LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
LUT School of Energy Systems
LUT Mechanical Engineering

Syed Azad Chowdhery

QUADCOPTER ASSISTANT FOR A MOBILE ASSEMBLY ROBOT

Examiners: Professor Heikki Handroos
D.Sc. Lauri Luostarinen

ABSTRACT

Lappeenranta University of Technology
LUT School of Energy Systems
LUT Mechanical Engineering

Syed Azad Chowdhery

Quadcopter assistant for a mobile assembly robot

Master's thesis

2015

63 pages, 40 figures, 8 tables, 2 graphs and 1 pie chart

Examiners: Professor Heikki Handroos.
D.Sc. Lauri Luostarinen.

Keywords: Quadcopter, accurate landing, automatic charging station, microcontrollers.

Science has revolutionized the human life. The advance progress in science and research is making human life easier and more comfortable. The new and emerging technology of micro drone is penetrating and widening the scientific research. This thesis is a part of work in which a unique work is carried out, although related research paper and journal are available. Design and development of automatic charging station for a ready to fly quadcopter is rare and unusual work. The work is carried out as an standard engineering process that include requirements gathering, creating the required document (this thesis is a part of required document as well), selection of suitable hardware, configuring the hardware, generate the code for software, uploading code to the microcontroller, troubleshooting and rectification, finalized prototype and testing. Thesis describe how mechatronics engineering is useful in generating a customized and unique project. At the starting phase of this project (before purchasing a ready to fly quadcopter) every single aspect of this work was known. The only unknown alternatives was a battery and charger. Several task was achieved including design and development of automatic charging station, accurate landing and telecast a live video on additional screen. At starting it was decided that quadcopter should follow the mobile robot, during study it was concluded there is no such quadcopter available in market to auto follow a robot indoor.

This works starts with a market survey and comparing the different brands of quadcopter that meets all the requirements and specifications of the mobile robot assembly. Selection of quadcopter is a result of discussion and meeting with the team members, supervisor, professor and project manage.

ACKNOWLEDGMENTS

This project was carried out under the support of laboratory of intelligent machine at LUT. I would like to serve my thanks to, Professor Heikki Handroos for providing me this great opportunity as a paid thesis work, thesis supervisor Lauri Luostarinen (D.Sc.), Juha Koivisto (laboratory technician) and Hamid Roozbahani (project manager), who provided me opportunity to take part in the research and development of this work. My honest anticipation with the member of mobile robot assembly team, including Samrat, Sameer, Andres, Weiting who work in a determined way and support me through their knowledge and information regarding their own topic. This work is part of group work so every individual, worked on this project need to be considered to accept my gratitude and thanks.

Syed Azad Chowdhery

Lappeenranta University of Technology, 8th of November 2015.

TABLE OF CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

mAh	Milli-Ampere-Hours
NO	Normally Open
NC	Normally Connected
V_{out}	Output Voltage
V_{in}	Input Voltage
Wh	Watt-Hours
AAV	Autonomous Aerial Vehicle
BL-DC	Brushless Direct Current
DC	Direct Current
ESC	Electronic Speed Controller
EASA	European Aviation Safety Agency
FPV	First Person View
FPS	Frame per Second
GPS	Global Positioning System
HDMI	High Definition Multimedia Interface
HD	High Definition
ISR	Intelligence, Surveillance, Reconnaissance
ICAO	International Civil Aviation Organization
IMU	Inertial Measurement Unit
LiPo	Lithium Polymer
LiDAR	Light Detection and Ranging
MAV	Micro Aerial Vehicle
PaRS	Photogrammetry and Remote Sensing
PVDF	Polyvinyl dine fluoride
PCB	Printed Circuit Board
ROA	Remotely Operated Aircraft

RPV	Remotely Piloted Vehicle
RPAS	Remotely Piloted Aircraft System
RPA	Remotely Piloted Aircraft
SLAM	Simultaneous Localization and Mapping
UAV	Unmanned Air Vehicle
UAV^x	Uninhabited Aerial Vehicle
UDP	User Datagram Protocol

1 INTRODUCTION

The UAV (unmanned air vehicle) is known with different names that are categorized according the function, size and weight. UAV[X] (Uninhabited aerial vehicle), ROA (remotely operated aircraft), RPV (remotely piloted vehicle), AAV (autonomous aerial vehicle), MAV (micro aerial vehicle) are some of the names given to Quadcopter. One of the common name given to quadcopter is UAV. However, drone is the general term used for all unmanned aerial vehicles and the basic difference between the terms "Drone" and "Quadcopter" is one of characterization. (Norris, 2014, pp. 25-33.) An air craft with ability of hovering is termed as drone (Freeman & Freeland, 2015; Boucher, 2014). For the simplicity of work the word "Quadcopter" is used in this thesis.

Quadcopter belongs to a particular group of drones with four motors (brushless DC (Direct current) motor) that make lift for vertical take-off through their propellers. The quadcopter Inspire 1 is used in this research work, which is shown in below figure (see the figure 1). There are two possible combination (+ and x) for all quadcopter as shown in figure (see the figure 2). According to figure (see the figure 2), Inspire 1 falls under the category x configuration. Two clockwise and two counterclockwise motors rotate in order to cancel the effect of torque. (Norris, 2014, p. 37.)

Figure 1. DJI Inspire 1 Quadcopter (DJI, 2015).

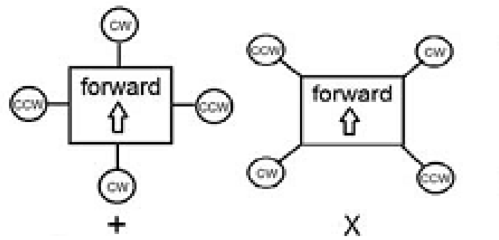


Figure 2. Configuration of Quadcopters (Norris, 2014, p. 37).

.

Researches are carried out in the field of quadcopter for the efficient use in practical life. Research includes both at academic (robotics and controls research) and industrial or commercial level. While working on this project, the internet is surveyed for the selection of suitable quadcopter, and it was concluded that quadcopter has growing market. (Norris, 2014.) Companies are providing quadcopters and each company have their unique feature and technology (Gupta, Jha & Kumar, 2014, p. 15).

1.1 Background of the work

The work is carried out in Laboratory of intelligent machines at LUT (Lappeenranta University of Technology). Several quadcopters are taken under consideration for the best option. Inspire 1 from DJI product (Chinese company product) is chosen after comparing with different quadcopters in the market. The scope of the work related to this project is based on the mobile robot project. In this project the quadcopter becomes the peripheral part of mobile robot. The quadcopter is supposed to assist the mobile robot by providing a live video streaming. When the quadcopter is discharged, it lands on the robot's platform to get an automatic charging process and fly again for assisting the robot. Inspire-1 quadcopter is a ready to fly quadcopter manufactured by DJI. For charging process, the battery should be retrieved from quadcopter and should be charged separately. Inspire-1 comes with two batteries and each battery has the capability of twenty two minutes of flight time. Inspire-1 comes with two transmitter or remote controller. Master controller is set to control the movements (pitch roll and yaw) of the quadcopter, while the slave controller is set for controlling the camera and gimbal. Remote controllers are equipped with a smart tablet for FPV (first person view). The controller telecast the FPV to the monitor through HDMI (High definition multimedia interface) in the control room of the mobile robot. Therefore, selection of suitable quadcopter and development of automatic charging station is the core purpose of this research work.

1.2 Requirements and limitations of the work

The top-tier goal for the project was to achieve completely autonomous take-off, accurate landing, live video streaming, development of automatic charging station and follow the mobile robot indoor without GPS (Global positioning system). These requirements are given in table (see table 1), these requirements and limitations are totally based on the discussion and meeting with the team of mobile robot project. Following list provide the requirement and limitation of the work.

Table 1. Requirement and Limitation of the work.

S.No	**Requirement and Limitation**	**Achievement**
1	Size of drone should not be more than 50 cm	The Quadcopter size is under 50cm
2	Automatic take off	Auto take off option available
4	Indoor follow me	Unachieved
5	Automatic charging	Auto charging developed
6	Camera rotation and tilt	Camera can rotate and tilt
8	HD (high definition) online streaming	HD steaming possible
9	Cost should not be more than 4,000 Euros	Cost is under required limit
10	Complicated turn off/on system of battery	This problem has been solved
11	Landing zone should be accurate	Accurate landing zone can be achieved by manual landing
12	Battery changing process involve human operation	Auto charging station developed

So far, automatic charging station, automatic take off and selection of suitable quadcopter for this work are the goals, which have been achieved in this work. Auto landing on the mobile robot platform, auto follow indoor are the goals that are not achieved due to time constraint and quadcopter’s closed loop system.

Size, cost, camera pan and tilt option, auto take off and auto landing are the main constraint in selection of the suitable quadcopter for this project. The complicated turning on/off process of power button of battery is the main problem in creating an automatic charging process because, the battery should not be charged while the battery is in on condition. Three solutions are proposed to solve the problem of power button while only one is selected and practically applied after finding and comparing the best alternatives among these three options. Three alternatives are as follows.

1 Remove the Main PCB circuit from Batter: The PCB (Printed circuit board) circuit from the battery can be removed and connects the positive and negative terminal of the battery to the charging platform. The removal of PCB circuit causes loss of information from the quadcopter to the remote controller. The PCB circuit transfer battery information to the controller. If circuit is removed, several flights information from the quadcopter that are transmitting through the battery are lost. The battery transfers the following information to the controller.

- Battery level to the controller.
- Total flight time remain.
- Battery discharge rate.
- Charging and discharging status during charging process.

2 Using actuators for on/off operation on battery: Actuators are mechanical; this actuator must be placed at the top of the battery’s switch to perform the function of On/Off. These actuators need to be connected to the micro controller to send the command and signal, however, these function can be achieved using relay, that’s was the main reason that this option was not considered.

3 Using Micro controllers, relay and contact switches: This option was selected for developing an automatic charging station for Inspire 1. The detail about this option is discussed in the later part of this work in Chapter 6.

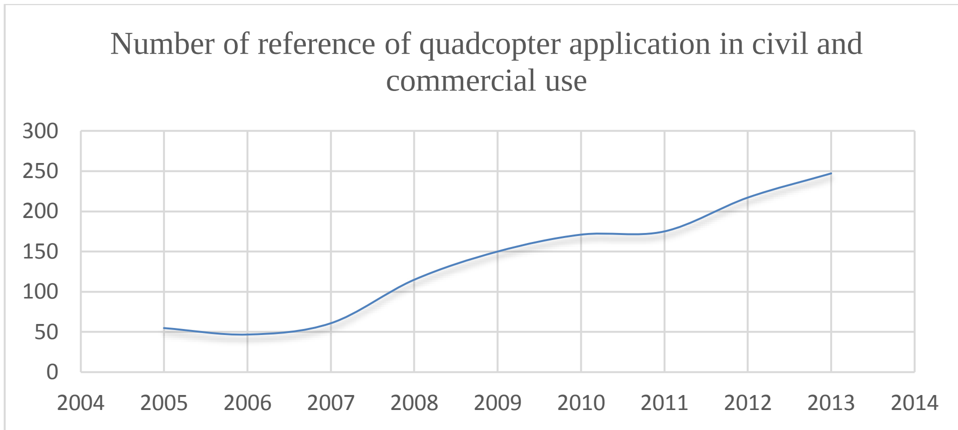
1.3 Applications of Quadcopters

The use of quadcopter has been drastically increased in the recent year and the quadcopter application seems continuously to grow in the near future. The reason behind the growth is; huge amount of research are carried out in the control, mechatronics and automation at both industrial and academic level. (Colomina & Molina, 2014.)

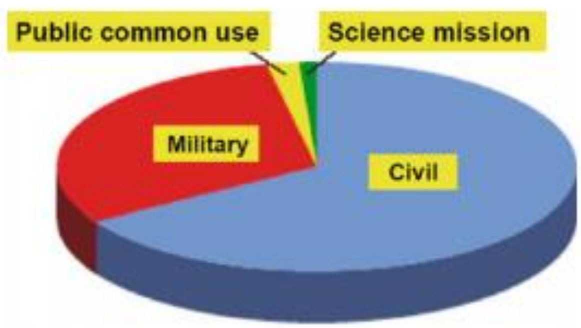
Some of the applications are:

- Law enforcement
- Security patrols on private property
- Agricultural surveying
- Communications relay
- Incident command support
- Aerial mapping
- Aerial photography
- Severe weather telemetry
- University research projects
- Search and rescue operation

Quadcopter has wide range of benefits at military and civilian level. The below graph (see graph 1) summarize how the number of quadcopter reference has been increasing from the year of 2005 to 2013. There are several uses and applications of quadcopters that still need to be developed in the near future. (Colomina & Molina, 2014.) Pie chart 1 illustrate the several usages of UAV, beside military usage the quadcopters are used in these following areas, while some of them are discussed in detail (Nonami, 2010, p. 21).



Graph 1. Number of reference of quadcopter applications in civil and commercial use (mod. Colomina & Molina, 2014, p. 3/19).



Pie chart 1. Several usages of UAV (Nonami, 2010, p. 22/348).

1.3.1 Social

Using quadcopter, in sports, that has the capability to follow the desired target at a certain distance has become a common practice. A quadcopter named Lily can maintain the distance from the user from 1.75 meter to 30 meter maximum. Sportsmen use this technology while recording their activities, and to closely look, if something mishap happened. Only one camera (Quadcopter) is used instead of using multiple cameras. Auto follow option making it easy and cost effective to use just one quadcopter (camera) instead of using multiple camera at multiple sites. That saves time, cost and extra labor. (Lily, 2015.)

Beside sports purpose, quadcopter are widely used in construction industries for measuring the area of the sites, to determine uneven surface, and for three dimensional (3D) volumetric analysis. Quadcopter are becoming a compulsory tools for the constructions work. (Precision, 2015.)

On March 2011, a nuclear power plant in Japan was under the tidal wave attack, the condition of the entire location was contaminated with radiation, and quadcopters were used to survey the situation of the entire scenario above the ground, sending many information like radiation percentage, temperature and live videos. (Shah, Dutt & Modh, 2014.)

1.3.2 Agriculture

Human have been always looking for the easiest and the most efficient way to carry out difficult and tedious job. The advanced technology and involvement of sensor and controller in the robotic quadcopter are enabling the use of quadcopters in the field of agriculture for crop surveillance. Infrared camera and sensor based quadcopter are being used to survey over the crop field to observe the real time quality of crops and their leaves. Using image processing, the field is surveyed and goods are transported to the desired location; that save extra movement of human being and provide fast way of looking after the crops. It also provide warning of different temperature zone in the field. Industries are building special quadcopter that are intended to operate only on crop fields. (Patel et al., 2013.) In Japan, quadcopters are considered to be an integral part of farm equipment (Li, Shan & Gong, 2009, p. 38). These two figures (see the figure 3 and figure 4) show the quality of bad and good crops by analyzing the quality of image.

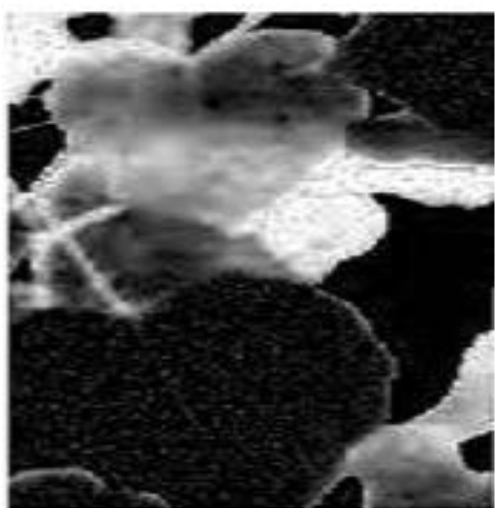


Figure 3. Processed Image of bad crop (Patel et al., 2013)**.**

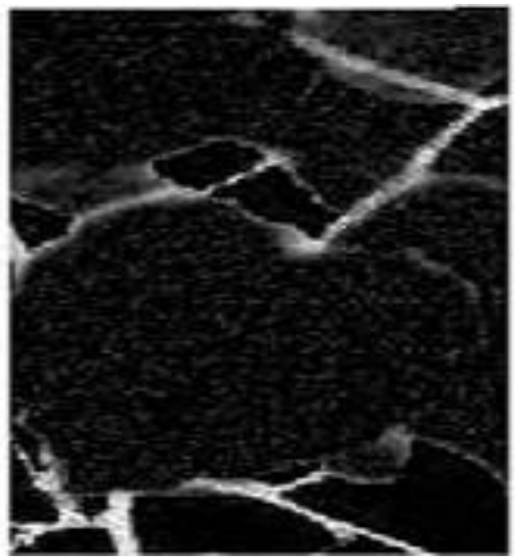


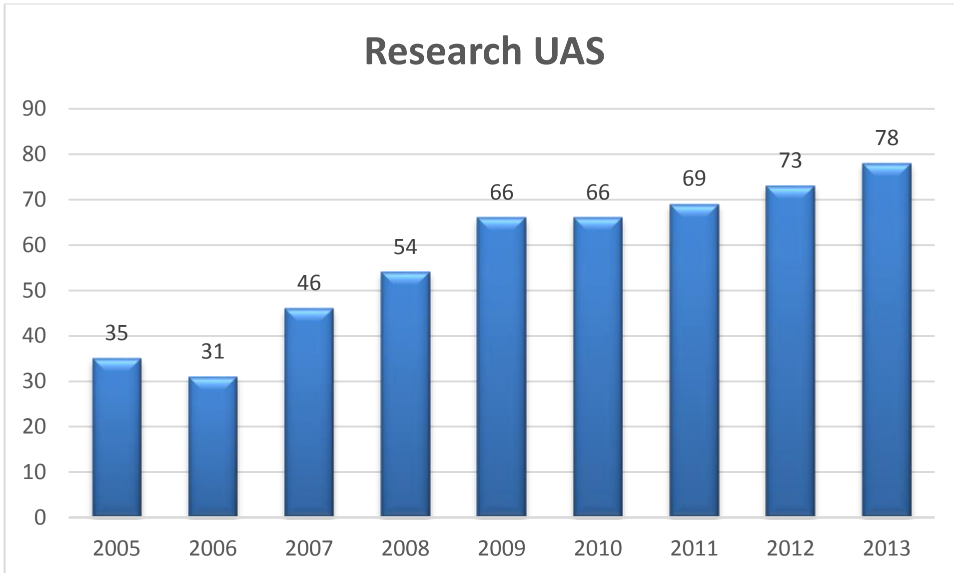
Figure 4. Processed Image of good crop (Patel et al., 2013).

1.3.4 Military

Quadcopter are used as distant weapon without using human interaction. The first use of drone in the military as weapon was in 1930 during the World War I. There are 49 countries involved in the research work for the development of quadcopter for military purpose. (Wang, Wu & Li, 2011, p. 37.) In military quadcopters are usually used for monitoring, ISR (intelligence, surveillance, reconnaissance) and inspection in critical and dangerous location. Due to the sound of the moving propeller and light weight, use of quadcopters are still avoided by the military application. However, future research will bring some window to use the quadcopter for the military use. (Nonami, 2010, p. 22.)

1.3.5 Research

In 2004 PaRS (Photogrammetry and Remote Sensing) conference, first research paper related to UAS was presented, that was held in Istanbul. In 2008, 21 research paper related to the UAS was presented in Beijing. In 2012 in International Society for Photogrammetry and Remote Sensing (ISPRS) nine session for UAS was presented. Numerous research have been made on quadcopter by overall analysts worldwide. Impact of UAS can be observed when important conference are including paper, journals and research work in their own domain The below graph (see graph 2) summarize how the number of quadcopter reference has been increasing from the year of 2005 to 2013 for research purpose. (Colomina & Molina, 2014.)



Graph 2. Research on UAS (Mod, Colomina & Molina, 2014).

1.4 International and local laws for Drone.

The international laws for the drone are made in a UN organization, the ICAO (International Civil Aviation Organization), headquarter is located in Montreal. ICAO is concerned with the safety issues of drone throughout the world The section of the law set by ICAO stated in 1.1 is that Authorization and permission is needed from the state's aviation authorities to fly a remotely piloted aircraft (RPA), for example, if the aircraft is flying from the one state to other then authorization is needed from the host country. (Clarke & Moses, 2014, p. 272.)

So according to this section the individual Laws are made to operate the drone with in a specific country and region and local laws should be followed for drone operation. ICAO is still unable to include all the constraint and limitation of using UAV, many countries has not yet developed the regional laws for using UAV because they are looking forward towards ICAO to develop a complete set of laws that can easily be adopted and implemented to their own aviation rules. (Clarke & Moses, 2014, p. 272.) Some research companies are helping in the development of the Laws for quadcopter by providing their inputs to air traffic authorities, these companies also want to develop certified and authorized UAS to launch their product in the market (Colomina & Molina, 2014).

1.4.1 European Aviation Safety Agency

The EASA (European Aviation Safety Agency) set the rules and regulation for the Drones within the Europe, the rules are set according to the weight of the drone, for example, the drone exceeding the weight of 150Kg are treated as commercial drone, EASA categorized the drone in three categories according to weight distributions. (EASA, 2015.)

1. Above 150Kg
2. Between 20kg to 150kg
3. Below 20kg

According to the above the list, category one and two are eliminated, only option three is taken under consideration. The weight of quadcopter used in this work is around 4Kg approximately. Therefore, only third category law is considered. The aircraft below 20 Kg does not need to be licensed. Finnish legislation concerning the UAV are controlled by Finnish Transport Safety Agency is Trafi. The laws obeys all the sections of EASA with further modification that vary from region to region. (EASA, 2015.)

Following are the main points the consideration of the point is only important for the outdoor flight.

- UAV should be less than 20Kg (exceeding 20Kg will need a license, this law also obey EASA and ICAO).
- The altitude of the flying drone is limited to 150 Meters (This is set according to the region and not mentioned in EASA and ICAO).
- The maximum possible distance of operating area is 500 meter.
- The weather should be appropriate (rainy and snow weather are not considered as favorable along with high speed of wind, however the speed limit of the wind is not set because it highly depend on the UAV weight as well).
- Should not make a flight near airport zone.

- The aircraft should be controlled and seen by the controller throughout the flight operation and should not be leave unattended at any point and the age of the pilot (the person operated the controller) should be minimum 18 years old.
- The aircraft should not be operated in dense populated area and the distance between the populated area and the aircraft should be kept 150 meters at least.

(Linko, 2014.)

The above points are based on the Bachelor thesis of Aalto University; an email based conversations between the writer and Trafi as the writer emailed the Trafi to inquire about limitations of flying. As there is no such published law is available in Finland to operate quadcopter because it highly depends on the weight and type of quadcopter. (Linko, 2014, pp. 11-13.) Since, Inspire is intended to operate indoor where human entrance into the room is restricted therefore, these laws are not considered very deeply in this research work. Flying in highly populated area would be totally different as flying the quadcopter indoor.

2 COMPONENTS OF QUADCOPTERS

Quadcopters have variation in size, shape, function, feature and weight. However, weight is the main concern for the engineers and researcher for the moving objects. Reduction of weight is possible through the usage of light weight material like plastics, carbon fiber, aluminum alloys and sandwiched structure. The selection of material highly effects on the efficiency, battery consumption and flight time of quadcopters. (Zhang et al., 2015.) A quadcopter has following parts:

1 Frame body (material and properties)
2 Arm (length of arm and material)
3 Centre plate (size and weight)
4 Landing skid
5 BL-DC (Brushless DC motor)
6 Flight controller (Brain of quadcopter)
7 Electronic speed control
8 Propeller (material and size)
9 Battery (Lithium polymer battery)

2.1 Frame body, arm and center plate

The main body of the quadcopter is known as frame; four arms, four brushless DC (Direct current) motors, flight controller and camera are mounted on the frame. The frame consists of four arms as shown in the figure (see the figure 5). The motor are mounted at the end of the arm equidistance from the center of the quadcopter while the flight controller is assembled in the center plate. (Rajin & Shawn, 2015; Siebert & Teizer, 2014.) Factors considered while selecting the material for the quadcopter’s frame are rigidity, stiffness and strength. However; material inspection, testing and analysis (static and dynamic) are done to select the suitable material for the frame. (Gupta et al., 2014.) During market study, it was observed that each quadcopter is identical, while proper balance between strength of material and weight are ignored by the manufacturers. Still, this area needs to be dig into detail to optimize the use of material for arms. (Zhang et al., 2015.)

Figure 5. Quadcopter Body Frame and Inertial Frame (Zhang et al., 2015, p. 224).

2.2 Flight controller

The quadcopters are controlled by the radio signal called “carrier”. These signals are transferred through controller (transmitter) to the flight controller (receiver) of the quadcopter. The flight controller acts as the brain of the quadcopter, it tells each of the motors how fast it should rotate to control the given command. (Norris, 2014, p. 150.) The ultrasonic based flight controller is able to measure the distance between the quadcopter and the controller (Hanafi et al., 2013). The flight controller controls three types of motion in the quadcopter that are defined as roll, pitch and yaw (see the figure 6). Roll is the rotation of quadcopter around its longitudinal axis. Pitch is defines as the upward and downward motion of quadcopter. Yaw is the forward and backward or left and right motion of quadcopter. (Clarke, 2014.)

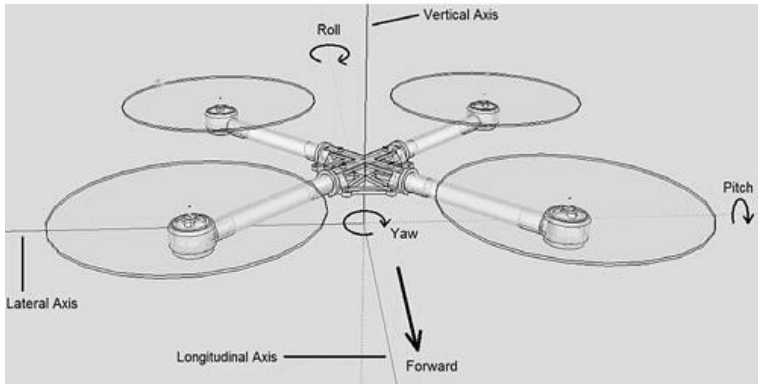


Figure 6. Quadcopter principal axes and respective rotational motions (Norris, 2014, p. 37).

2.3 Electronic Speed Controller

Speed ESC or Electronic speed Controller (See the figure 7) is the controller that receives the signal from the flight controller. The purpose of ESC is to control the speed of each individual motor. Each motor has its own ESC circuit, all the four ESC are connected to the flight controller. (Jeremia, Kuantama and Pangaribuan, 2015.) The ESC receives its input signal from the flight controller. This input signal (often termed as servo signal) is transferred to the BL-DC motor. The difference between receiving and delivering the signal is known as delay, the delay is between 1millisecond to 2 millisecond. The motor response time should be minimum, to get a stable flight of quadcopter. Different manufacturers are available in the market to produce ESC. Some experiment on ESC was performed, connecting all four individual ESC with four BL-DC motors and it was found that the behavior of each motor was not same with single command of input to those four ESC. (Carrillo, 2013, p. 55.)

Figure 7. ESC: (a) top view; (b) bottom view (Carrillo, 2013).

2.4 Brushless DC motors

Light weight, high efficiency, high torque and small size are the main cause of using Brushless DC motor in quadcopters. They use electronic communication instead of the mechanical system, produce less noise as compared to DC motor and are economic to maintain. Synchronization of these motor take place over an integrated power supply switch or inverter. These motors are manufactured in such a way that the wire is wounded on stator and rotor part is consist of permanent magnet. (Norris, 2014, p. 126.)

Below figure shows (see the figure 8) an example of wire wounded stator and permanent magnet rotor.

Figure 8. Brushless DC motor (BL-DC) (Carrillo, 2013, p. 54).

2.5 Battery

LiPo (Lithium polymer) battery is used in commercially available quadcopters, consist of multiple batteries in single unit, for example, DJI Inspire 1 has six LiPo battery in a single unit. The status of each single cell can be seen on the tablet screen. Table (see table 2) provide specifications of DJI Inspire 1 battery and charger. Inspire 1 battery is shown in figure (see the figure 9). It is recommended in user manual guide to use only DJI made battery. These batteries have internal PCB circuit board that are used to transfer data from aircraft to the controller, these data are very useful and complementary part of the flight, use of any other battery will only make the aircraft on but flying is not possible. (DJI, 2015.)

Table 2. Battery and charger specifications of Inspire 1 (DJI, 2015).

S.No	Battery	Charger
1	Capacity: 4500 mAh (milliAmpere)	AC input 220 V
2	Voltage: 22.2 V	Voltage 26.3 V (output)
3	Battery Type: LiPo 6S	-
4	Energy: 99.9 Wh (watt hours)	Rated Power100 W
5	Net Weight: 570 g	-
6	Operating Temperature Range: -10° to 40° C	-

Figure 9. DJI Inspire 1 battery (DJI, 2015).

According to Warne (2005, p. 377) "Considerable efforts have been made to commercialize lithium polymer batteries utilizing a polymer such as polyethylene oxide instead of an organic solvent to dissolve the lithium salt in the electrolyte. Such systems would be able to safely utilize lithium metal as an electrode, which would considerably increase capacity. Unfortunately the electrical resistance of the polymer is still slightly too high for wide-scale commercialization, but some important advances have been made. A slightly different compound based on a gel electrolyte has been more successful and most commercial polymer lithium batteries are of this type. Here, a liquid non-aqueous electrolyte is encapsulated in a polymer gel, typically PVDF (polyvinyl dine fluoride) or. Apart from the immobilized electrolyte, such gel-based polymer batteries are very similar to more conventional lithium ion batteries. The polymer construction facilitates a range of innovative concepts based upon winding and folding to the various elements.”

LiPo batteries (Lithium polymer) are mostly used in quadcopter because, they are light weight, allow maximum fight time, compact density as compared to other batteries. They have short charging time, durability and long discharge time. (Shah et al., 2014.)

2.6 Propeller

Propellers (see the figure 10) are used to lift the quadcopter, two clockwise and two anticlockwise rotating propellers cancel the gyroscope effect of each motor and making quadcopter more stable. The propeller material, used by most of the manufacturer are carbon fiber while, size depends on the lift force and power of the motor. (Shah et al, 2014.)

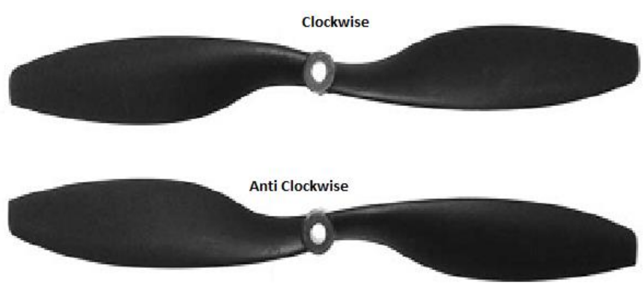


Figure 10. Propellers (mod. Norris, 2014, p. 86).

Other Component: Optional components are also available from the manufacturers of quadcopters. Additional features can be obtained using these components. Following list of parts are developed by reviewing different manufacturer’s official websites. For example DJI Inspire 1 is equipped with some of these addition parts as well. Some examples are given below and can be found also on Carrillo (2013, p. 50)

1 Gimbal for camera (if camera tilt and rotation are needed)
2 Camera (in some Quadcopter camera are fixed and does not tilt or rotate)
3 Vision based positioning system

4 Sonar
5 Gyroscope
6 Metal detector
7 Sensors for temperature
8 Thermal camera
9 Night vision system
10 LED light to operate the Quadcopter in dark
11 Infrared camera
12 Accelerometer
13 Magnetometer/Compass
14 Inertial Measurement Unit

DJI inspire 1 is equipped with IMU, accelerometer, lights, vision based positioning system, GPS, gyroscope, gimbal with camera and magnetometer (DJI, 2015).

3 MOBILE ASSEMBLY ROBOT

Typically, mobile robots are able to move from one place to another autonomously, without assistance from external human operators. Unlike the majority of industrial robots, that can move only in a specific workspace, mobile robots have the special ability of moving around freely within a predefined workspace to achieve their desired goals. This moving capability makes them suitable for a large repertory of applications in structured and unstructured environments. Ground mobile robots are distinguished as wheeled mobile robots and legged mobile robot. (Tzafestas, 2014, p. 24.) The mobile robot in this project work belongs to the wheeled mobile robot. Mecanum wheels are used in order to get high stability and maneuverability. Wheel is shown in below figure (see the figure 11). Mecanum wheel capability is called Omni directionality (Tzafestas, 2014, p. 35). Mecanum wheels have three degree of mobility and three degree of steer ability (Tzafestas, 2014, p. 46).

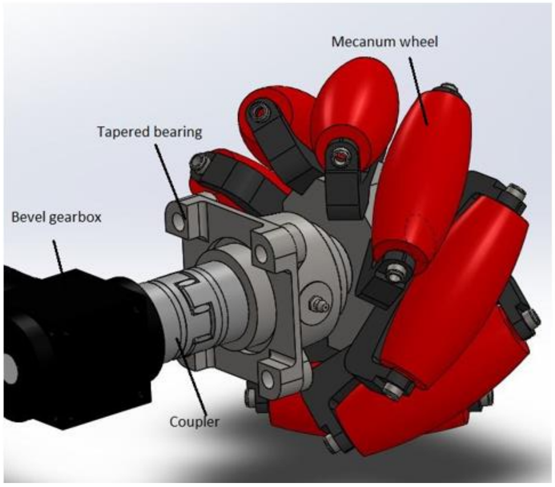


Figure 11. Mecanum wheels used for mobile robot (CAD model).

3.1 Overview

Design of the mobile without plastic cover is shown in figure (see the figure 12). The mobile robot consist of Mecanum wheels, UR10 robotic hands (manipulator), gripper, LiDAR (light detection and ranging), cameras, hearing aids and a Quadcopter. Ideal model is presented in figure (see the figure 13); an idea how the final robot will looks like. The control room for the robot consist of seven screen for monitoring the robot activity, quadcopter will go through the area which the mobile robot cannot access, the live video streaming of quadcopter in one of the seven screen (there are seven individual monitor screen in the control room) serves better working and guidance for the robot. LiDAR is used to scan 3D point cloud information and sent to the control room (Wang et al., 2011).

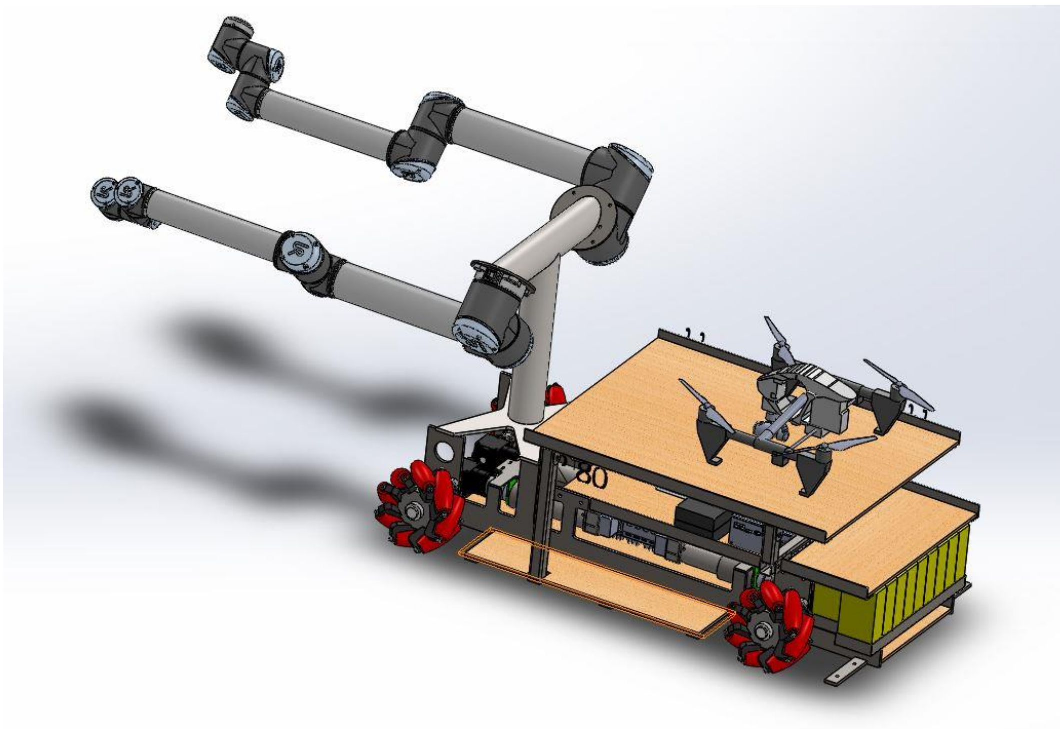


Figure 12. Model of mobile robot without cover (CAD model).

Figure 13. Mobile robot (ideal model of mobile robot).

The purpose of the mobile robot project is to create a robot that can perform a desired task, for this purpose robot planning is considered, robot planning means how the mobile robot achieve its desired task and complete the task efficiently with zero error. Three step are involved in robot planning are path planning, motion planning and task planning. (Tzafestas, 2014, p. 439.)

Path planning: It is related to the programming of all types of locomotive robot, path planning tells a robot how it is going to move around an environment. The robot should know its overall structure of the environment to move freely and safely without damaging the property or damaging itself. Path planning can be done both the way, either before the movement start or during the movement as well. (Tzafestas, 2014, p. 446.)

Motion planning: Motion of robot according to the given command, the motion planning is followed by the path planning to respond a certain input and execute the command safely, it is consider as the sub goal or a subset of main goal or subset of path planning. (Tzafestas, 2014, p. 446.)

Task planning: Task planning includes world modelling, task specification and robot program synthesis. World modelling is related to generation of CAD (computer aided designing) of objects and surrounding. The sequence of change in world modelling is known as task specification. The final part of the task planning include task specifications that is, to perform a certain action successfully, the command include picking a certain object, feedback error or sensing the objects. (Tzafestas, 2014, p. 447.)

3.2 Quadcopter assistance

The use of quadcopter in the robotic environment is increasing in these day. In this report some examples are given about related research works, to integrate a quadcopter with mobile robot system. The camera of quadcopter has the ability (due to hovering and flying capability of quadcopter) to go to the area where mobile robot camera is not accessible, furthermore, the quadcopter camera provide good quality picture and sometime a live video of the entire problem. (López-Nicolás & Mezouar, 2014.) In this perspective it is concluded that, developing the specific purpose quadcopter can have more customized option rather than buying a readymade quadcopter from the manufacturer. The problem with the ready to fly quadcopter is that each company has their own version of programming, any interpretation or modification in readymade program increases the risk of accident. But somehow, in this work a working automatic charging station was developed because the quadcopter programming is not being interpreted or modified. This quadcopter will help the mobile robot to achieve it desired task through live video streaming.

Example of similar work: In Czech republic Technical University in Prague, department of Intelligent and Mobile Robotics Group developed a mobile robot with a quadcopter assisting it as shown in figure (see the figure 14). Another work is carried out in which Aeryon scout is programmed and modified in such a way that it's follow a robot outdoor.

Figure 14. Example of quadcopter assisting robot indoor (Saska, Vonásek and Přeučil, 2013).

Figure 15 below presents a related work. A quadcopter is following a mobile robot outdoor, as the GPS signal only works outdoor. To achieve this target of auto follow, the robot shown below is programmed with C++ software that is integrated with the GPS system of quadcopter and the communication took place through Wi-Fi signal by a UDP (user datagram protocol). UDP communication sends the raw data of its current position to the satellite and GPS respond to that position accordingly. Further detail can be found in. (Daly, Ma and Waslander, 2014, pp. 187-188.)

Figure 15. Example of quadcopter assisting robot outdoor (Daly et al., 2014, p. 188).

4 SELECTION OF QUADCOPTER

First part of this project started with the market survey, it took around four month to select a suitable and professional quadcopter to meet all the requirements of the work. However, due to built-in operation and several constraints some target are still uncompleted. At the starting phase of this project these nine quadcopters shown in figure (see the figure 16) are considered. Study was conducted in detail to find the suitable one among these quadcopters.

Figure 16. Few available quadcopters in market. Names are mentioned for each quadcopter. These pictures are taken from the respective manufacturer's official websites. (DJI, 2015; TurboAce, 2015; Parrot, 2015; Walkera, 2015; 3DRDrone, 2015; Hubsan, 2015; Aeryon, 2015; Draganfly, 2015.)

4.1 Market review

The global unmanned aerial systems (Quadcopter) market revenue is worth 5400.0 M€ as of in 2013 and is expected to grow up to 6350.0 M€ by 2018 (Colomina & Molina, 2014). It has been estimated that the worldwide UAV business sector will be worth up to $80 billion by 2020 (Valavanis & Vachtsevanos, 2015, p. 171).

Table compares the different quadcopters in the market, a summary is presented for the comparison between different model with origin, size and flight time (see table 3). The flight time depends on the number of Lithium polymer batteries used, and weight of the quadcopter. One of the professional quadcopter available in market is Skyranger by a company in Canada named Aeryon, due the high cost this option was eliminated for the study. The SkyRanger camera has the capability of zoom 30 times of an image with high definition, moreover built in several sensors for multi-tasking. (Aeryon, 2015.) All these information and data are gathered from the official website of the manufacturer. While considering the alternative the origin of the quadcopter played an important role in the selection. Preference was given to the European region but unfortunately, there is only one professional drone manufacturer available in France, due the fixed camera (absent of tilt and rotate option) in bebop quadcopter, this option was expelled.

Table 3. Comparison of model and with different origin (DJI, 2015; Turbo, 2015; Parrot, 2015; Walkera, 2015; 3DRDrone, 2015; Hubsan, 2015; Aeryon, 2015; Draganfly, 2015).

S.No	**Companies**	**Origin**	**Model Name**	**Size**	**Flight time**	**Battrery**
1	DJI Innovations	China	Phantom 3	590 mm Diagonal Size	23 min	4480 mAh, 15.2 V
2	Parrot	France	Bebop Drone	33x38x3.6cm	11 min	1200 mAh Lithium Polymer
3	Blade / Horizon Hobby	USA	BLADE® 350 QX2	465x465x138mm	15 min	3000 mAh 11.1V Li-Po
4	Walkera	China	QR X350 Premium	303 x 303 x 176mm	25 min	3000 mAh 29.6V LiPo
5	3D Robotics	California	X8+	35 cm x 51 cm x 20 cm	12 min	10,000 mAh 14.8V
6	Aeryon	Canada	SkyRanger	102cm diameter,24 cm height	50-min	N/A
7	Draganfly	Canada	Guardian	diameter: 72.5cm,Height: 25.5cm	N/A	N/A
8	DJI Innovations	China	Inspire 1	438x451x301 mm	18 min	6000 mAh LiPo

The table below (see table 4), information were gathered during the research work, all these data are gathered using official website of the manufacturer. In this table different features are compared. Pan tilt, live video streaming, cost, overall sizes, auto landing options and flight times are compared. Some companies provide built in screen on the remote controller, while some company does not produce compatible remote controller. Some of the companies gives additional feature of using tablet or smart phones that are compatible with remote controller.

Table 4. Comparison of different features.

S.no	Models	1m Diameter	Video Resolution	Pan & tilt	Auto Landing	Automatic follow	Live video stream FPV	On screen controller &resolution	Flight time	Battery	Cost	Company
1	H109S X4 Pro	370 mm	1920 x 1080p @ 30 fps	yes	yes	yes	yes	yes	30 min	High-Density 3S 11.1V 7000mAh	1399.99 US$	Hubsan
2	INSPIRE 1	559 to 581 mm	HD	tilt +360	yes	yes	yes	No	18 min	5700 mAh	£2,749	DJI
3	Typhoon Q500+	565mm	FULL HD 1080p - Adjustable 60, 50 or 48 FPS	yes	yes	yes	yes	5.5" LCD Sceen	25 min	5400mAh 3S 11.1V LiPo	£949	Yuneec
4	SCOUT X4	600 mmm	HD	yes	yes	yes	yes	Transmitter not included	25 min	29.6V 6000mAh	753 Euro	WALKERA
5	Voyager 3	473 x 463 x 300mm	1080P 60FPS HD	yes	yes	yes	yes	5" LCD screen 640 x 480P	20-25 min	29.6V 6000mAh Li-po	1838 Euro	WALKERA
6	Chroma ™ Camera Drone	332mm	1080p/60fps video	yes	yes	yes	yes	5 ½ inch Live video	30 min	11.1V 3S 5400mAh Li-Po	1099 Euro	horizon hobby

4.2 Cost and feature comparison of several drones

A comparison of three most suitable quadcopters is presented in table (see table 5). Comparison is made for size, price, features and uses. The official price of Skyranger was not available, some suppliers proposed the cost more than 10,000 US Dollar for SkyRanger. Phantom does not have vision based position system and it is the previous model of DJI Company. That is why Inspire 1 was preferred for this work. Inspire 1 has vision positioning system and its remote control has extra HDMI port to add another screen for FPV.

Table 5. Cost and feature comparison of best three alternatives (DJI, 2015; Aeryon, 2015).

Product/Features	**skyranger**	**Phantom3**	**Inspire 1**
Flight time	50 Min	23 Min	22 Min
Size	1.02 Meter Diameter	06 Meter Diameter	0.4 Meter Diameter
Price	N/A	$1,259 USD	3,199 euro
Other feature	Tactical situational awareness & targeting Perimeter & convoy security Covert Intelligence,surveillance and Reconnaissance (ISR) Anti-piracy, tactical ship boarding,De-mining Emergency & disaster response https://aeryon.com/aeryon-hdzoom30	3-axis gimbal stabilized 4K camera HD wireless video transmission Full remote camera control capability App controlled manual camera settings GPS-free indoor stabilisation Camera display in 720p HD on mobile device Photos: 12 Megapixels 3-axis, 360^0 rotating gimbal FLIGHT TELEMETRY	The controller has an HDMI and USB port allowing you to connect mobile devices or compatible screens. Vision based position system
Uses	Military and governmnent Application	Professional use	Research and professional

4.3 Features and specification of selected quadcopter

Specifications of DJI Inspire 1 meets major requirements of this work, including over all dimensions 44 x 30 x 45cm (17.3 x 11.8 x 17.7in), vision based positioning system, arms are made of strong carbon fiber and these arms lift upward after takeoff to provide a full 360^0 view from 4K camera at 30FPS (frame per second), camera has the capability of shooting HD video and 12 megapixel photos, the camera lens consists of 9 separate lenses. Secondary remote control used for camera during flight system with a compatible mobile (smart phone or tablet). Tablet or mobile can give full Flight telemetry including height and battery status etc. Hovering and stabilization of Inspire 1 is possible due to IMU (Inertial Measurement Unit). The IMU also provide steady and stable motion of Inspire 1, taking into account of 6-axis gyroscope. Gimbal motion is controlled by BL-DC motor. Mobile and tablet System Requirements: Apple tablet of mobile (iOS 8.0 or later) Android 4.1.2 or later. Pan and tilt Range of Camera: tilt: -90° to +30° and rotate: ±320°. (DJI, 2015.)

Modification of quadcopter battery: The basic purpose of this work is to select a suitable quadcopter and to develop an automatic charging station. The quadcopter is supposed to be landed on the robot platform.

The landing of quadcopter on the accurate position was the main challenge without damaging and touching any part of robot. Since, the robot is intended to operate indoor, so the GPS system of craft does not work.

The charging process is developed using microcontroller (Arduino), the process begins after the quadcopter lands on the platform of robot. The legs of the quadcopter are modified with copper plates; copper plates are connected to the battery main terminals (positive and negative terminal) through wires.

- Development of automatic charging station is carried out in engineering way, proceed according to the engineering process which involves
- Gathering information for the automatic charging station
- Creating the required document for each of the component and specify their functions
- Hardware needed for the development of station and check the compatibility of each hardware
- Code generation for the process
- Loading/debugging the code to the micro controller
- Troubleshooting and rectification
- Finalized the model after successful result from the test

Remote Controller: DJI Inspire 1 remote controller is shown in the figure below (see the figure 18). Tablet is attached to the controller to get the FPV (first person view). In aviation industry, FPV define as the watching on the screen what the aircraft sees. Live HD (high definition) video streaming is possible on tablet and controller has a HDMI (High-Definition Multimedia Interface) port to add another screen to get a live streaming. Two controller sets are ordered to get separate control of camera on the secondary or slave remote while, primary or master remote only serves for controlling the quadcopter. Following list (see table 6) describes the features of the controller. The features listed in table below are shown in figure (see the figure 17).

Figure 17. Controller with operation numbers (DJI, 2015).

The list (see table 6) correspond to the figure (see the figure 17), which describes the remote control function. Since DJI Inspire is a professional quadcopter therefore, practice and training are needed to become an expert flyer and also to have a safe flight. These options are necessary part of work to know and get expertise in flying the quadcopter Inspire 1.

Table 6. List of operation for controller (DJI, 2015).

S.no	Names	Number	S.no	Names	Nummbers
1	Power button	1	**12**	Camera setting dial	12
2	Transformation switch	2	**13**	Video recording button	13
3	Return home button	3	**14**	Flight mode switch	14
4	Control sticks	4	**15**	Shutter button	15
5	Status LED	5	**16**	Playback button	16
6	Battery level LEDs	6	**17**	HDMI port	17
7	Power port	7	**18**	Micro USB port	18
8	Mobile device holder	8	**19**	CAN port	19
9	Antenna	9	**20**	USB port	20
10	Handle bar	10	**21**	Back button	21
11	Gimbal dial	11			

5 COMPONENTS OF CHARGING STATION

To develop an automatic charging station, information was collected about the equipment. Detailed study was done for each single component, including their specifications and working. After study of components, a suitable model of each component was selected, below table (see table 7) is generated that will help in developing an automatic charging station for Inspire 1.

Table 7. List of components to develop charging station.

S.No	**Component**	**Quantity**
1	Microcontroller (with Bluetooth module)	2
2	Power Relay	3
3	Voltage regulator	1
4	Fuse	2
5	Reed Switch	4
6	Magnetic switch	4
7	Wire	(red and Black)
8	Copper plate	2 (200X200mm)

5.1 Microcontrollers

Arduino is a customizable microcontroller with microprocessor board, are based on C programming, has the capability to perform certain action as per given command. Arduino can be programmed using C / C++ languages. Different sized Arduinos are available with different features (see the figure 18). User can select the desired processor based on the memory size and dimension of the Arduino. Arduino are able to integrate with sensor actuators and GPS systems. They have been part of robotic projects since 2005. The use of Arduino does not need high level of programming skills, writing a program on C language is not much difficult. (Purdum, 2012.) Arduinos can be used to make mini robots in which Arduino act as the brain of the robot in many application like quadcopter, ships and transport agents (Grimmett, 2014, p. 26).

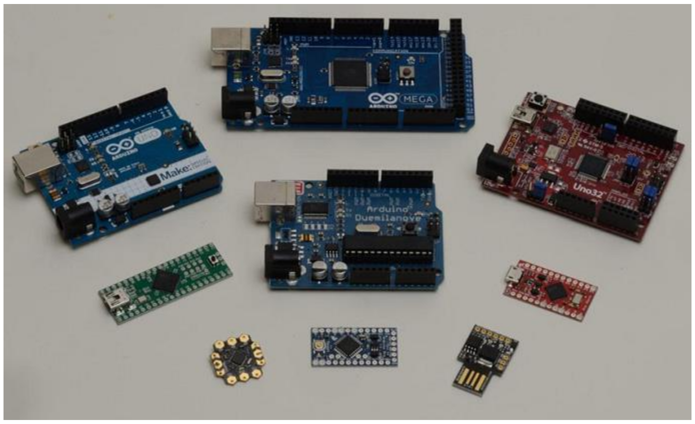


Figure 18. Different Arduino available in market (Purdum, 2012, p. 33).

Selection of Microcontroller: Selection of suitable and compatible microcontroller was one of the difficult task for the development of automatic charging station. Several microcontrollers are studied and compared, in order to find out the suitable controller. The selection was based on many constraints that come during the practical performance of the quadcopter Inspire 1. Some of these constraints are dimension, memory of microcontroller and processing speed. (Purdum, 2012; Grimmett, 2014.)

Arduino MEGA 2560: The figure shows (see the figure 19) the simple Arduino mega 2560 model. The dimension 101x53mm and capable of holding data of 256 KB (kilobytes), with processor speed of 16Mhz, 54 I/O digital pin and 16 analog inputs, serial port and USB (universal serial bus) connection. (Grimmett, 2014, p. 47.) This model was used to give the demonstration of the automatic charging station but it was not considered for further work due to its large dimension size.

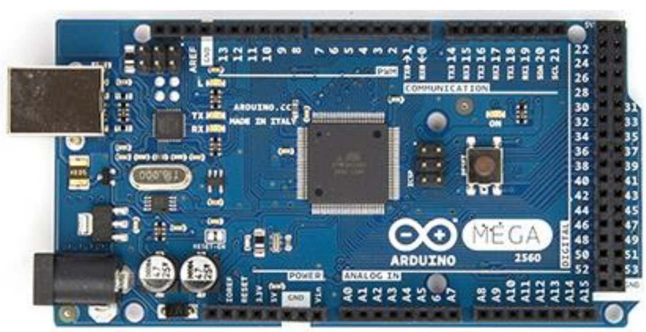


Figure 19. Arduino Mega 2560 (Grimmett, 2014, p. 47).

Bluno Nano Arduino BLE Bluetooth Microcontroller: This model of Arduino is selected (see the figure 20) for this work because of its small size 53x19x12mm, light weight 20g, blue tooth communication model, transparent communication through serial port, DC supply of 7V~12V DC or USB powered or external pin, Atmega328 processor and compatible with the Arduino Uno pin. (Dfrobot, 2015.) This Arduino allows to develop customized hardware and software, need less energy to operate. During the flight of Inspire 1, this Arduino is not powered off and will take the power from the battery, so selecting a low power consumable Arduino is the best option for this work. If the Arduino will dissipate large amount of power from the battery, it will results in lowering the total flight time.

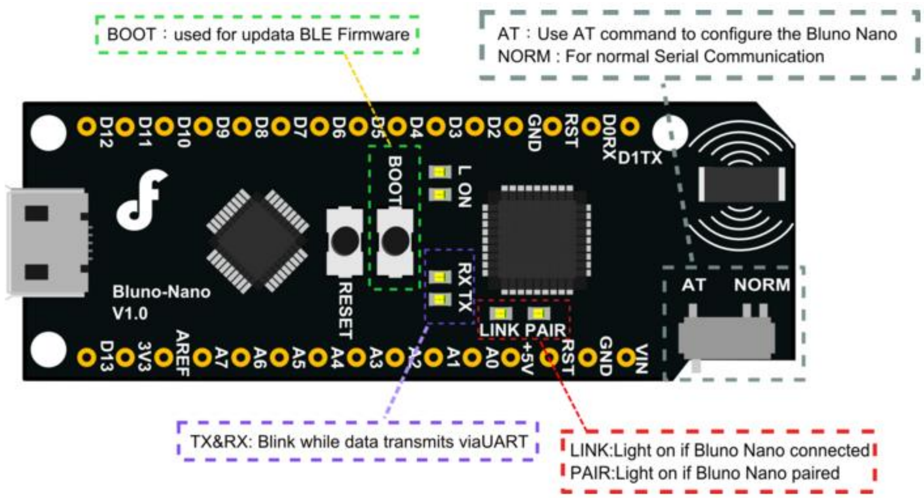
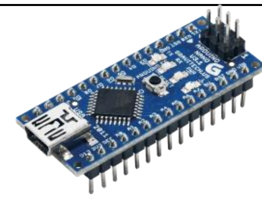
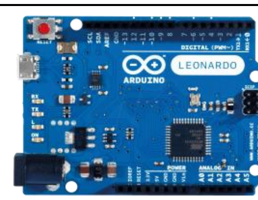


Figure 20. Bluno Nano Arduino BLE Bluetooth Microcontroller (Dfrobot, 2015).

Table 8 below summarize some specifications of different microcontroller, it can be observed from the table that the processing speed vary from size to size, and memory becomes the main factor for selecting a microcontroller. The generated code on C language are uploaded to the microcontroller through the USB port. If the code exceed the maximum size of memory then the uploading process will be failed. The digital input pins can be used to perform multiple actions in parallel or sequence manner, pins are the way of communication for actuator, relay switches and sensors. Pins are used for both input and output feedback. (Purdum, 2012.)

Table 8. List of different microcontrollers in market (Arduino, 2015).

S.no	Microcontoller	Flash memory	SRAM	Speed	I/O Pins	Picture
1	Arduino Uno	32K	2K	16Mhz	14	
2	Arduino Nano	32K	2K	16Mhz	14	
3	ATmega2560	256K	8K	16Mhz	54	
4	Arduino Leonardo	32K	2.5K	16Mhz	20	
5	Arduino Due	512K	96K	84Mhz	54	

5.1.1 Programming of the microcontroller

The programming in Arduino is different as compared to the normal C language, Arduino is based on open source programming which is subset of normal C language and a different compiler also distinguish it from normal C language, there are four basic statement for all languages expression, statement, statement block and function block. (Purdum, 2012, pp. 23-25.)

Expression: operand and operator are used to make an expression, operand are the data while operator are the mathematical or logical agents. For example, a+b is an expression, in which “a and b” are operand and “+” is the operator. Operands are the any variable assign and operator performs the certain action on the operand. The expression is known as binary expression, binary expression always need two operand while +,-, x and / are the binary operator, the unary operant consist of only one operand and a ternary operator consist of three operands. (Purdum, 2012.)

Statement: A complete instruction is known as statement, the statement ends on semicolon (;). Examples is, j=50; Equal sign is called assignment operator, the equal sign assign the operand j (a variable) a particular value to the right side of the statement. (Purdum, 2012.)

5.2 Power Relays

Relays are electromagnetic devices, can respond when an input is given and connects the terminal to the desired terminal and when the input is disengaged they can regain the initial status of electrical circuits. Relays are used in many electrical and electronic appliance, home appliances, robot, communication devices, automobiles and electrical circuits. Figure below (see the figure 21) presents the block diagram of relay working. (Blackburn & Domin, 2007, p. 35.)

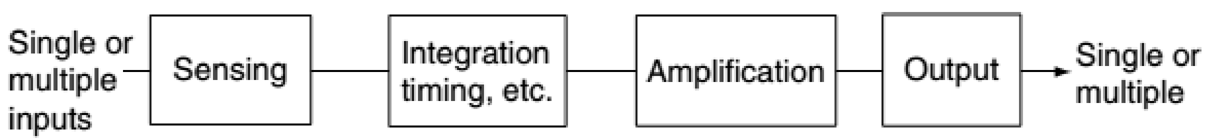


Figure 21. Logic representation of an electric relay (Blackburn & Domin, 2007, p. 35).

Reliability, selectivity and speed are the factors that are considered when selecting a relay for a specific purpose (Blackburn & Domin, 2007, pp. 48-50). The relay used in this work is 1 POLE - 5A Medium Load Control manufactured by FUJITSU (see the figure 22). It is an electromagnetic relay, when power is supplied, the switch changes its position from normally connected (NC) to normally open (NO), and these relays are widely used in microprocessor control system (Warne, 2005, p. 254).

Figure 22. Power Relay (Fujitsu, 2015).

Working principle of electromagnetic relay: The internal circuit diagram is presented in the below figure (see the figure 23). The two free ends (end A and B) of the relays are used to send the signal, this signal is used to activate the electromagnetic system. When no signal is received that relay common (C) is connected to the normally connected terminal (NC). When power is supplied, the electromagnetic system activates and switch is connected to the normally open (NO) terminal. The electromagnetic relays are used where isolation is needed from other components, if the contact is corroded then the connection is not so effective so selecting a suitable and better brand of relay also provides a better performance. (Warne, 2005, p. 254.) While selecting a relay five factor are important namely, reliability, selectivity, speed of operation, simplicity and economic (Blackburn & Domin, 2007, p. 48).

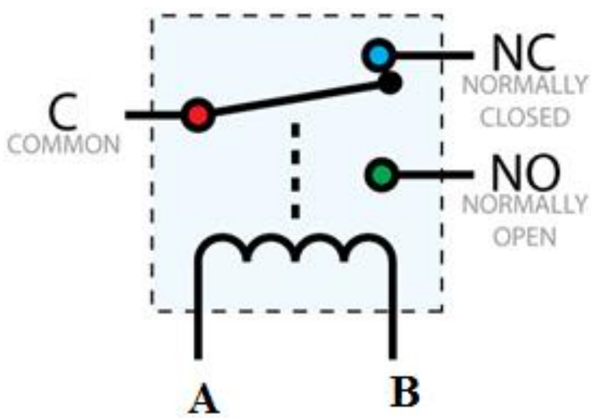


Figure 23. Circuit diagram of relay (mod. Phidgets, 2015).

5.3 Reed switches

Reed switches (see the figure 24) are used to complete the circuit, fast response and light weight are the main characteristics of these type of switches, it has the ability to response to small amount of change in weight, and widely used in communication, control, home appliances, measurement and automotive electronic devices. This fast way of communication enables it to select for this project, in charging station the two microcontrollers are communicating themselves, and therefore this communication must be fast, stable, efficient and reliable. Reed switches are widely used in automobile industry because of their light weight, small size, reduced cost and long life. It can be converted into proximity switch when a magnet is attached. (OSDC, 2015, pp. 13-20.)

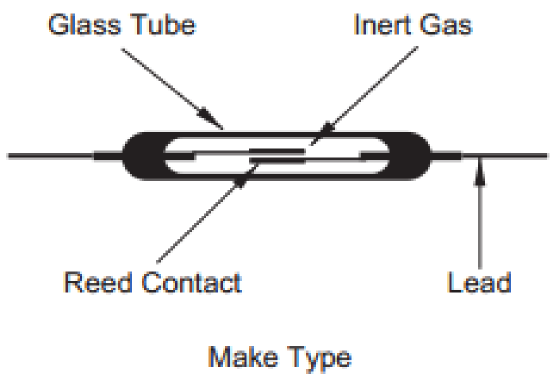


Figure 24. Reed switches (OSDC, 2015).

Working principle of reed switch: Working principle of reed switches are shown in figure (see the figure 25), is based on the mechanism, two ferrous metallic small pins are enclosed in inert gas glass tube, when a magnetic field is applied the ferrous metallic pins attached to each other to complete a circuit (OSDC, 2015). In this project, four reed switches are used and, are connected to the base of platform below the copperplates, these four reed switches become activated when the quadcopter land and the magnetic field generates due to magnet attached to the base platform. The reason of using four switches are to make the system more reliable, if any one of the reed switch detect the weight of the quadcopter first, the auto charging process immediately starts. These switches are connected to the Arduino on the base station that will be discussed in later part of the report in section Development of automatic charging station.

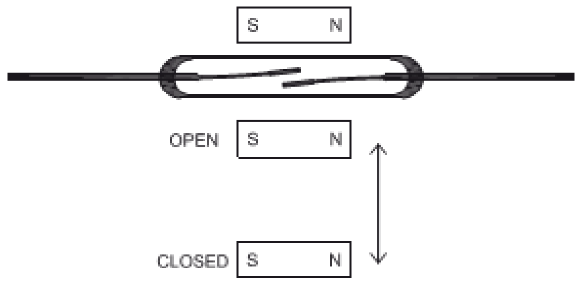


Figure 25. Working of Reed Switch (OSDC, 2015).

5.4 Voltage Regulators

A simple DC-DC converter (see the figure 26) is used for the purpose of applying voltage to the Arduino on the quadcopter, the voltage regulator works on the principle of dissipating the extra amount of power that pass through the resistor, convert the input voltage (V_{in}) into a required small output voltage (V_{out}). (Wens & Steyaert, 2011, p.25.)

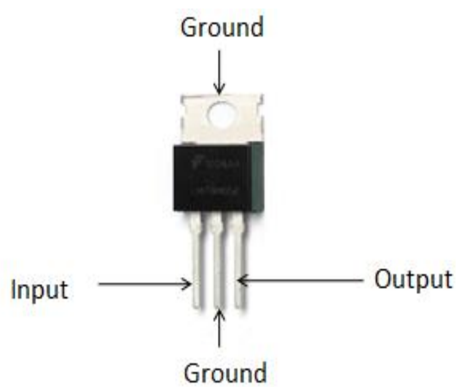


Figure 26. DC-DC Voltage regulator (mod. Robotshop, 2015).

Figure above shows (see the figure 26), a three terminal voltage regulator used in this work. According to the quadcopter manufacturer, it is not recommended to carry any kind of pay load to the Inspire 1. Since this work is based on research work therefore it was decided that small amount of weight can be carried out by the quadcopter. Voltage regulator of model name LM78M05CT 5V 0.5A Voltage Regulator is selected for this work due to its small size (19x10x4.5 mm) and weight (20 grams). Input voltage ranges from 7-35 volts, battery of quadcopter will provide 22.6 volts that's is suitable for this regulator while the output of 5 volts will be connected to Arduino (5 volts is required voltage demand of Arduino).

5.5 Fuse

Fuse (see the figure 27) is a safety electrical device, it is widely used in most electronic and electrical devices to minimize chances of accident due to variation of current, voltage and overheating. These variations are caused due the extra heat up of the device. As the variation increases, the fuse breaks the circuit and prevents the device from further damage. The fuse is connected in the device in such a location/position so that the replacement process could be easy. Fuse are used with fuse holder that can easy be replaced. (Warne, 2005, p. 242.)

Figure 27. Fuse (Robotshop, 2015).

6 DEVELOPMENT OF AUTOMATIC CHARGING STATION

For making an automatic charging station, data collection is important to understand the basic process of charging. To verify the hypothesis of this work a test is carried out with one Arduino, the test was performed manually after bypassing the battery’s main on/off switch.

The Inspire 1 battery has a special method of charging, the battery should be retrieved (take out) from the quadcopter in order to start the charging process. The technical part of this work is to charge the battery within the quadcopter after it lands on the robot platform. The battery should turn off, before starting the charging process.

Turing on/off battery procedure involves

1. Pressing the power button for one second
2. Releasing the button for one second
3. Again press the button for two to three seconds

6.1 Prototype, testing and demonstration

Arduino is used as a microcontroller to make charging process. After landing the quadcopter the Arduino will turn off the battery and the charging process starts. Figure shows (see the figure 28) how the quadcopter lands on the platform. Parts needed for making the automatic charging station has already been discussed above. Process include the following steps

1 Landing of Quadcopter on the platform.

2 Contact switch complete the circuit due to the weight of the copter that land on the platform as shown in Figure (see the figure 28).

3 Contact switch sends the command to the microcontroller board on the platform.

4 Microcontroller receives the complete circuit command and it will turn off the quadcopter by sending the command to the relay.

5 This command will also transferred to start the charging process.

6 After the battery get charged (for example one hour of elapsed time) sending the command to turn on the quadcopter.

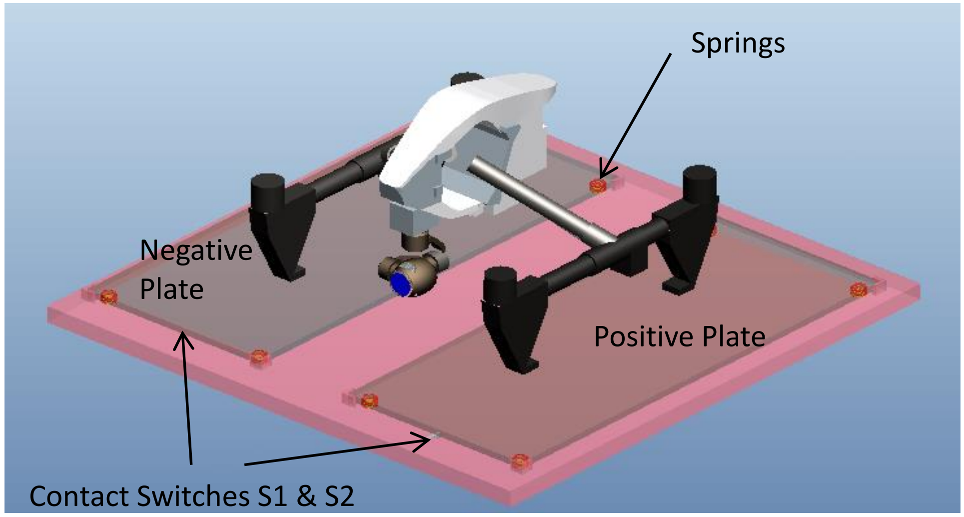


Figure 28. Platform with Quadcopter (created on Pro e wildfire 5).

The above figure (see the figure 29) shows how quadcopter land on the platform and circuit get complete as a response of contact switch. This model is just an overview of the process, practically it is done manually by pressing switch (S1 and S2). Below figure (see the figure 29) shows the contact area and how force will create to enable the contact switch (S1 and S2).

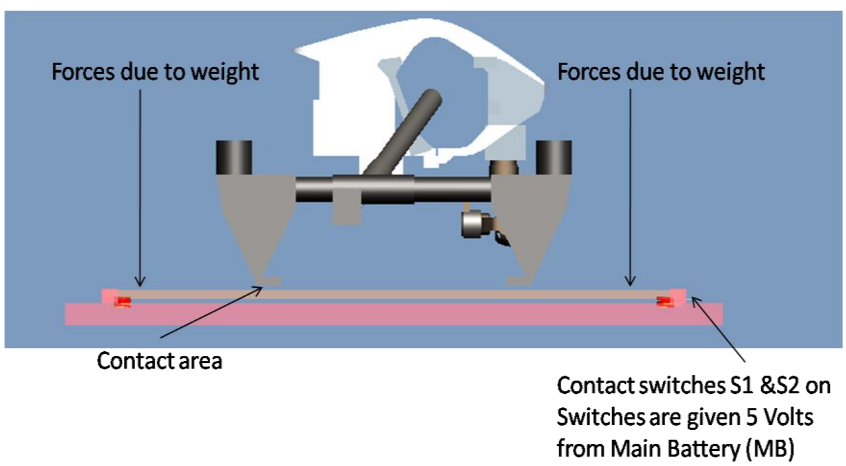


Figure 29. Contact switch complete the circuit (created on Pro e wildfire 5).

Circuit Diagram for demonstration of work: The below figure (see the figure 30) describe how the arduino is connected to the relay. The arduino is connected to the 5 volts of battery swicht S1 and S2 are connected to the digital input of the arduino when the cicuit is complete due to the weight. S1 and S2 the digital pins (d11 and d12) will send the command and arduino will start to process the fuction as written in c command. Turn of the power of battery and connect the relay port to the charging terminal.

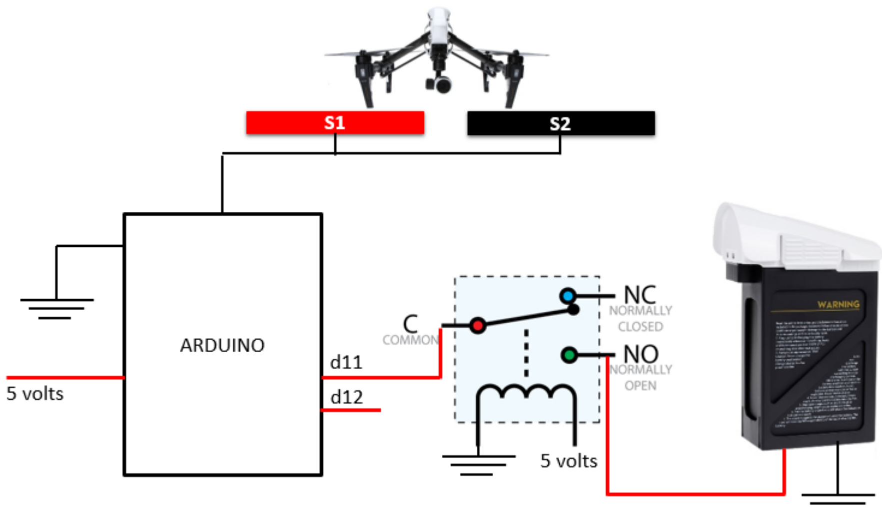


Figure 30. Circuit diagram for charging.

When switches S1 and S2 complete the circuit as shown in figure (see the figure 31), which shows that the power button of battery is by passed and connected to relay. By sending a simple set of command as shown in the testing section (see the figure 33), the Arduino turns off the battery to start the charging process.

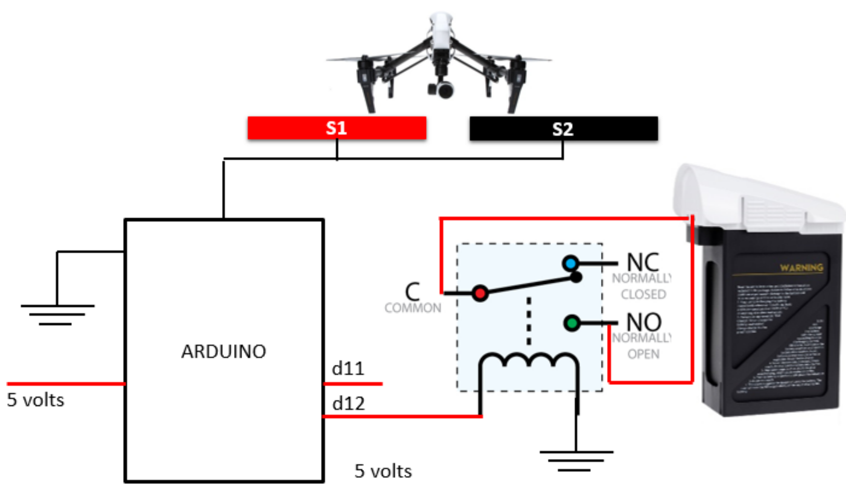


Figure 31. Circuit diagram for power button.

The testing of the Arduino is done through a set code generated on C language as shown in figure (see the figure 32). Battery was successfully turned off, furthermore the battery terminals was successfully connected to the charging terminal as shown in the circuit diagram above (see the figure 31). The following experiment was done manually by connecting the contact switches, which shows that this system really works and can be used to develop an actual model of auto charging station using Arduino, relay and switches. The actual model is developed and discussed in next part of this report in Chapter 6.2.

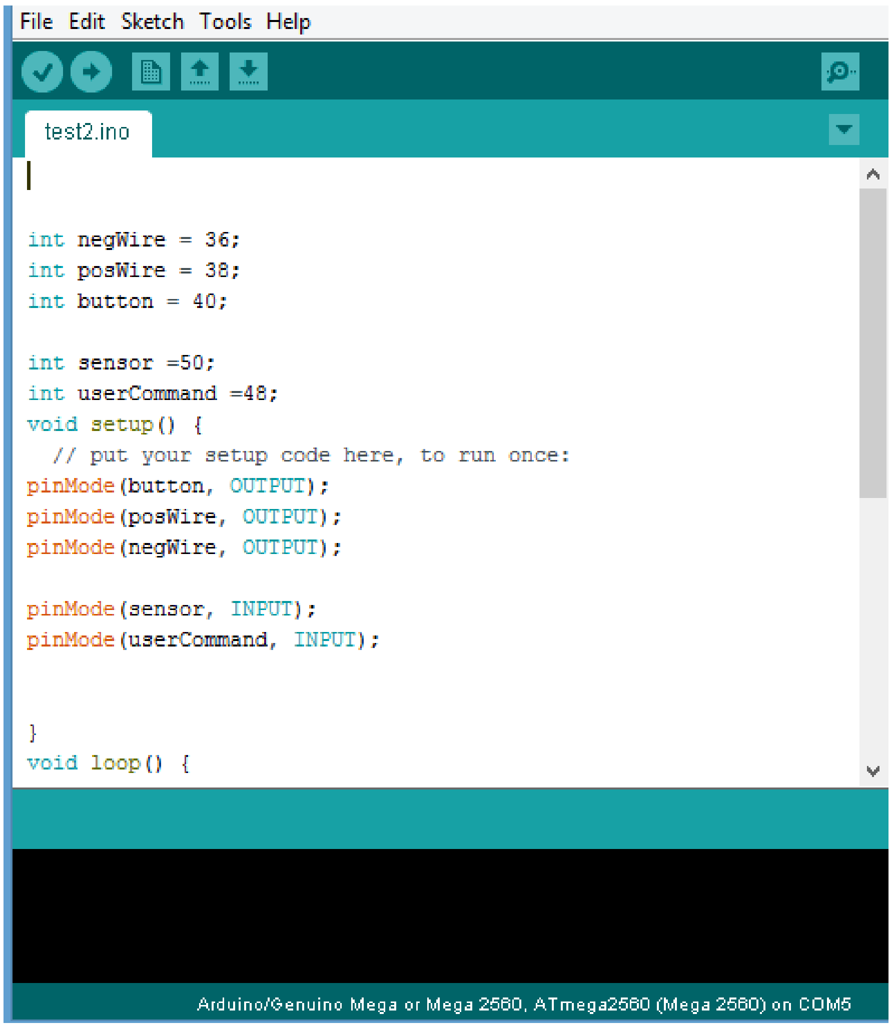


Figure 32. Code for turning off battery on C language.

6.2 Working model

Overview of auto charging station is presented in figure (see the figure 33). Arduino 1 is attached with the quadcopter while Arduino 2 is attached with mobile robot which serves as the base station for the quadcopter. The microcontrollers are equipped with blue tooth module. The quadcopter microcontroller named as Arduino 1 while the microcontroller on the mobile robot named as Arduino2 (base station). Both the Arduino should be turn on all the time because Arduino have their own on/off button if the Arduino is turned off then it should be turn on manually which will fade the whole process as the actual purpose of this work is to make a process that is human free. So the Arduino 1 will take the power from the quadcopter Battery and Arduino 2 is connected to the main battery of the mobile robot. Arduino needs 7-12volts and the size is 53x19x12mm which can be easy be adjusted in the quadcopter's battery. Following steps are included in the whole process

1. Landing of quadcopter.
2. Activation of proximity sensor due the increase of weight on the platform.
3. Microcontroller on the platform Arduino 2 receives command from the proximity sensor.
4. Arduino 2 will send the command to Arduino 1 to turn off the quadcopter.
5. The Quadcopter get turn off and the relays disconnect the supply of the power from battery to the quadcopter.
6. After few second of turning off, the positive and negative relay will connect the quadcopter battery terminal to the charger.
7. After charging relay disconnect the power from charger and connect the power from battery to the quadcopter to fly again.

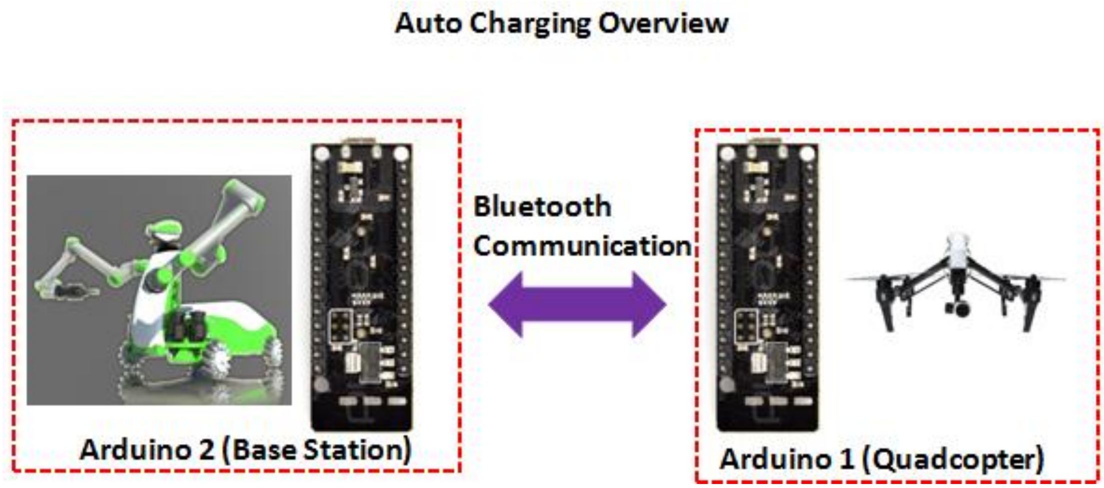


Figure 33. Overview of auto charging.

Figure below shows (see the figure 34) the separate units for battery. The quadcopter battery should be connected to the quadcopter during flying. After landing the quadcopter battery connection should be disconnected from the quadcopter. After disconnecting the battery from the quadcopter, the battery is ready to communicate with the battery charging circuit to start the charging process, it is worth mentioning here that the disconnection does not mean to remove the battery from the quadcopter.

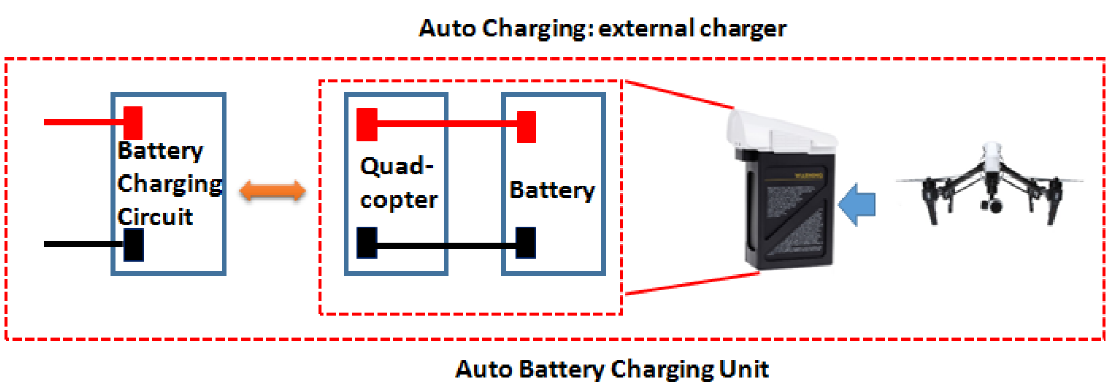


Figure 34. Component of charging process.

A secondary circuit diagram is shown in figure (see the figure 35). Arduino 1, three relays, voltage regulator and fuse are attached to the battery of the quadcopter. This Arduino takes 5volts of power from the battery. A step down voltage regulator (LM78M05CT 5V specification is mention in section 6.4) is used to convert 22VDC of battery into 5VDC for Arduino. In between the connection of Arduino and battery a fuse is used to avoid any short circuit due the variation of current as shown in figure (see the figure 35). The ground terminal of the battery is connected to separate two relays as shown in figure (see the figure 35). Third relay is also connected to the battery. One terminal (one end) of each relay is connected to the ground of the battery as shown in the figure (see the figure 35) with black colored wire. Other one end of these three relays are connected to the digital input of Arduino named as d11, d12 and d10. These three relays are in state of normally connected when there is no input. The first two relays (relay_+ and relay_-) are for the charging the positive and negative wire of the battery, common terminals of these two relays (terminal C) is connected to the positive and negative terminal of the battery. In normally connected status these terminals are supplying power to the quadcopter when no input is entered through the Arduino. Third relay also have the same function in normally open status it keeps the battery on to be used for the quadcopter during flying stage. After landing and receiving the signal from the Arduino on the base station, Arduino can change the state of the relay from connected to open and vice versa, which means the supply of the power from the batter to the quadcopter is disengaged and connected to the charger while the third relay turn off the quadcopter battery to start the charging process.

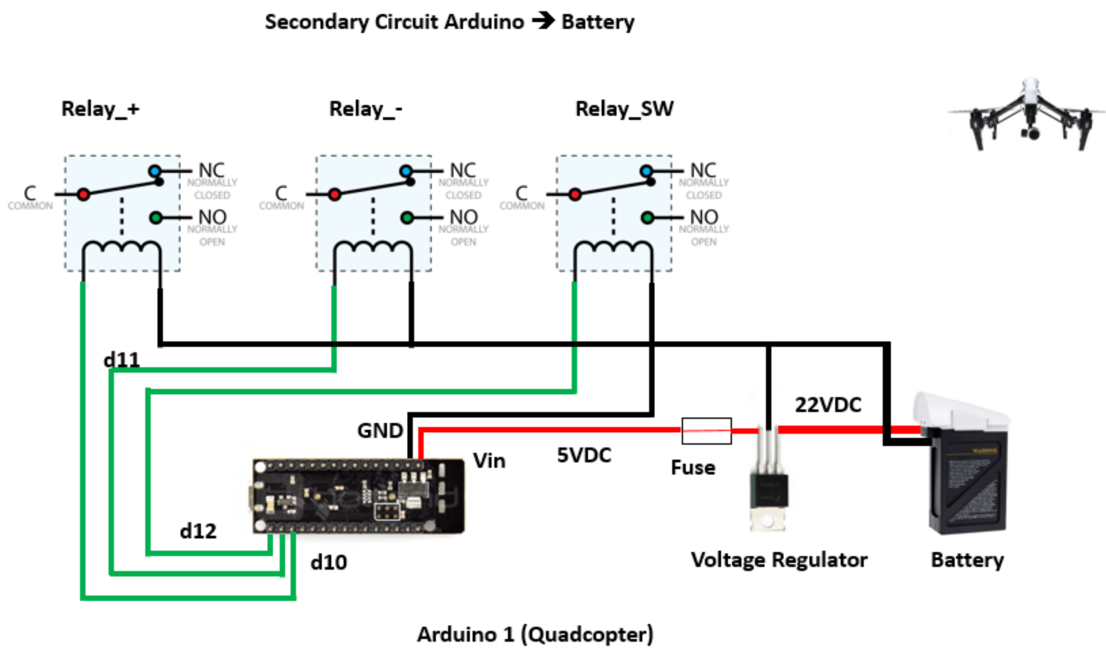


Figure 35. Secondary circuit.

Now consider the below figure (see the figure 36). Relay is connected to the main power of the battery; the power button of the battery is by passed by using very thin wire in order to send the command for turning off the battery. The battery should not be in running status while charging, that is why turning off the battery was the main task for charging. The turning off the battery process comprises of three stages which are as follows

1. Press the power button for one second
2. Release the power button for one second
3. Again press the power button for two or three seconds

However the battery is not turned off with the help of actuator, rather than it was done by sending the signal through Arduino 1 after it lands on the mobile robot. When Arduino 1 on the quadcopter receives the signal from the Arduino 2 from the base station, Arduino 1 is programmed to perform the following operation.

If Arduino 2 is high then Arduino 1 on the battery performs following commands

Turning off the battery: Pin d12 high for one second, d12 low for one second and d12 high for three seconds. These steps will turn of the quadcopter.

Connect to the charger: After 5 second of d12 last high, d10 and d11 are high for 1 hour. This step will disconnect the power of battery from quadcopter and connects the battery terminals to the charger.

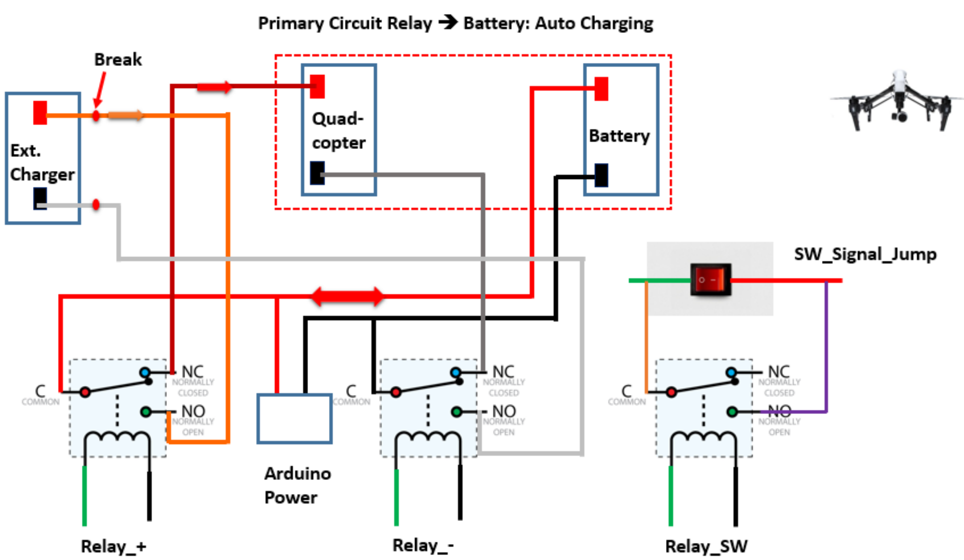


Figure 36. Primary circuit.

How the mobile robot knows the Landing: Figure below shows (see the figure 37) the mechanism of sensing the quadcopter landing process. This is done with the help of magnetic switches and reed switches. These reed witches behaves as the proximity sensor when magnetic field is applied. The proximity sensor can detect very small amount of change in weight, which comes across as a result of quadcopter landing. The mobile robot is manufactured with a platform consisted of two platform. Each platform has copper plate which serves as positive and negative terminal (platform + and platform -) as shown in figure (see the figure 37). From the battery two wires of positive and negative terminals are coming out at the landing skid of the quadcopter. After landing the relay will disconnect the power from battery to quadcopter and change the state to normally open as discussed earlier in section 6.2. The variation in distance between the magnet and reed switch completes the circuit, four magnets for each reed switches are used, if any one of the reed switch comes in contact with the magnet, the proximity sensor responds and complete the circuit, these proximity sensors are connected to the Arduino 2 digital input d9, d10, d11 and d12 while the other end of the reed switch is connected to the 5volts of DC supply. Arduino 2 on the base station is connected to the 5volts power through the main battery of mobile robot. Completion of circuit command from the proximity is received on Arduino 2 (base station). Arduino 2 is programmed in following way, if pin d9 or d10 or d11 or d12 is high then active the Arduino 1 on the quadcopter battery.

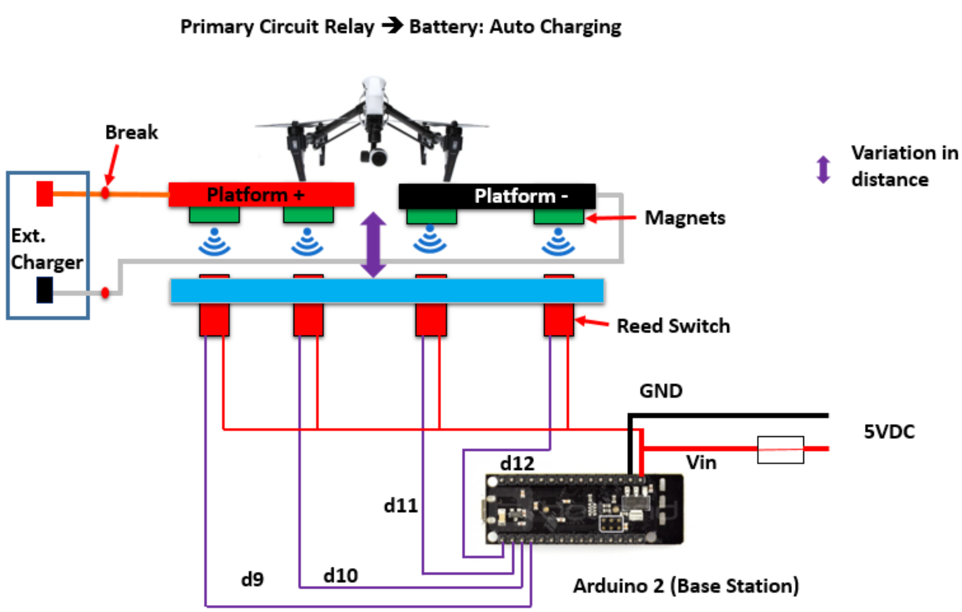


Figure 37. Primary circuit for relays.

6.3 Testing

Testing start when all the connections are made as shown in section 6.2. Statement is made of each digital input as mentioned in Chapter 5.1.1. A working model with successful test has already been discussed in Chapter 6.1. This model is somehow similar to the testing model except here, two Arduino with Bluetooth modules used (see the figure 38) of wire and to make an efficient way of communication between the microcontrollers. The difference is only the use of proximity sensor. The sensor send the command to the Arduino 2 on the base station to activate the Arduino 1 on the battery and all set of command is same as discussed in Chapters 6.1 and 6.2.

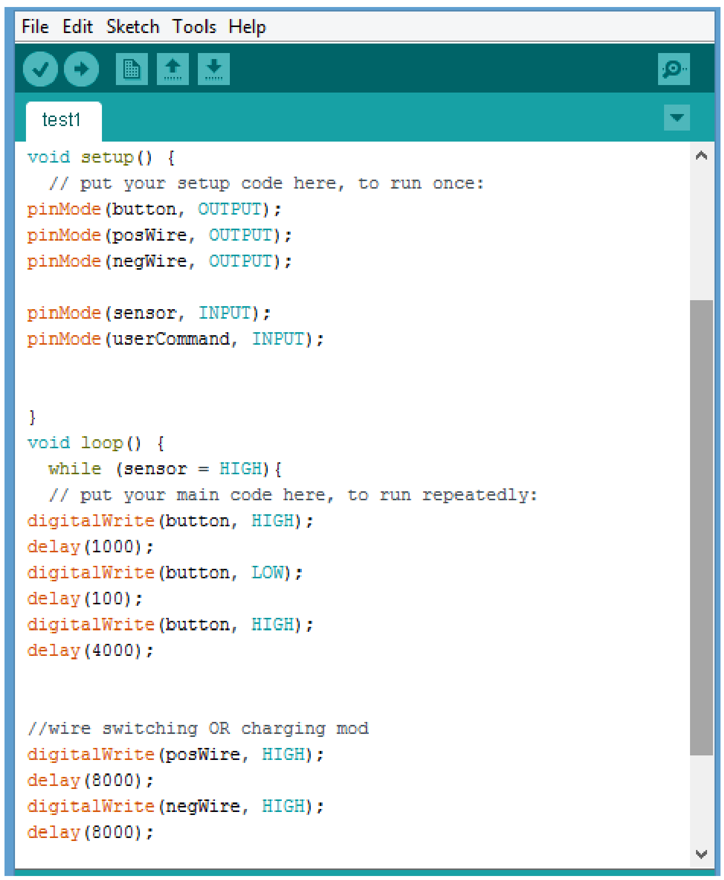


Figure 38. Testing of working model, codes on C language for customized microcontroller.

7 RESULT

As a result of this work two main targets are achieved. First target is, DJI inspire 1 is selected after comparing it different models in the market. Second target is, functional automatic charging station is designed and developed.

7.1 Quadcopter selected for work

Quadcopter selected for this work has automatic take off, live video streaming, HDMI port provides addition of extra screen to the control room of the mobile robot. Camera can rotate 360° and tilt +30° to -90° (this 360° rotation is only available in Inspire 1 model). Inspire 1 meets all the required specifications of the work that make it unique and perfect for this work and also for future research as well.

During the work, it was concluded that GPS does not work indoor, radio signal of GPS are not quite strong to penetrate through the wall of buildings/houses. Vision based positioning system will help in the future work to make an auto follow that will follow the mobile robot indoor, SLAM (simultaneous localization and mapping) is an algorithm used to make an indoor follow quadcopter.

Other option for indoor auto follow are

Option 1: Write a firmware that support indoor follow and develop a software for controller, which has the option of follow indoor.

Option 2: Replace the Flight controller, search a suitable FC that support Indoor follow option and develop a transmitter that sends the command for auto follow.

7.2 Auto charging station

The result obtained from the test is a working automatic charging station. The test was performed in the Lab and after landing the quadcopter accurately on marked position for the charging pad. Figure shows component of charging station (see the figure 39).

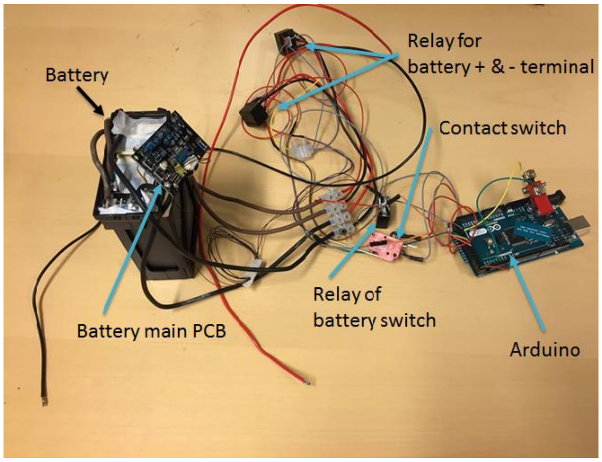


Figure 39. Components of charging for test.

As a result of this work a charging station (see the figure 40) is developed, which is capable of charging the quadcopter battery automatically after it lands on the mobile robot platform. The charging time takes one hour to fully charge a battery. After charging, quadcopter is ready to fly again to provide the assistance to the mobile robot through its live video streaming. The charging pad is equipped with proximity sensors, which can detect small amount of change in weight and send the command to the microcontroller. The microcontroller are programmed in such a way that it can turn off the battery and connects the terminal of battery to the charging unit. For testing purpose this was done successfully, program on C language turn the battery off and connect the terminals of battery to the charging unit. Below figure shows how charging can be done through connecting the positive and negative terminals of the battery.

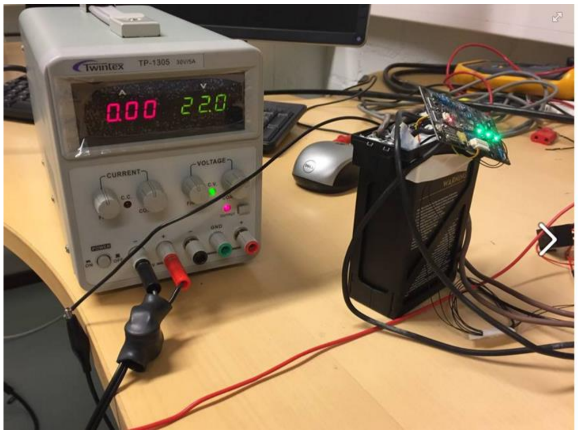


Figure 40. Automatic charging through external charger.

8 CONCLUSION

In this work, Inspire 1 was selected for the assistant of mobile robot assembly. It is very stable, one of the professional quadcopter available in the market for the research work. During the research it was founded that GPS does not work indoor. Researches are ongoing to make an auto follow quadcopter indoor. Mapping is the technique that is done through visual positioning system. Inspire 1 has vision positioning system, this is why Inspire 1 was selected. Due to time limitation, the work was only concluded to the selection of the quadcopter and then making of an automatic charging station. Automatic charging station was developed with the help of microcontrollers, relay and switches. Microcontroller with Bluetooth module was used to avoid minimum number of wire from the quadcopter to the main platform. There were only two wires for the charging that comes out from the quadcopter, while all the functions are made with Bluetooth communication that's was the main reason of using two microcontroller (Arduino 1 and Arduino 2) as mention in section 6 (development of charging station). Use of relay made it easy to control the whole system, programming in C language also make it possible to make the changes in the program as needed (customized C language).

The future work related to this quadcopter, is to check the reliability and repeatability of the automatic charging station along with study of factor of safety. Vision based position system will help in the future work, to make an automatic follow option that will follow the mobile robot where ever it goes, with a certain maintained distance. Another future work that can be carried out is, a light sensor placed on the battery that senses about the battery on/off status. When the battery is turned off the sensor sends the command to the Arduino 1. This work was carried out in a six month of limited time and due to tough time schedule these options ware only theoretically presented.

REFERENCES

3DRDrone. 2015. X8+ | 3DR | Drone & UAV Technology. [Online]. [Accessed 18 November 2015]. Available at: https://3drobotics.com/x8/

Aeryon. 2015. Aeryon SkyRanger the benchmark for VTOL s UAS – Aeryon Labs Inc. [Online]. [Accessed 18 November 2015]. Available at: http://aeryon.com/aeryon-skyranger

Arduino. 2015. Arduino-Products. [Online]. [Accessed 19 November 2015].Available at: https://www.arduino.cc/en/Main/Products

Boucher, P. 2014. Domesticating the Drone: The Demilitarization of Unmanned Aircraft for Civil Markets. Science and Engineering Ethics. pp. 1-20.

Blackburn, J. & Domin, T. 2007. Protective relaying. 3rd ed. Boca Raton, FL: CRC Press. 664 p.

Carrillo, L. R. G., López,A. E. D., Lozano, R. & Pégard, C. 2013. Quad rotorcraft control. Vision-based hovering and navigation. London: Springer. 179 p.

Clarke, R. 2014. Understanding the drone epidemic. Computer Law & Security Review, 30(3). pp. 230-246.

Clarke, R. & Moses, L. 2014. The regulation of civilian drones' impacts on public safety. Computer Law & Security Review, 30(3). pp. 263-285.

Colomina, I. & Molina, P. 2014. Unmanned aerial systems for photogrammetry and remote sensing. ISPRS Journal of Photogrammetry and Remote Sensing, Volume 92. pp. 79-97.

DJI. 2015. Inspire 1 - Features | DJI. [Online]. [Accessed 16 November 2015]. Available at: http://www.dji.com/product/inspire-1/feature

Daly, J., Ma, Y. & Waslander, S. 2014. Coordinated landing of a quadrotor on a skid-steered ground vehicle in the presence of time delays. Autonomous Robots, 38(2). pp. 179-191.

Dfrobot. 2015. Bluno Nano. [Online]. [Accessed 16 November 2015]. Available at: http://www.dfrobot.com/index.php?route=product/product&product_id=1122#.VkUO9LcrLcc

Draganfly. 2015. Draganflyer Guardian Four Rotor UAV Helicopter Aerial Video Platform. [Online]. [Accessed 18 November 2015]. Available at: https://www.draganfly.com/uav-helicopter/draganflyer-guardian/

EASA. 2015. EASA | European Aviation Safety Agency. [Online]. [Accessed 16 November 2015]. Available at: https://www.easa.europa.eu/

Freeman, P. & Freeland, R. 2015. Agricultural UAVs in the U.S: Potential, Policy, and Hype. Remote Sensing Applications, Volume 2. pp. 35-43.

Fujitsu. 2015. Product detail - Fujitsu UK. [Online]. [Accessed 18 November 2015]. Available at: http://www.fujitsu.com/uk/pdut/detail/1184935/relays/FTR-F1

Grimmett, R. 2014. Arduino robotic projects. Birmingham. UK: Packt Pub. 230 p.

Gupta, A., Jha, V. & Kumar, V. 2014. Design and Development of Remote Controlled Autonomous Synchronic Hexarotor Aerial (ASHA) Robot. Procedia Technology, Volume 14. pp. 51-58.

Hanafi, D., Qetkeaw, M., Ghazali, R., Than, M., Utomo, W. & Omar, R. 2013. Simple GUI Wireless Controller of Quadcopter. International Journal of Communications, Network and System, 06(01). pp. 52-59.

Hubsan. 2015. Hubsan X4Pro Quadcopter with HD Camera. [Online]. [Accessed 18 November 2015]. Available at: http://www.hubsanx4pro.com/

Jeremia, S., Kuantama, E. & Pangaribuan, J. 2015. Design and construction of remote-controlled quad-copter based on STC12C5624AD. Bandung, Indonesia: International Conference on System Engineering and Technology (ICSET) 2012. pp. 1-6.

Li, D., Shan, J. & Gong, J. 2009. Geospatial technology for earth observation. New York: Springer. 556 p.

Lily. 2015. Lily-Camera. Reinvented. [Online]. [Accessed 16 November 2015]. Available at: https://www.lily.camera/

López-Nicolás, G. & Mezouar, Y. 2014. Visual control of mobile robots. Robotics and Autonomous Systems, 62(11). pp. 1611-1612.

Linko, M. 2014. Multirotor use Limiter and Problems. Undergraduate Thesis from Aalto University. [Online document]. [Accessed 20 November 2015]. Available: http://cse.aalto.fi/en/midcom-serveattachmentguid-1e48788e3abc28a878811e4b7decfb0ebbf4-b1d4b1d/sci_2014_linko_mikael.pdf.

Nonami, K., Kendoul, F., Suzuki, S., Wang, W. & Nakazawa, D. 2010. Autonomous flying robots: Unmanned Aerial Vehicles and Micro Aerial Vehicles. Tokyo: Springer. 329 p.

Norris, D. 2014. Build your own quadcopter: Power up Your Designs with the Parallax Elev-8 New York. USA: McGraw-Hill. 368 p.

OSDC. 2015. OKI-ZTfoCX. [Online]. [Accessed 16 November 2015]. Available at: http://www.osdc.co.jp/en/data/pdf/databook_en_2010.pdf

Parrot. 2015. Parrot Bebop Drone. Lightweight yet robust quadcopter - 14 megapixel Full HD 1080p Fisheye Camera - Skycontroller - 3-axes image stabilization. [Online]. [Accessed 18 November 2015]. Available at: http://www.parrot.com/products/bebop-drone/

Patel, N., Patel, A., Faldu, M. & Dave, R. 2013. Quadcopter for Agricultural Surveillance. Advance in Electronic and Electric Engineering, 3(4). pp. 427-432.

Phidgets. 2015. 3051 User Guide - Phidgets Support. [Online]. [Accessed 16 November 2015]. Available at: http://www.phidgets.com/docs/3051_User_Guide

Precision. 2015. Drones for Construction - Precision Drone. [Online]. [Accessed 16 November 2015]. Available at: http://www.precisiondrone.com/construction

Purdum, J. 2012. Beginning C for Arduino. 2nd ed. New York: Apress. 280 p.

Rajin, R. & Shawn, M. 2015. Miniature Wireless Quadcopter. Bridgeport, CT, USA: University of Hartford UAV Team. pp. 1-3.

Robotshop. 2015. LM78M05CT 5V 0.5A Voltage Regulator. [Online]. [Accessed 16 November 2015]. Available at: http://www.robotshop.com/en/lm78m05-voltage-regulator.html

Saska, M., Vonásek, V. & Přeučil, L. 2013. Trajectory Planning and Control for Airport Snow Sweeping by Autonomous Formations of Ploughs. Journal of Intelligent & Robotic Systems, 72(2). pp. 239-261.

Shah, N., Dutt, J. & Modh H. 2014. Quadrotor – An Unmanned Aerial Vehicle. International Journal of Engineering Development and Research IJDER, 2(1). pp. 1299-1303.

Siebert, S. & Teizer, J. 2014. Mobile 3D mapping for surveying earthwork projects using an Unmanned Aerial Vehicle (UAV) system. Automation in Construction, Volume 41. pp.1-14.

Tzafestas, S. 2014. Introduction to mobile robot control. London: Elsevier. 750 p.

TurboAce. 2015. Turbo Ace Matrix-G + Devo 10. [Online]. [Accessed 18 November 2015]. Available at: http://www.turboace.com/turbo-ace-matrix-g-devo10-gyrox3.aspx

Valavanis, K. & Vachtsevanos, G. 2015. Handbook of Unmanned Aerial Vehicles. Dordrecht: Springer. 3022 p.

Walkera. 2015. QR X350 Premium Walkera. The world's most professional consumer UAV of racing. [Online]. [Accessed 18 November 2015]. Available at: http://www.walkera.com/En/Products/AerialDrones/QRX350Premium/

Wang, Z., Wu, L. & Li, H. 2011. Key technology of mine underground mobile positioning based on LiDAR and coded sequence pattern. Transactions of Nonferrous Metals Society of China, Volume 21. pp. 570-576.

Warne, D. 2005. Newnes electrical power engineer's handbook. 2nd ed. Amsterdam: Newnes. 480 p.

Wens, M. & Steyaert, M. 2011. Design and implementation of fully-integrated inductive DC-DC converters in standard CMOS. Dordrecht: Springer. 282 p.

Zhang, Q., Chen, J., Yang, L., Dong, W., Sheng, X. & Zhu, X. 2015. Structure Optimization and Implementation of a Lightweight Sandwiched Quadcopter. Intelligent Robotics and Applications. pp. 220-229.