CHAPTER 1

INTRODUCTION

As per the survey ,in India Solid waste management has been a major concern for a long time. India produces 42.0 million tons of Municipal Solid Waste (MSW) annually at present. According to a recent consensus, the per capita waste generation in India is increasing at a rate of 1.3% per annum. Garbage generated annually across the globe amounts to billions of tons today, with almost one lakh metric tons of garbage generated in India per day. This can cause a major impact on the environment. With urbanization in India, the scale of cities and the number of residents is rising and with it is increasing the amount of urban waste generated .

While most urban waste management systems in place are designed for regular collection of waste from fixed locations at regular intervals, there are certain places (remotely located) which go unnoticed and are therefore, not cleaned. Many solutions have been designed for effective garbage management. However, this process is time-consuming as it requires on human interaction. A better solution designed for this problem is to use sensors and AI based drone for obtaining information and collect the solid wastes.

Through extensive background study and data collection, it can be concluded that most of the current automated waste management systems rely on IoT and hardware devices such as infrared sensor, ultrasonic sensor, metal sensor, etc. for detection of garbage and subsequent communication of the bin status. Other than this, there are waste sorting systems based on image processing which identify metal materials or other special types of waste. However, these become dysfunctional in case of paper and plastic products. Moreover, there are very few existing artificially intelligent systems which are self-sufficient for waste classification. With a combined approach consisting of the hardware devices such as a drone, Raspberry Pi, Camera Module, GPS and GSM module and TensorFlow image processing software algorithms, this paper offers a better and innovative solution to the problem of effective waste detection and management in wide and remote areas.

This system aims to achieve the following:

- To identify solid waste disposed at inappropriate places
- To collect the solid wastes and transport it to the dustbins or dump yards.
- Help maintain cleanliness in places such as beaches, roads, institutions, cities etc.

CHAPTER 2

LITERATURE REVIEW

Developing Surveillance and monitoring system can be quite challenging at times, since the system should be designed with the consideration of environment to be monitored.

Good surveillance system needs to have dynamic features. e.g. Monitoring camera that are mobile and can move around the area being monitored.

There are several monitoring and surveillance RC vehicle which are been used. These vehicles can monitor in land or air or in the water but not in 3 modes.

Even amphibian vehicles are viable on land as well as on the water surface but not on air.

Unmanned Aerial Vehicle (UAV)

Unmanned aerial vehicles are aircraft with no on-board crew or passengers. They can be automated drones or remotely piloted vehicles (RPVs). UAVs can fly for long periods of time at a controlled level of speed and height and have a role in many aspects of aviation.

The first pilotless vehicles were built during the first world war. These early models were launched by catapult or flown using radio control. In January 1918, the US Army started production of aerial torpedoes. The model that was developed, the Kettering Bug was flown successfully in some tests, but the war ended before it could be further developed.

During the inter-war period the development and testing of unmanned aircraft continued. In 1935 the British produced a number of radio-controlled aircraft to be used as targets for training purposes. It's thought the term 'drone' started to be used at this time, inspired by the name of one of these models, the DH.82B Queen Bee. Radio controlled drones were also manufactured in the United States and used for target practice and training.

Fig 2.4 Drone

Reconnaissance UAVs were first deployed on a large scale in the Vietnam War. Drones also began to be used in a range of new roles, such as acting as decoys in combat, launching missiles against fixed targets and dropping leaflets for psychological operations.

"Abraham Karem born in 1937, is regraded as the founding father of UAV (drone) technology. "Karem built his first drone during the Yom Kippur war for the Israel Air

Force. In the 1970s, he moved to USA and founded his company Leading Systems Inc. He started the manufacturing of his home garage. Later on, the sophisticated ‘Amber’ which eventually evolved into the famous ‘Predator’ drone that brought him the title of “drone father”. Karem has been described by the Economist magazine as the man who “created the robotic plane that transformed the way modern warfare is waged and at the age of 80 he continues to pioneer other airborne innovations.”

In few parts of the world depending on application specific, the vehicles make a move, where even ambient conditions are too concerned. Considering all these effects the UUVs with highly potential one is innovated. This vehicle can change its mode according to the situations around them. For example: during heavy wind blow ground vehicle is preferred, to have a large area covered within small time air vehicle is preferred and for marine monitoring water vehicle is chosen. The above concern with “all three purposes can be achieved by Universal Unmanned Vehicle (UUV), which can glide in the sky, roll on the ground and surf on the water”.

CHAPTER 3

OBJECTIVES

The objective of this project is to build a UAV which can detect and picks up the trash and put it on the dump yard.

The following are the objectives:

- Proper controlling of UAV by XBOX controller.
- Interface of camera for surveillance purposes
- Wireless transmission of the videos/images captured by camera to remote station.
- Providing assistance for the defence people by continuous monitoring.

CHAPTER 4

DEVELOPMENT PROCESS

The overview of the development process being followed for the UAV.

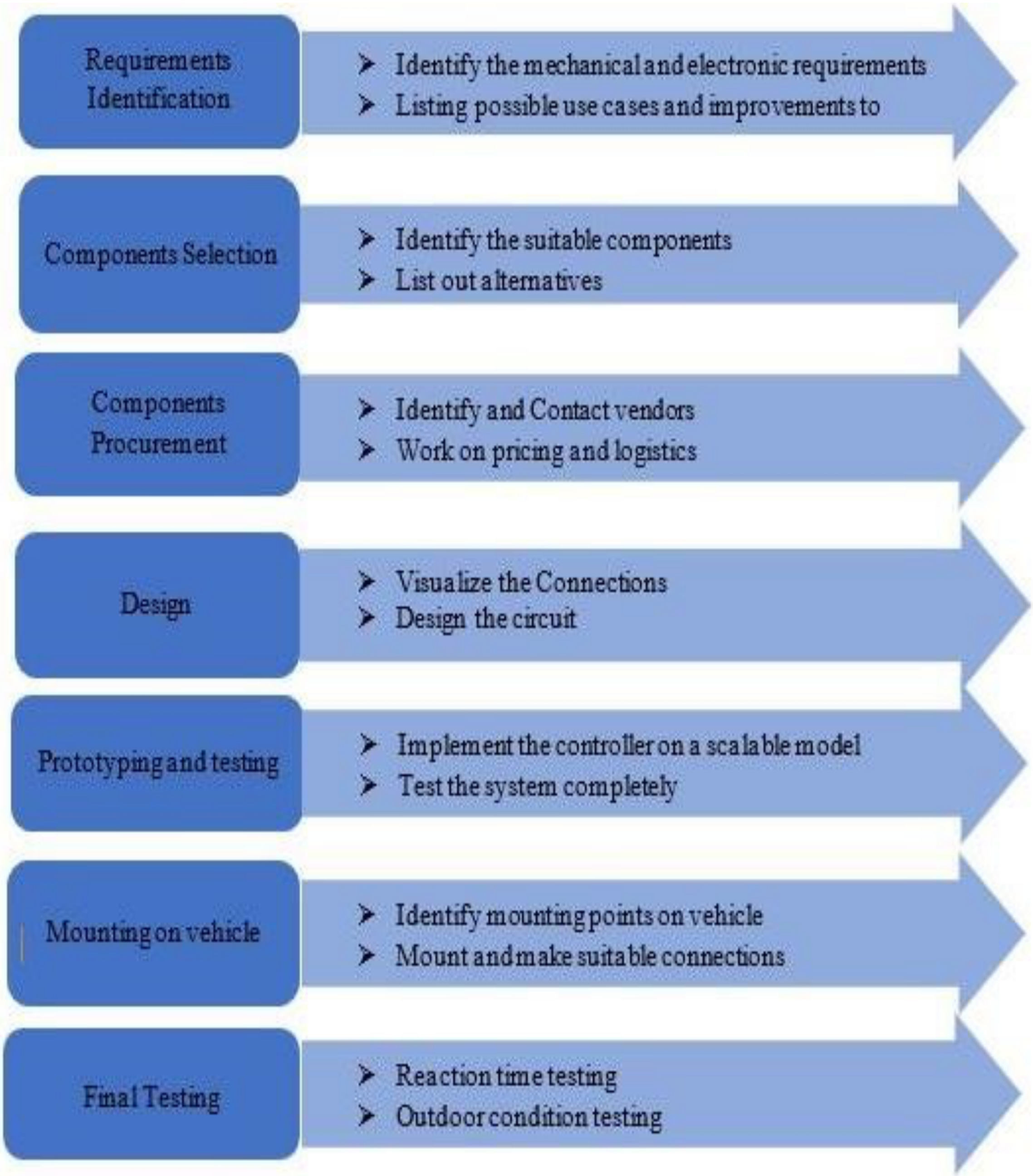

Fig 4 Development Process

CHAPTER 5

BLOCK DIAGRAM

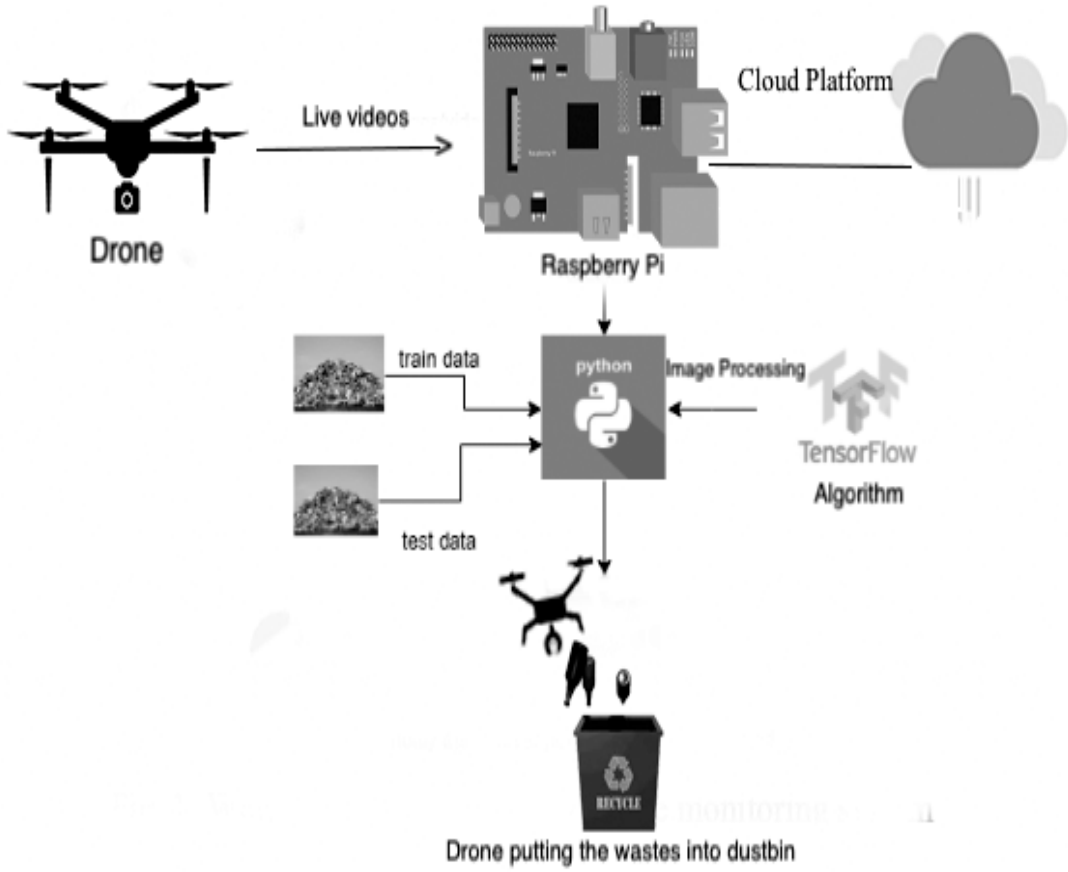

Figure 1 : Working of proposed waste management using drone

CHAPTER 6

PROJECT REQUIREMENTS

6.1 Hardware Requirements

- Raspberry Pi
- DC motor Controller
- DC Gear motor
- Pi Camera
- ESC (Electronic Speed Controller)
- Propellers
- Sensors and modules
- Battery
- BLDC motor
- Power distributor
- Pi cooling fan

6.2 Software Requirements

- C/C++ Code

6.3 Other Requirements

- Xbox controller

CHAPTETR 7

TECHNICAL SPECIFICATION

7.1 Raspberry Pi 4 Model B

Fig 7.1.1 Raspberry Pi 4 Model B+

7.1.1 Overview

Raspberry Pi is a portable, powerful and minicomputer. The board length is only 85mm and width is only 56mm. It can be used for many of the things that your desktop PC does, like high-definition video, spreadsheets, word-processing, games and more. Raspberry Pi also has more wide application range, such as music machines, parent detectors to weather stations, tweeting birdhouses with infra-red cameras, lightweight web server, home automation server, etc.

- Famous in part for its small size, the Raspberry Pi line of inexpensive computers is famously no bigger than a deck of cards, and the Raspberry Pi 4 Model B measures just 3.4 x 2.2 x 0.4 inches. That puts it in the same 3.4 x 2.2 footprint offered on older models of the Raspberry Pi, but it's actually slimmer by almost a quarter inch. And it's almost identical in weight, weighing in at 46 grams (1.62 ounces) – just a gram heavier than previous generations, like the Raspberry Pi 3 B+ (45 grams, or 1.58 ounces).
- But in addition to these familiar ports and connections, the Pi 4 also delivers enormous flexibility. Less common ports include both Camera Serial Interface (CSI), Display Serial Interface (DSI) and a microSD card slot that lets you add storage to the Pi, which comes with no onboard storage of its own.

Specifications

- Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz
- 1GB, 2GB or 4GB LPDDR4-3200 SDRAM (depending on model)
- 2.4 GHz and 5.0 GHz IEEE 802.11ac wireless, Bluetooth 5.0, BLE
- Gigabit Ethernet
- 2 USB 3.0 ports; 2 USB 2.0 ports.
- Raspberry Pi standard 40 pin GPIO header (fully backwards compatible with previous boards)
- 2 × micro-HDMI ports (up to 4kp60 supported)
- 2-lane MIPI DSI display port
- 2-lane MIPI CSI camera port
- 4-pole stereo audio and composite video port
- H.265 (4kp60 decode), H264 (1080p60 decode, 1080p30 encode)
- OpenGL ES 3.0 graphics
- Micro-SD card slot for loading operating system and data storage
- 5V DC via USB-C connector (minimum 3A*)
- 5V DC via GPIO header (minimum 3A*)
- Power over Ethernet (PoE) enabled (requires separate PoE HAT)
- Operating temperature: 0 – 50 degrees C ambient

Pin Description

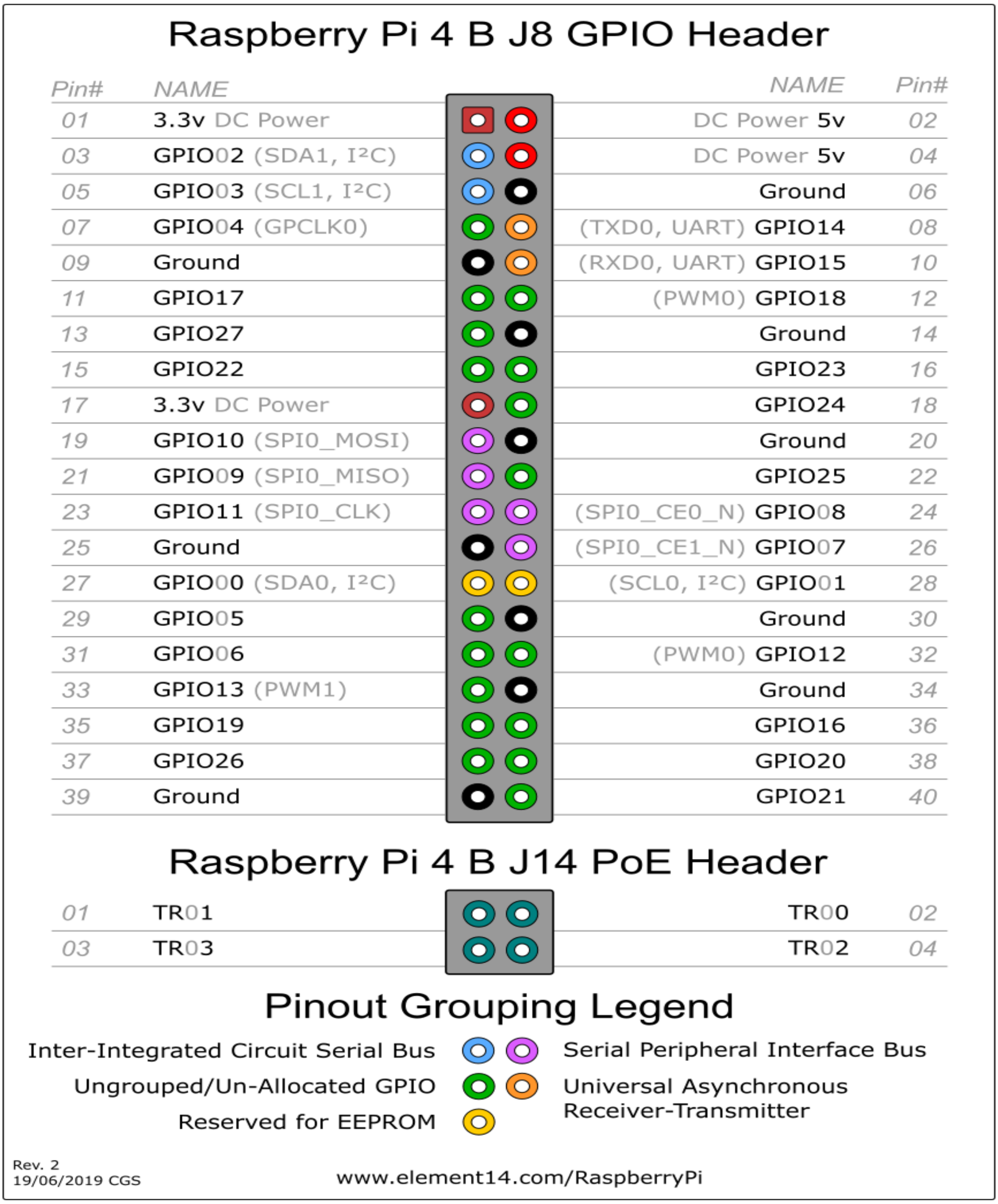

Fig 7.1.2 Raspberry Pi 4 B GPIO pin Description

7.1.2 Detail Look

Display Parallel Interface (DPI)

A standard parallel RGB (DPI) interface is available the GPIOs. This up-to-24-bit parallel interface can support a secondary display.

SD/SDIO Interface

The Pi4B has a dedicated SD card socket which suports 1.8V, DDR50 mode (at a peak bandwidth of 50 Megabytes / sec). In addition, a legacy SDIO interface is available on the GPIO pins.

Camera and Display Interfaces

The Pi4B has 1x Raspberry Pi 2-lane MIPI CSI Camera and 1x Raspberry Pi 2-lane MIPI DSI Display connector. These connectors are backwards compatible with legacy Raspberry Pi boards, and support all of the available Raspberry Pi camera and display peripherals.

USB

The Pi4B has 2x USB2 and 2x USB3 type-A sockets. Downstream USB current is limited to approximately 1.1A in aggregate over the four sockets.

HDMI

The Pi4B has 2x micro-HDMI ports, both of which support CEC and HDMI 2.0 with resolutions up to 4Kp60.

Audio and Composite (TV Out)

The Pi4B supports near-CD-quality analogue audio output and composite TV-output via a 4-ring TRS 'A/V' jack.

The analog audio output can drive 32 Ohm headphones directly.

Temperature Range and Thermals

The recommended ambient operating temperature range is 0 to 50 degrees Celcius. To reduce thermal output when idling or under light load, the Pi4B reduces the CPU clock speed and voltage. During heavier load the speed and voltage (and hence thermal output) are increased. The internal governor will throttle back both the CPU speed and voltage to make sure the CPU temperature never exceeds 85 degrees C. The Pi4B will operate perfectly well without any extra cooling and is designed for sprint performance - expecting a light use case on average and ramping up the CPU speed when needed (e.g. when loading a webpage). If a user wishes to load the system continually or operate it at a high termperature at full performance, further cooling may be needed.

7.2 Geared DC Motor - 1000 RPM

DC Motor – 1000RPM – 12Volts geared motors are generally a simple DC motor with a gearbox attached to it. This can be used in all-terrain robots and variety of robotic applications. These motors have a 3 mm threaded drill hole in the middle of the shaft thus making it simple to connect it to the wheels or any other mechanical assembly.

1000 RPM 12V DC geared motors widely used for robotics applications. Very easy to use and available in standard size. Also, you don’t have to spend a lot of money to control motors with an Arduino or compatible board. The most popular L298N H-bridge module with onboard voltage regulator motor driver can be used with this motor that has a voltage of between 5 and 35V DC or you can choose the most precise motor diver module from the wide range available in our Motor divers’ category as per your specific requirements.

Nut and threads on the shaft to easily connect and internally threaded shaft for easily connecting it to the wheel. DC Geared motors with robust metal gearbox for heavy-duty applications, available in the wide RPM range and ideally suited for robotics and industrial applications. Very easy to use and available in standard size. Nut and threads on the shaft to easily connect and internally threaded shaft for easily connecting it to the wheel.

Specifications and Features

Fig 7.2 Geared DC Motor

- RPM: 1000.
- Operating Voltage: 12V DC
- Gearbox: Attached Plastic (spur)Gearbox
- Shaft diameter: 6mm with internal hole
- Torque: 0.5 kg-cm
- No-load current = 60 mA(Max)
- Load current = 300 mA(Max).

Specification:

Table 7.2 specification of Geared DC Motor

Sl.no	Components	Parameters	Value	Units
1.	1000 RPM Johnson Geared Motor	Rated RPM	1000	RPM
		DC supply	4 to 12	V
		No load current (at 12V)	50	mA
		Load current(max) at 12V	300	mA
		Torque at 12V	1	kg-cm
		Total length	46	Mm
		Motor diameter	36	Mm
		Gear head length	21	Mm
		Output shaft	Centred	
		Shaft diameter	6	Mm
		Shaft length	22	Mm
		Motor weight	80	Grams
		Threaded drill hole	3	Mm
2.	Brushless DC Motor (BLDC)	RPM/Volt	1000	KV
		Motor weight	55	Grams
		Diameter	30	Mm
		Length	40	Mm
		Max thrust	900	Grams
		Min ESC recommended	18	A
		Efficiency	80	%
		Efficiency current (>75%)	4-10	A
		Current capacity	12A/60s	
		Load current	At 10V: 0.5A	
		Working voltage	7-12	V

7.3 Flight Controller

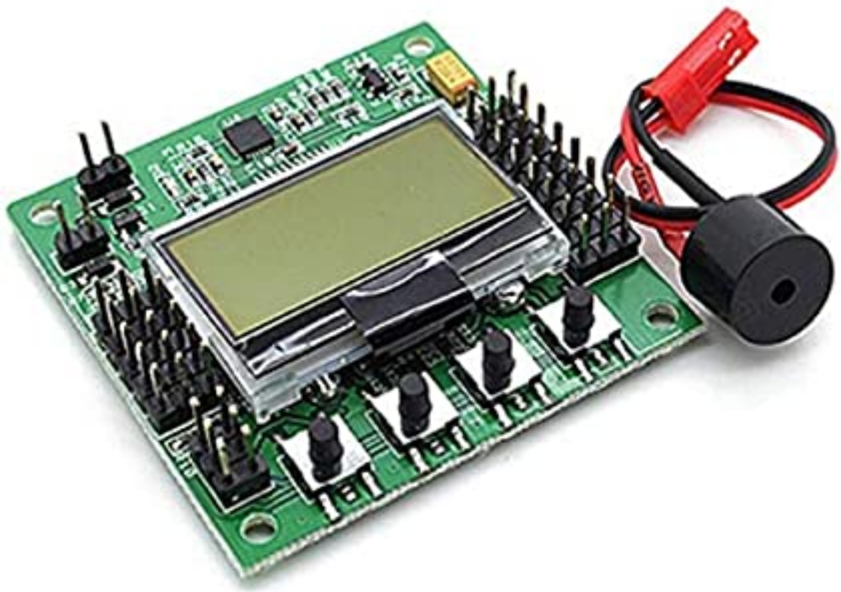

Fig 7.4: Flight Controller

The KK2.1.5 Multi-Rotor controller is a flight control board for multi-rotor aircraft (Tricopters, Quadcopters, Hexcopters etc). Its purpose is to stabilize the aircraft during flight. To do this it takes the signal from the 6050MPU gyro/acc (roll, pitch and yaw) then passes the signal to the Atmega644PA IC. The Atmega644PA IC unit then processes these signals according the users selected firmware and passes control signals to the installed Electronic Speed Controllers (ESCs). These signals instruct the ESCs to make fine adjustments to the motors rotational speed which in turn stabilizes your multi-rotor craft. The KK2.1.5 Multi-Rotor control board also uses signals from your radio systems receiver (Rx) and passes these signals to the Atmega644PA IC via the aileron, elevator, throttle and rudder inputs. Once this information has been processed the IC will send varying signals to the ESCs which in turn adjust the rotational speed of each motor to induce controlled flight.

7.4 Xbox Controller

Fig 7.4: Microsoft XBOX Controller

Xbox One Wireless Controller is the primary controller for the Microsoft Xbox One console. The controller maintains the overall layout found in the Xbox 360 controller, but with various tweaks to its design, such as a revised shape, redesigned analog sticks, shoulder buttons, and triggers, along with new rumble motors within the triggers to allow for directional haptic feedback.

Layout

A standard Xbox One controller features ten digital buttons, a syncing button, two analog triggers, two analog sticks and a digital D-pad. The right face of the controller features four digital actions buttons; a green "A" button, red "B" button, blue "X" button, and yellow "Y" button. The lower right houses the right analog stick, in lower left is a digital D-pad and on the left face is the left analog stick. Both analog sticks can also be "clicked in" to activate a digital button beneath. In the center of the controller face are digital "View", "Menu" and "Guide" buttons. The "Guide" button is labelled with the Xbox logo, and is used to turn on the console/controller and to access the Dashboard. Unlike the Xbox 360 controller, the Xbox One controller features a white backlit Xbox logo on its guide button and does not feature the "ring of light" that served as an indicator for the controller's assigned number (1 to 4). The left and right "shoulders" each feature a digital shoulder button, or "bumper", and an analog trigger.

NOTE: Because of the unavailability of accessing Defence radio bandwidth, it was best replaced by Xbox one wireless controller. The controller works on Bluetooth communication with Raspberry pi- 4.

7.5 Electronic Speed Controller (ESC)

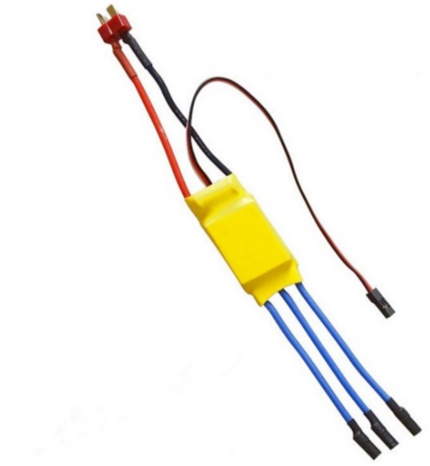

Fig 7.5 30A electronic Speed Controller

An electronic speed control or ESC is an electronic circuit that controls and regulates the speed of an electric motor. It may also provide reversing of the motor and dynamic braking. Miniature electronic speed controls are used in electrically powered radio controlled models. Full-size electric vehicles also have systems to control the speed of their drive motors.

30A ESC Features

- Continuous Output: 30A
- Burst Output: 40A for 15 seconds
- UBEC: 5V/3A
- Lipo Battery: 2 - 4s (cells)
- NiCd/NiMH: 5 - 12s (cells)
- Voltage Input: 6.4v - 16.8v
- Size: 54mm x 26mm x 11mm
- Weight: 32g
- Motor Type: Brushless Motor

Function

An electronic speed control follows a speed reference signal (derived from a throttle lever, joystick, or other manual input) and varies the switching rate of a network of field effect transistors (FETs) .[1] By adjusting the duty cycle or switching frequency of the transistors, the speed of the motor is changed. The rapid switching of the transistors is what causes the motor itself to emit its characteristic high-pitched whine, especially noticeable at lower speeds.

Different types of speed controls are required for brushed DC motors and brushless DC motors. A brushed motor can have its speed controlled by varying the voltage on its armature. (Industrially, motors with electromagnet field windings instead of permanent magnets can also have their speed controlled by adjusting the strength of the motor field current.) A brushless motor requires a different operating principle. The speed of the motor is varied by adjusting the timing of pulses of current delivered to the several windings of the motor.

Brushless ESC systems basically create three-phase AC power, as in a variable frequency drive , to run brushless motors. Brushless motors are popular with radio controlled airplane hobbyists because of their efficiency, power, longevity and light weight in comparison to traditional brushed motors. Brushless AC motor controllers are much more complicated than brushed motor controllers.[2]

The correct phase varies with the motor rotation, which is to be taken into account by the ESC: Usually, back EMF from the motor is used to detect this rotation, but variations exist that use magnetic (Hall effect) or optical detectors. Computer-programmable speed controls generally have user-specified options which allow setting low voltage cut-off limits, timing, acceleration, braking and direction of rotation. Reversing the motor's direction may also be accomplished by switching any two of the three leads from the ESC to the motor.

7.6 Pi Camera

The Raspberry Pi Camera Module is a custom designed add-on for Raspberry Pi. It attaches to Raspberry pi by way of one of the two small sockets on the board upper surface. This interface uses the dedicated CSI interface, which was designed especially for interfacing to cameras. The CSI bus is capable of extremely high data rates, and it exclusively carries pixel data.

Fig 7.6 Raspberry Pi Camera

The board itself is tiny, at around 25mm * 23mm * 8mm. It also weighs just over 3g, making it perfect for mobile or other applications where size and weight are important. It connects to Raspberry Pi by way of short flexible ribbon cable. The camera connects to BCM2835 processor on the Pi via the CSI bus, a higher bandwidth link which carries pixel data from the camera back to the processor. This bus travels along the ribbon cable that attaches the camera board to the Pi.

Features

- Resolution: 5 MP
- Interface Type: CSI (Camera Serial Interface)
- Supported Video Formats: 1080p @30fps, 720p @60 fps and 640*480p 60/90 video
- Fully Compatible with Raspberry Pi 3 Model B
- Small and Lightweight camera module.
- Plug-n-Play camera for Raspberry Pi 3 Model B.

7.7 BLDC Motor

A brushless DC electric motor (BLDC motor or BL motor), also known as electronically commutated motor (ECM or EC motor) and synchronous DC motors, are synchronous motors powered by DC electricity via an inverter or switching power supply which produces an AC electric current to drive each phase of the motor via a closed loop controller. The controller provides pulses of current to the motor windings that control the speed and torque of the motor.

The construction of a brushless motor system is typically similar to a permanent magnet synchronous motor (PMSM), but can also be a switched reluctance motor, or an induction (asynchronous) motor.

The advantages of a brushless motor over brushed motors are high power to weight ratio, high speed, and electronic control. Brushless motors find applications in such places as computer peripherals (disk drives, printers), hand-held power tools, and vehicles ranging from model aircraft to automobiles.

BLDC Motor Selection

Table 7.7 BLDC Motor Specification

Sl.no	Parameters	A2212 1200KV BLDC Motor	N2836 1500KV BLDC Motor	A2212 2450kv BLDC motor
1.	KV(rpm/v)	1200	1500	2450
2.	Max Power	220/3	370W	550W
3.	Max thrust	1265/4 g/S	1200gms	1295
4.	Weight	23g	72gms	49.5g
5.	Recommended Propeller for Battery	10*4.5	12*4.5 for 2S battery 10*4.5 for 4S battery	5040,5045,6045 inches
6.	Battery	2S-3S LiPo	2S-3S LiPo	Max 3S
7.	ESC(Amp)	30A	40A	40A
8.	Dimensions: • Motor diameter • Motor length • Shaft diameter • Shaft length	28mm 3.17mm	28mm 36mm 65.5mm 5mm	3mm

10 length in inches & 4.5 pitch in inches

Decision

The motor chosen for the final design dependent on weight, power (KV), current drop and cost. The motor must have maximum thrust to lift up and maximum current draw lower than ESC output rating. The shaft diameter is another factor as a thicker shaft makes for more durable motor.

Implementation

A2212 is a brushless out runner DC motor specifically made to power Quadcopters and Multirotor. It is a 2200kV motor. It provides high performance, super power and brilliant efficiency. These motors are perfect for medium size quadcopters with 8 inch to 10-inch propellers. Use this to build powerful and efficient quadcopters.

Perfect with our F450 quadcopter frame. Our 40A ESCs can be used to drive the motor.

Specification of A2212 motor

Fig 7.7 BLDC

- KV: 2200 kV
- No load Current: 10 V: 0.5 A.
- Current Capacity: 12A/60s
- No Load Current @ 10V: 0.5A
- No. Of Cells: 2-3 Li-Poly
- Motor Dimensions: 27.5 x 30mm
- Shaft Diameter: 934;3.17mm
- Shaft diameter: 3.175mm.
- Minimum ESC Specification: 18A (30A – 40A Suggested)
- Thrust @ 3S with 1045 propeller: 1200 gms approx
- Thrust @ 3S with 0945 propeller: 750 gms approx
- Thrust @ 3S with 0845 propeller: 650 gms approx.

7.8 Propellers

The propellers shall be large enough to provide adequate lift for the quadcopter, but small enough to lift on the chosen frame. Propellers are also specific for the direction of rotation, making it necessary to match propellers with motors.

Propeller is a type of fan that transmits power by converting rotational motion into thrust. A pressure difference is produced between the forward and rear surfaces of the airfoil-shaped blade, and a fluid (such as air or water) is accelerated behind the blade.

Decision Criteria

The choice between plastic or carbon fiber propellers depended on multiple factors. The blades needed to be robust enough to handle moderate collisions, balanced enough to limit vibrations and have appropriate length and pitch values. Motors driving the propellers are rated for the specific propellers sizes, so this is taken effect as well. Larger propellers (and those with higher pitch) can provide more lift, because they move more air, but they also require more power.

Implementation

Plastic propellers are chosen since carbon fiber propellers are more expensive and much stronger, making them more dangerous if they were to contact object or a person. Keeping this in mind plastic propellers are chosen which helps to stay under the budget. The length chosen is 10 inches with a pitch of 4.5 degrees as this provided the best balance of lift without sacrificing stability and also it provided the required thrust.

Fig 7.8 Propeller

7.11 Battery

The battery provides stable voltage, high current, power to all the components in UUV.

Requirements

The battery powering the UUV shall provide power for all on-board sensors and components, as well as ESC and motors. The battery shall have protective circuitry to prevent overcharging and over discharging which can cause batteries catch fire and explore.

Features

- Very small in size and weight compared to Ni-cd, Ni-MH and Lead acid batteries
- Full charge in 180 minutes with special charger
- Long life with full capacity for up to 1000 charge cycles
- Low maintenance

Choosing Battery

- Model as 4 * 20 Amps ESCs (They will burst 30A each too>
- Battery will need to be able to supply 24A * 4 = 96 A
- The Amps a battery can provide can be found by mAh capacity * C rating
- Another way, Divide the Amps needed by mAh rating to get the C rating that is required
- Remember that 1000mAh = 1 Amp
- 100 Amp / 1.8 Ah = 55.55 C needed
- But needed is
- 100 Amp /5.2 Ah = 19.23C (Approx. 25)

Battery Selection and Decision

Table 7.9 Battery comparison

Lithium Polymer (LIPO) Rechargeable battery 11.1V 5200MAH 25C	Lithium Polymer (LIPO) Rechargeable battery 11.1V 10000MAH 25C	Lithium Polymer (LIPO) Rechargeable battery 11.1V 16000MAH 25C
• 480 Grams weight ➢ Dimension: 138mm*40mm*30mm • Discharge current: 25*5200mAh = 130Amp • Max charging current: 5A	1. 688 Grams weight ➢ Dimension: 200cm*63mm*24mm 2. Discharge current: 25*10000mAh = 250Amp 3. Max charging current: 1A	1. 1050 Grams weight ➢ Dimension: 180mm*72mm*36mm 2. Discharge current: 25*16000mAh = 400Amp 3. Max charging current: 5A

The prototype decision was to use 5200mAh battery which has met the design specification of the project. The battery also reached time requirement.

The multiple electrical components on the UUV (for ESC & BLDC motor for flight) are powered by a power distribution system which is connected to the battery.

Fig 7.11 5200 mAh Battery

CHAPTER 8

QUADCOPTER BASICS

8.1 QUADCOPTER

A quadcopter, also called a quadrotor helicopter or quadrotor, is a multirotor helicopter that is lifted and propelled by four rotors. Quadcopters are classified as rotorcraft, as opposed to fixed-wing aircraft, because their lift is generated by a set of rotors (vertically oriented propellers).

Quadcopters generally use two pairs of identical fixed pitched propellers; two clockwise (CW) and two counter clockwise (CCW). These use independent variation of the speed of each rotor to achieve control. By changing the speed of each rotor it is possible to specifically generate a desired total thrust; to locate for the centre of thrust both laterally and longitudinally; and to create a desired total torque, or turning force.

Quadcopters differ from conventional helicopters, which use rotors that are able to vary the pitch of their blades dynamically as they move around the rotor hub. In the early days of flight, quadcopters (then referred to either as 'quadrotors' or simply as 'helicopters') were seen as possible solutions to some of the persistent problems in vertical flight. Torqueinduced control issues (as well as efficiency issues originating from the tail rotor, which generates no useful lift) can be eliminated by counter-rotation, and the relatively short blades are much easier to construct. A number of manned designs appeared in the 1920s and 1930s. These vehicles were among the first successful heavier-than-air vertical takeoff and landing (VTOL) vehicles. However, early prototypes suffered from poor performance, and latter prototypes required too much pilot work load, due to poor stability augmentation and limited control authority.

8.2 Quadcopter Dynamics

We will start deriving quadcopter dynamics by introducing the two frames in which will operate. The inertial frame is defined by the ground, with gravity pointing in the negative z direction. The body frame is defined by the orientation of the quadcopter, with the rotor axes pointing in the positive z direction and the arms pointing in the x and y directions.

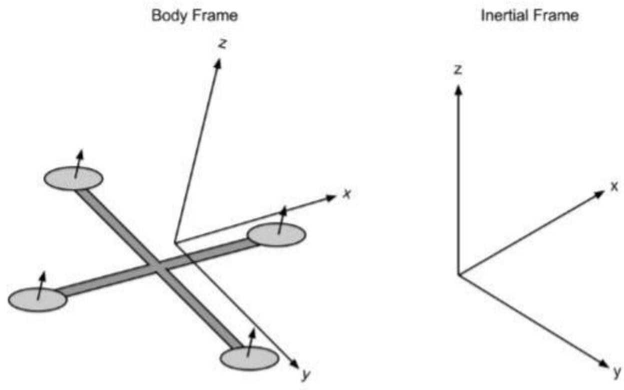

Fig 8.1 Quadcopter body Frame and Inertial Frame

Kinematics Before delving into the physics of quadcopter motion, let us formalize the kinematics in the body and inertial frames. We define the position and velocity of the quadcopter in the inertial frame as $x = (x, y, z)^T$ and $\dot{x} = (\dot{x}, \dot{y}, \dot{z})^T$, respectively.

Similarly, we define the roll, pitch, and yaw angles in the body frame as $\theta = (\varphi, \theta, \psi)^T$, with corresponding angular velocities equal to $\dot{\theta} = (\dot{\varphi}, \dot{\theta}, \dot{\psi})^T$. However, note that the angular velocity vector ω 6= $\dot{\theta}$. The angular velocity is a vector pointing along the axis of rotation, while $\dot{\theta}$ is just the time derivative of yaw, pitch, and roll.