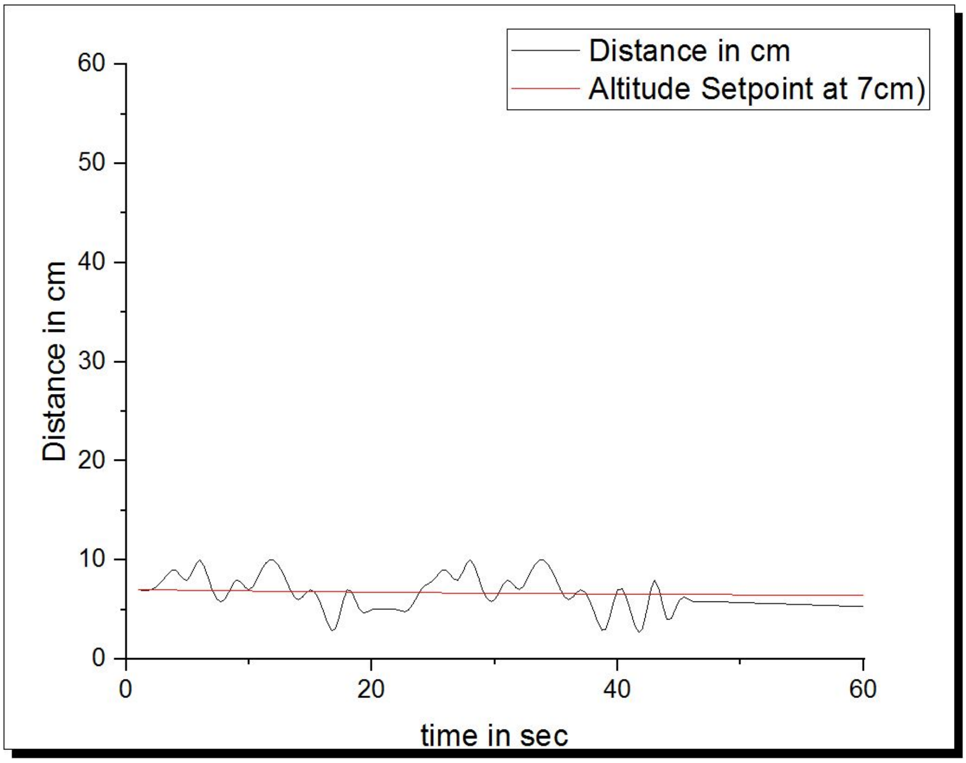


Figure 43: Altitude Control mechanism



(a) Ultrasonic data for Altitude setpoint at 30cm



(b) Ultrasonic data for Altitude setpoint at 7cm

Figure 44: Results of quadcopter for varying altitude setpoints

CHAPTER 8

FUTURE SCOPE

This chapter discusses a few possible extensions of our work and also reviews related open problems.

Throughout my thesis, we introduced a general low-cost platform for the educational purpose which should be simple to use, safe, easy to implement with minimal need of any prerequisites and should use a low-power platform. The System was designed considering all these conditions, but to make the system stable, I have considered some future changes that can be implemented in order to achieve the desired goal.

Some of them would be:

- Instead of using a low-cost active control technique for the hovering mechanism, which created some hardware issues previously, a passive hovering mechanism could be implemented. This mechanism would require a small drone with small propellers so that it will be easier to test the system and try the hovering mechanism on a pre-constructed track. The construction of the track would also require some structural changes so that we can use the track as the base to make the drone hover using the differential pressure and thrust.
- Use of more robust and efficient proximity sensors like 2D LIDAR sensors. The delay issues of ultrasonic sensors can be reduced using the 2D LIDAR sensors which work on light instead of ultrasound and hence have faster working as compared to ultrasonic. The delay issues will be

reduced and also the number of sensors needed will be reduced. Only one sensor can be used to scan the ground surface and detect the altitude of the quadcopter.

- Use of high-quality cameras such as the Raspberry Pi camera module and also an efficient and a good microprocessor such as Raspberry Pi, which has the higher processing power and uses approximately 700 MHz processor as compared to FRDM KL25Z which uses 48 MHz processor.
- Using Open Source Flight controller so as to use a software solution based on open standards. Open-source flight controllers provide some great features like point and click programming configuration for advanced functionality, multiple command modes and also the configuration of fail-safe programming options. Open source also provides you with the functionality to get the data from the inertial sensors and log the data accordingly.

CHAPTER 9

CONCLUSION

The main goal of this thesis was to develop a Low-cost Autonomous line following quad-copter using a low-cost line sensing camera and PID control algorithm for educational purpose. The objective was to utilize existing modeling techniques to design and implement a control system for line following quadcopter. Batteries and motors were tested and made operational after generating PWM from the Microcontroller Unit. Calibration of ESCs and motors was done in order to create a stable flight. Moreover a communication between flight controller and micro-controller was achieved and a control algorithm was created to get the desired stability of the drone. Various issues were faced in the implementation of the line following system due to altitude instability of the quadcopter, back-thrust and drift issues of the system. So as to make the altitude of the drone stable and improve the analog camera output provided to the micro-controller, an altitude control technique was implemented using ultrasonic sensors and a PID control algorithm was considered to stabilize the system in the vertical direction. The performance of the drone was improved by using this technique and manual tuning of the gains on the flight controller.

CITED LITERATURE

[Aguilar et al. , 2017] Aguilar, W., Casaliglla, V., and Polit, J.: Obstacle avoidance for low-cost uavs. In IEEE 11th Int Conference on Semantic Computing, ICSC 2017, 2017.

[Ahmed et al. , 2016] Ahmed, A. H., Ouda, A. N., Kamel, A. M., and Elhalwagy, Y. Z.: Attitude stabilization and altitude control of quadrotor. In 2016 12th International Computer Engineering Conference (ICENCO), pages 123–130, Dec 2016.

[ARM,] ARM: Arm based freedom kl25z.

[Bora and Erdinç, 2007] Bora, E. and Erdinç, A.: Modeling and pd control of a quadrotor vtol vehicle. In 2007 IEEE Intelligent Vehicles Symposium 2007, June 2007.

[Claudio Vianna Junior et al. , 2013] Claudio Vianna Junior, J., Cesar De Paula, J., Leandro, G., and Bonfim, M.: Stability control of a quad-rotor using a pid controller. Brazilian Journal of Instrumentation and Control, 1:15, 10 2013.

[contributors, 2019] contributors, W.: Helicopter rotor, 05 2019.

[DJI, 2013] DJI: Naza- m lite quick start guide, 2013.

[DJI, 2015a] DJI: Dji e305 tuned propulsion system, 2015.

[DJI, 2015b] DJI: Dji f450 430 lite esc's, 2015.

[Felipe et al. , 2003] Felipe, B., Paul, S., Jayant, S., Darryll, P., Lael, R., and Ron, P.: Design, analysis and hover performance of a rotary wing micro air vehicle. In Journal of the American Helicopter Society, volume 48, pages 80–90, 2003.

[Freaks, 2010] Freaks, E.: Ultrasonic ranging module hcsr04, 2010.

[Gabriel et al. , 2007] Gabriel, M, H., Haomiao, H., Steven, L, W., and Claire, J, T.: Quadrotor helicopter flight dynamics and control: Theory and experiment. In AIAA Guidance, Navigation and Control Conference and Exhibit, pages 2007–6461, August 2007.

[Gupte et al. , 2012] Gupte, S., Mohandas, P., and Conrad, J.: A survey of quadrotor unmanned aerial vehicles. In Southeastcon, 2012 Proceedings of IEEE, pages 1–6, 2012.

[Kada and Ghazzawi, 2011] Kada, B. and Ghazzawi, Y.: Robust pid controller design for an uav flight control system. In The World Congress on Engineering and Computer Science (WCECS) 2011, volume 2, October 2011.

[Kinetis, 2019] Kinetis: Kinetis® design studio integrated development environment (ide), 2019.

[Krossblade, 2019] Krossblade: History of quadcopters and multirotors, 2019.

[Markus et al. , 2009] Markus, A., Zhang, T., Kolja, K., and Martin, B.: Visual tracking and control of a quadcopter using a stereo camera system and inertial sensors. In 2009 IEEE International Conference on Mechatronics and Automation, page 2863–2869, Aug 2009.

[Metni et al. , 2005] Metni, N., Hamel, T., and Derkx, F.: Visual tracking control of aerial robotic systems with adaptive depth estimation. In Proceedings of the 44th IEEE Conference on Decision and Control, pages 6078–6084, Dec 2005.

[Mohamad et al. , 2015] Mohamad, Taib, M., Ahmad, Shahran, I., Zairi, Ismael, R., and Nuraiza, I.: Steering control method based on tsl1401 linear sensor array. ARPN Journal of Engineering and Applied Sciences, 10, 01 2015.

[NAZA-M, 2013] NAZA-M: Naza-m lite flight controller board, 2013.

[Polulu, 2011] Polulu: Servo control interface in detail), 2011.

[Prathamesh et al. , 2014] Prathamesh, S., Saee, P., Jagdish, R., and Arish, S.: Quadcopter – obstacle detection and collision avoidance. International Journal of Engineering Trends and Technology (IJETT), 17(2):84–87, Nov 2014.

[Samir et al. , 2004] Samir, B., Pierpaolo, M., and Roland, S.: Design and control of an indoor micro quadrotor. In 2004 IEEE International Conference on Robotics and Automation (ICRA 04), New Orleans, LA, volume 5, pages 4393–4398, April 2004.

[Sefidgari, 2013] Sefidgari, B, L.: Feed-back method based on image processing for detecting human body via flying robot. In International Journal of Artificial Intelligence and Applications(IJAIA), volume 3, 2013.

[Susilo et al. , 2014] Susilo, Adi, W., Achmad, W., and Yuni, Awan, W.: Auto level control systems of v-tail quadcopter. In International Journal of Latest Research in Science and Technology, volume 3, pages 1–6, May 2014.

[Syed and Wail, 2010] Syed, Ali, R. and Wail, G.: Intelligent flight control of an autonomous quadrotor, motion control. 01 2010.

[TAOS, 2011] TAOS: Tsl1401cl 128x1 linear sensor array with hold, 2011.

[Timothy et al. , 2005] Timothy, G, M., Raja, S., and Karl, H.: Obstacle detection for small autonomous aircraft using sky segmentation. In 2005 IEEE International Conference on Robotics and Automation, April 2005.

[TSL, 2016] TSL: Tsl1401cl linear sensor array with hold, 2016.

[Wei et al. , 2006] Wei, W., Gang, S., Kenzou, N., Mitsuo, H., and Osamu, M.: Autonomous control for micro-flying robot and small wireless helicopter x.r.b. In 2006 IEEE/RSJ International Conference on Intelligent Robots and Systems, Oct 2006.

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