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A Model Design in UAV Technology: A Multi-controller-based Wi-Fi Imaging Drone

Soham Chatterjee[1], Sanjita Moyra[2], Abhijit Banerjee[3]
[1, 2]M.Sc. (Pursuing) Department of Computer Science, Institute of Management Study, EM Bypass, 93 Mukundapur, Kolkata-700099, Maulana Abul Kalam Azad University of Technology
[3]State Aided College Teacher, Department of Computer Science, New Alipore College, Block-L, New Alipore, Kolkata-700053, University of Calcutta

Abstract: A noticeable advancement in the concept of "Unmanned Airborne Vehicle" (UAV) has been manifested with the advancement of the controller technology. Many critical Earth terrains and a few destinations required to be imaged. This challenge can be overcome by developing the imaging aviators. The modern technology is focusing on the flight controller systems for the purpose-driven work. Although there are some iconic developments in the flight automation system but yet there is a need of simplified flight controller with the support systems. The present work aims to develop a prototype of a Wi-Fi based imaging drone based on multicontroller processing system. A few concepts of earlier model designs on UAV technology are thoroughly studied and the scope of linking new modules for the enhanced precision in flight control are utilised in this work. Finally, this work has resulted into an open source editable "all-in-one" platform with a model algorithm that fits into the future designs along with the compatible supplementary hardware.
Keywords: UAV, PID, Wi-Fi, PWM, Android Application.

I. INTRODUCTION

The oldest operation using UAV`s for warcraft is dated back from July 1849 [1]. Forces of the Austrian military attempted the launch of 200 armed balloons from the land carrying approximately 13 kilograms more or less with a time fuse that was to be dropped over the targeted city [2-3]. Some were also launched from the ship SMS Vulcano. Unmanned aircrafts built during World War I which can be operated remotely which was a contribution of A.M. Low's expertise in early television and radio technology was used against the Zeppelins, the successor of British UAV`s in 1917 and 1918 [4-5]. Geoffrey de Havilland`s monoplane was the one that flew under control on March 21st 1917 [6]. A.M. Low known as "father of radio guidance systems" contributed to this effort and was later inducted into the international space hall of fame [7].

Not much later, on September 12th, the Hewitt-Sperry`s Automatic Airplane demonstrated the concept of unmanned aircraft intended for use of aerial torpedoes similar to that of cruise missiles of today. It was controlled by using gyroscope developed by Elmer Sperry of the Sperry Gyroscope Company [8]. In the year 2012 the U.S. Air Force deployed 7,494 modernized UAV`s [9]. By 2013 at least 50 countries developed UAV`s among which China, Israel, Iran and Türkiye designed their own variety. As of 2021, quadcopters instantiated the widespread popularity of hobby radio-operated aircraft and toys, however due to lack of autonomy and by new regulatory environments which require line of sight with the pilot the use of UAV`s in commercial and general aviation is still not achieved. At present no comprehensive list of systems exists, after wide proliferation of UAV technology [10].

UAV, Multirotor or Drone maybe a solution for most of the outweighed problems but it is kept limited or not been much worked on as it was also a complex system to be dealt with. The very usefulness and the miracles it can perform are always tinkling our very interest. This airborne system at its beginning stages utilizes the fundamentals and then become a unique system by advancing at each of its modular units. Advancements are done on individual modular units like Communication, Inertial Measurement Unit, Digital Motion Processors, Flight Controller and Camera and also on hardware specifications and intelligent firmware that's running in the different cores [11].

In the preliminary stages of the development QuardX UAV Model-1 was built on October 03, 2023 without camera and other hardware accessories. Thereafter at testing it was found that the coded proportional integral differential section (PID) shows some errors in gain control and feedback mechanism. Moreover, the receiver module and the android application were lagging due to excessive processing of the instructions.

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In the present work, the basics of a quadcopter are studied that includes operating methods of flight controller unit, transmitter and receiver for image and instruction along with the development of an android application and circuit design. An open-source quadcopter program modularity to overcome the dependencies on a particular set of tools and tactics are carried out in this work. This design has the potential to function with any module independently in such a way that if that module is substituted by an external supplement and may hardly affect the design internally. This study also breaks individual modules into functional units so that the design remains unified in terms of the functionalities and with the improved concurrency the efficiency of the particular unit to work independently increases.

II. METHODOLOGY

A. *Flight Controller*

1) *Inertial Measurement Unit (IMU):* The MEMS based IMU MPU6050 sensor in Fig. 1 measures the angular rate and acceleration that is currently on-board contains 3-axis accelerometer and gyroscope. This data is transferred to the flight controller follows I2C protocol after setting it up as Accelerometer, Gyroscope range has been set to 8G, 500Def/s respectively with the filter bandwidth of 44 Hz [12].

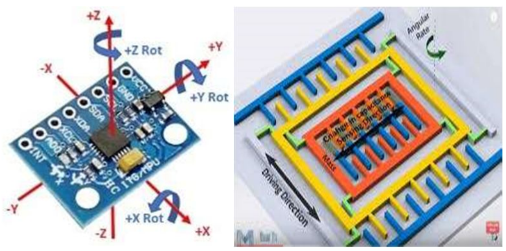

Fig. 1 MPU6050 and MEMS Mechanics (Credit: circuits-diy.com, encrypted-tbn1.gstatic.com)

2) *Digital Motion Processor (DMP):* The IMU having accelerometer and gyroscope together minimizes the effects of errors inherent in each sensor. Flight controller requests the IMU to get Accelerometer and Gyroscopic data using I2C protocol [13-14].

a) Accelerometer takes the measures of acceleration in 3 directions i.e., x, y and z. Direction of gravitational force is same with respect to earth but will experience different amount of acceleration along the three axes based on the orientation of IMU. Orientation of accelerometer provides roll and pitch accelerometer values

$$P_{acc} = \frac{180 \times atan2(accel_{x,} \sqrt{accel_y^2 + accel_z^2})}{\pi}; R_{acc} = \frac{180 \times atan2(accel_{y,} \sqrt{accel_x^2 + accel_z^2})}{\pi}$$

Where, P_{acc} and R_{acc} is pitch and roll angles computed from accelerometric values using Euler Angles.

Gyroscope takes the measurement of angular velocity along the three axes. It doesn't directly compute roll, pitch or yaw, but by integrating angular velocity over time computes the angle needed for specifying the orientation.

$$R_{gyr} = X_{gyr} + t_{inst};\ P_{gyo} = Y_{gyr} + t_{inst};\ Y_{gyr} = Z_{gyr} + t_{inst}$$

Where, R_{gyr}, P_{gyo} and Y_{gyr} are gyroscopic value for Roll, Pitch and Yaw respectively and t_{inst} is the time frame for the measurement taken.

b) Complimentary Filter observes the measurement over timeframe, containing statistical noise and other inaccuracies, and produces output for a variable, tending more accuracy than basing singular measurement.

The computed data from the IMU may not be accurate without. There are techniques such as Kalman filter that make using IMU in a real-time situation more reliable during flight.

$$Pitch = 0.98 \times (Pitch + P_{gyo}) + 0.02 \times P_{acc};\ Roll = 0.98 \times (Roll + R_{gyr}) + 0.02 \times R_{acc};\ Yaw = Yaw + Y_{gyr}$$

Where, Pitch, Roll and Yaw are the filtered data computed using Kalman's formula. Since Yaw cannot be filtered just by using accelerometer, is insufficient for Yaw calculation. So, the gyroscopic value for Z-Axis is taken into account for calculation of semi filtered Yaw.

3) *Signal Processing:* For the UAV to be operated manually the signal from the receiver is fed into the flight-controller board in form of PWM.

a) Signal reception uses pulseIn function and a perceptive logic level state to read the duty cycle of the incoming pulses at any given channel. In general, the signal received from the flight receiver, maybe within 1000µS to 2000µS (used in this scenario). By this method signal outputs like yaw, pitch, roll, throttle and sometimes auxiliary switches of the receiver are fed into the flight controller board.

b) Signal Mapping as transmitter and receiver is never totally accurate resulting in signal loss, jitter and unwanted change resulting in error. In a dynamic control system, there is no scope of wrong signal received at the receiver end. The signal is mapped between the range of 1000µS and 2000µS.

c) Trimming basically floors and ceils by comparing the signal, if it is greater than 2000µS then it will be set to 2000µS and if it's lesser than 1000µS then it will be set to 1000µS.

d) Adjustment of offset is done by the transmitter. The adjustment of the signal is between 50uS and -50uS. Any error of present in the reception end of flight controller then it can be manually adjusted.

4) PID (Proportional Integral Derivative) Algorithm: Stability and control of this dynamic system is handled effectively by this control system technique. It maintains the setpoint (altitude, yaw, pitch and roll) desired by the user even if there is disturbance or unwanted changes in the system [15]. PID block and its mechanism is defined below with flowchart Fig. 2.

a) Proportional system responds proportionally to the current error i.e., the difference between the user desired angle and the current angle is taken into account and output is based on the product of proportional constant and angular difference between two points.

If K_p is too high then the system will oscillate more before reaching a setpoint and if it's too less then it'll take more time in reaching the setpoint since the reaction will be slow.

b) Integral system responds to the error accumulated over time i.e., the long-term error is taken into account and responses by minimising the last minimal error like friction, vibration and other disturbances.

If K_i is too high then the oscillation will be maximum whereas being low it'll not be enough to counter future disturbances.

c) Derivative system responds to the rate of change of error i.e., the rate of change of error is taken into account and output is based on rate of angular change between the user desired angle and the current angle resulting in a dampening effect on the initial proportional response.

If K_d is too high it can cause instability (vibrate around the setpoint) and if its low then it'll not dampen the initial response resulting in overshoot.

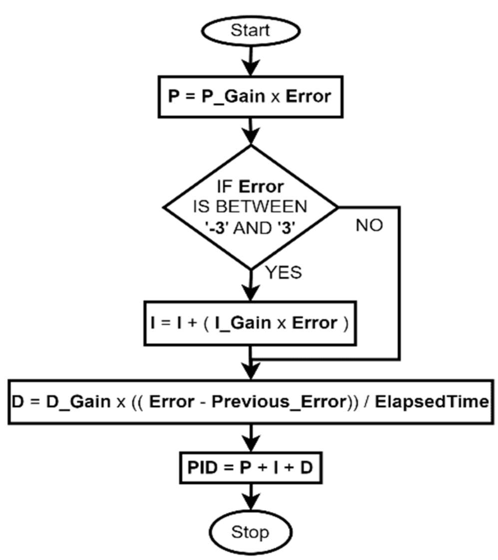

Fig. 2 One Axis PID Mechanism

d) Calibration and tuning correctly is a necessary step before flight operation.

The calibration of Accelerometer is done manually once before first flight and Gyroscope is to be calibrated automatically every time.

Tuning correctly is the essential part since the response of the PID controller depends on their tuning variables i.e., K_p, K_i and K_d.

e) Hardware and Response Mechanics is an essential part for the system to work meaningfully and work optimally. This is based on the mechanism and hardware to be worked with in a system. In the present system the chassis used is a quad X type structure with four propelling mechanisms. Calculation of the flight mechanics is given below.

$$prop_{RF} = throttle + Roll_{PID} + Pitch_{PID} + Yaw_{PID;}\ prop_{LF} = throttle - Roll_{PID} + Pitch_{PID} - Yaw_{PID;}$$

$$prop_{RB} = throttle + Roll_{PID} - Pitch_{PID} - Yaw_{PID;}\ prop_{LB} = throttle - Roll_{PID} - Pitch_{PID} + Yaw_{PID}$$

B. Wi-Fi Instruction Receiver

Wi-Fi with bandwidth of 2.4GHz is used here [16-17]. It follows a protocol oriented multi-channel communication wrapped up in a single transmission mode i.e., in form of request. This was done on ESP-07 in Fig. 3 a member of the NodeMCU family.
The Flight receiver has 4 PWM Channels and 2 Auxiliary Switches. The table of the Hardware Configuration is given in TABLE I.

Fig. 3 ESP-07(Credit: robu.in)

TABLE I
Receiver ESP-07 configuration

Variable Name	Assigned Pin	Use
Channel_1	4	Used to control PWM signal at the output pin
Channel_2	5	Used to control PWM signal at the output pin
Channel_3	12	Used to control PWM signal at the output pin
Channel_4	13	Used to control PWM signal at the output pin
Aux_1	15	Used to control PWM switch at the control
Aux_2	14	Used to control digital switch at the control
LED_BUILTIN	16	To indicate the board is operating (LED OFF if operating)

The communication done here in duplex mode uses forward network channel to receive HTTP request conjoined with the transmitter data and may receive signal strength and ADC data for battery level indication at the transmitter device. These data request is nothing but the PWM Signals that are to be applied at their respective channels. The flowchart explains the working procedure of embedded software in Fig. 4.

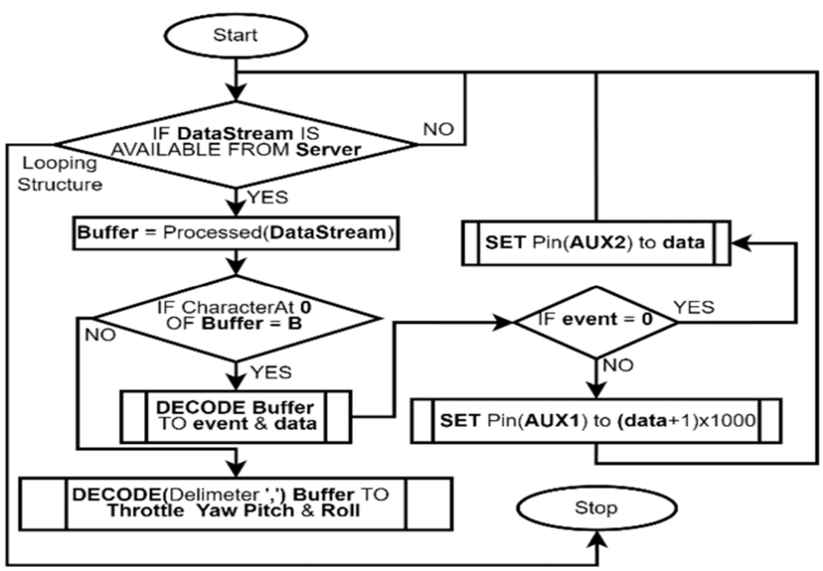

Fig. 4 Receiver Work Procedure

1) Receiver PWM channel and Joystick (Variable PWM):

If the craft needs to take off then the desired HTTP request would be-
http://<Local IP Address>/1000-2000/1500/1500/1500, where 1000µS and 2000µS are the minimum and maximum throttle respectively. Note that the Yaw, Pitch and Roll is idle at 1500µS
The instance instruction would result in the receiver receiving the statement
GET /1000-2000/1500/1500/1500 HTTP/1.1, Note that the minimum roll for both left and right is 1500µS.

2) Receiver Switch (PWM and Digital):

If the PWM switch has to be activated/deactivated the HTTP request would be-
http://<Local IP Address>/A1, where the PWM switch will be activated. also,
http://<Local IP Address>/A0, where the PWM switch will be deactivated.
This instance instruction would result in the receiver receiving the statement GET /A0-A1 HTTP/1.1
If the Digital switch has to be activated/deactivated the HTTP request would be-
http://<Local IP Address>/L1, where the Digital Switch will be activated. also,
http://<Local IP Address>/L0, where the Digital Switch will be deactivated.
This instance instruction would result in the receiver receiving the statement GET /L0-L1 HTTP/1.1

C. Wi-Fi Imaging Transmitter

ESP-32 is used for variety of modern services today as IOT development platform. One of them is ESP-32 CAM in Fig. 5 developed by Esspresif Technology. The ESP based camera module has a maximum resolution of 2 Mega Pixels. This is used as real-time video streamer and is operated during flight operation [18-19].

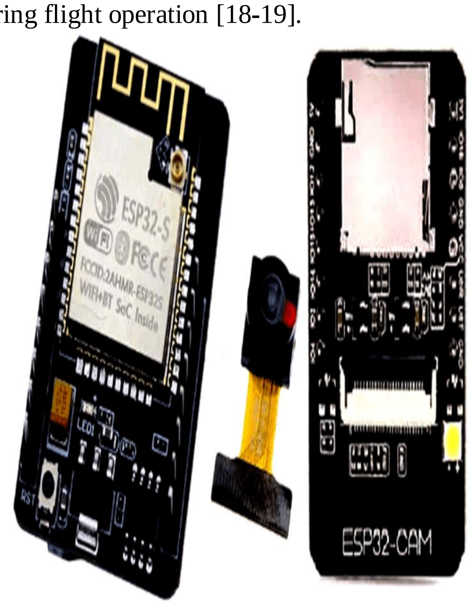

Fig. 5 ESP-32 CAM Fig. 3 ESP-07 (Credit: robu.in)

Features of ESP-CAM added to the application include:

1) IP address connectivity over Wi-Fi.
2) Stream control such as starting and stopping the stream at any point in time.
3) Resolution control between 1600 × 1200 and 160 × 120. This is done to ensure smooth streaming even when the signal strength is weak
4) Snapping an image and transferring is also a part of this program. This can be done even in the highest resolution i.e., in UXGA (1600 x 1200) mode.
5) Functions like vertical flipping and horizontal mirroring is added to set up alignment.
6) Facial Recognition is also available in the application for identification of the recorded image [20].
7) The flow-chart for Wi-Fi imaging transmitter is given in Fig. 6.

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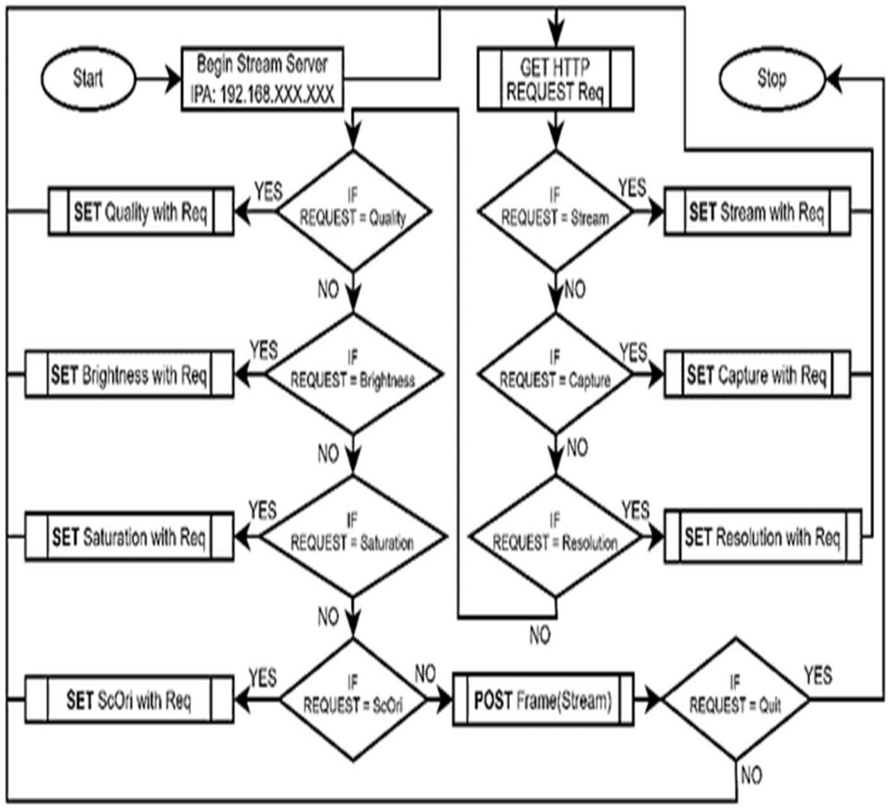

Fig. 6 ESP-32 CAM functions

D. Android Application Transceiver

MIT app inventor-based transceiver in Fig. 7 is built not only to control the UAV but also to receive frames real-time at flight in order to navigate the path [21-22]. It may be also used for recognition and is equipped with multiple tools explained below with function flowchart in Fig. 8.

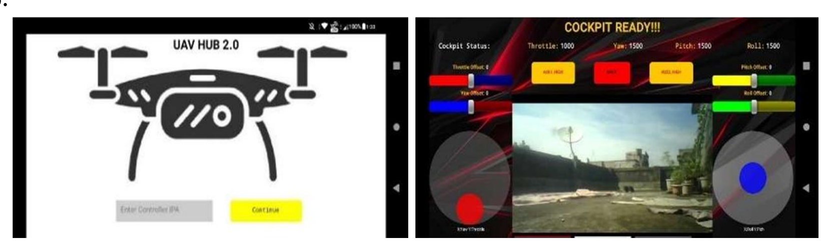

Fig. 7 UAV HUB 2.0

1) The designed android application is responsible for controlling the UAV and act as the instruction transmitter by communicating with the ESP07 receiver.
2) The basic controller mechanism in the application generates http requests for the receiver to receive the command for flight like Throttle, Yaw, Pitch and Roll.
3) Other functions include two Auxiliary switches, one for Digital switch and other for PWM Switching.
4) The application is also provided with 4 offset sliders over Throttle, Yaw, Pitch and Roll for removing any kind of noise present in channels.
5) It also receives the frames in the ESP32 video streamer. IP address is required to communicate with the receiver.
6) Commands to start/stop stream, image snapping, resolution control, vertical and horizontal alignment and other and other vital application like saving, recording or transferring.
7) This android application was built on MIT App Inventor. An android development platform by Massachusetts Institute of Technology based on JavaScript in the backend.

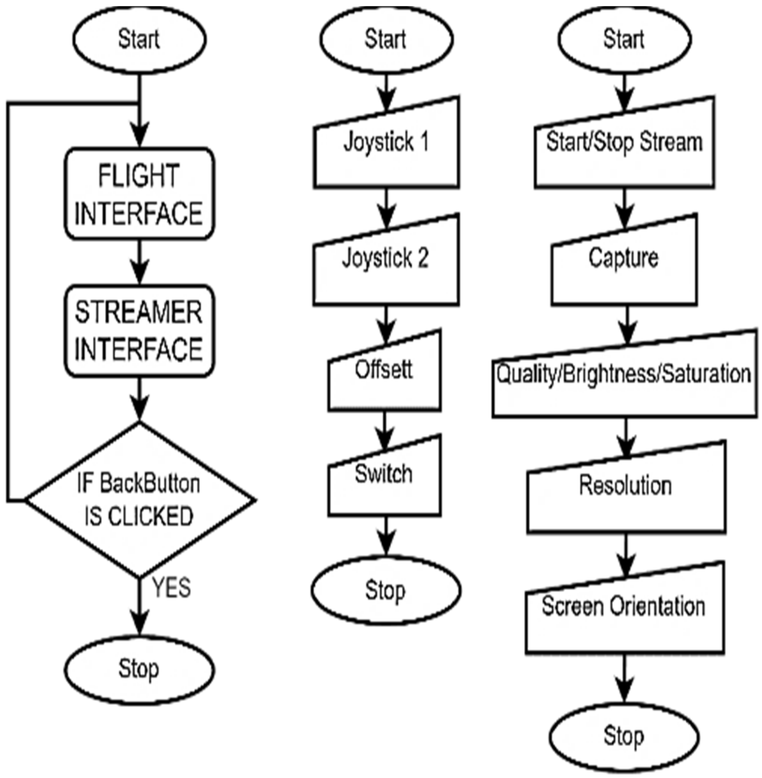

Fig. 8 UAV HUB 2.0 Functions

E. System Hardware Specifications

1) Instruments Used: TABLE II contains the list of instruments used in the present work.

TABLE II
Instruments list

Sl.No.	Device Name
1	1N5819 Diode
2	1uF 10V Capacitor
3	ATmega328P 5V Nano V3.0 Development Board 16MHz CH340 Type-C
4	MPU-6050 3-Axis Accelerometer and Gyro Sensor
5	Ai Thinker ESP-07 ESP8266 Serial Wi-Fi Module
6	ESP8266 Adapter Plate Serial Wireless WIFI Module-1pcs
7	ESP32 CAM Wi-Fi Module with OV2640 Camera Module 2MP For Face Recognition
8	MT76813DBI ESP8266 Serial Wi-Fi wireless Gain Antenna
9	Custom Aluminum + PVC Chassis
10	Kit4curious 4pcs 3-9v High Speed 24000rpm Dc Motor for DIY Experiments- Multi Color
11	DC 12V 2W LED Board
12	IRF540N (TO-220-3) MOSFET (Pack Of 2 ICs)
13	Orange HD Propellers 6045(6X4.5) Carbon Nylon Props 2CW+2CCW-2pairs Black
14	SPST ON-OFF Switch
15	GENX 7.4V 2S 1000MAH 35C / 70C PREMIUM LIPO LITHIUM POLYMER BATTERY
16	Multi-strand hook up wire 0.25mm Gauge

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2) Schematic of the hardware: Fig. 9 shows the hardware used in UAV.

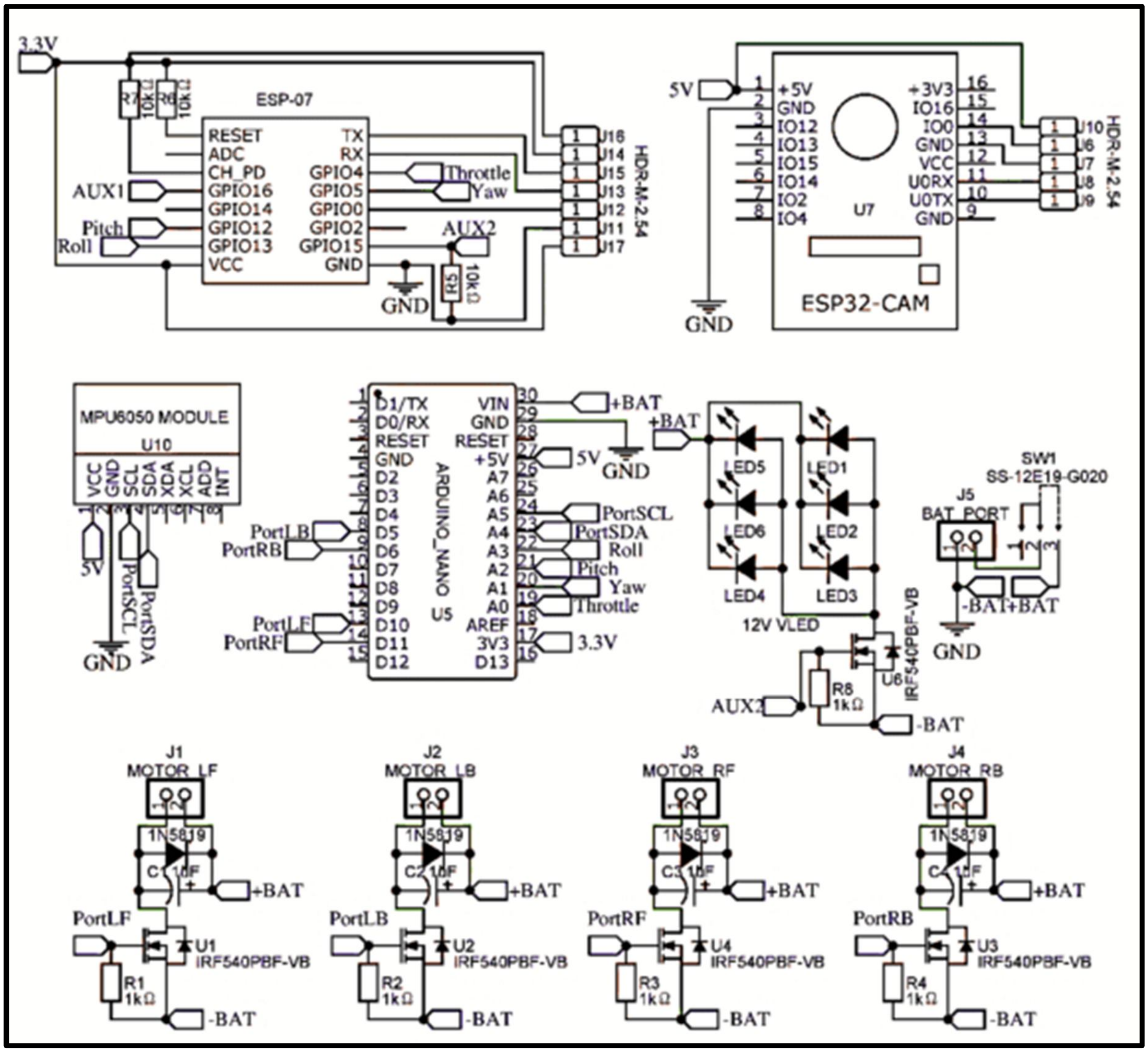

Fig. 9 UAV HUB 2.0 Schematic

III. RESULTS AND DISCUSSION

A. Prototype and Generation

QuardX UAV Model 2 was built on 24/05/2023 in Fig. 10 with camera. In this model the PID errors were reduced if not removed completely. The idea was to implement self-leveling feature. Receiver module was free from error and implemented successfully.

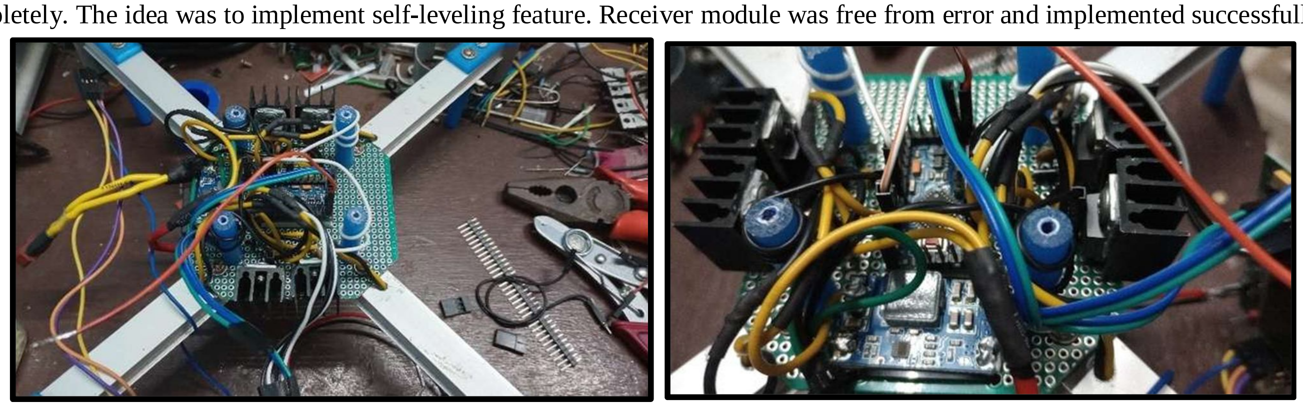

Fig. 10 Overview of QuardX Model 2(Current Model)

B. Payload Capacity (in grams) and PID Settings

Thrust Capacity:
Thrust Generated by 1 x Motor with 6045 Propeller = 150g
Total Thrust Capacity by 4 x Motor with 6045 Propeller = 600g
Payload Capacity = Thrust Capacity – Total Weight = 600g - 400g = 200g
In the present system offset for accelerometer in this case found was $X_{Acc} = 0.42$ and $Y_{Acc} = 0.66$.
The optimal value after tuning is found out to be $K_p = 0.75$, $K_i = 0.00025$ and $K_d = 0.05$.

C. *Chassis Dimension*

Fig. 11 shows the structural dimension of UAV.

1. Diagonal Length = 30cm
2. Total Height = 10cm

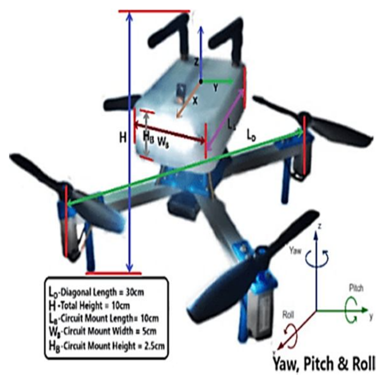

Fig. 11 UAV structural dimension

D. Android Application Interface and Function

QuardX android application UAV HUB 2.0 in Fig. 12 was built on 15/10/2021 on MIT App Inventor without imaging facilities. After revising a lot of times UAV HUB 2.0 was built on 20/05/2023. The application was successfully implemented but it was found that the joysticks were lagging due to a bug in software. It is being worked on for future work.

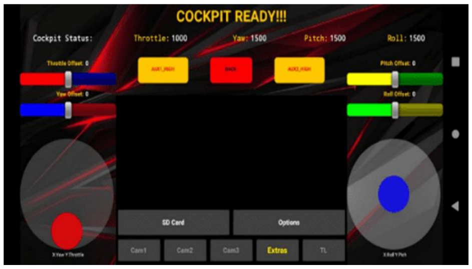

Fig. 12 Application Interface at Runtime: Home Screen Initialization

The application uses an addon camera webserver to start streaming frames given in Fig. 13.

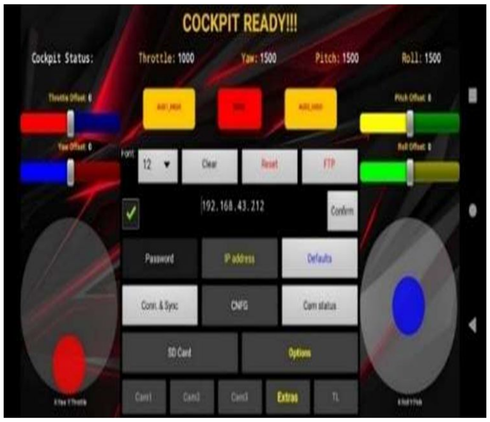

Fig. 13 Application Interface at Runtime: Camera IP Address Entry

Application during runtime at idle is given in Fig. 14.

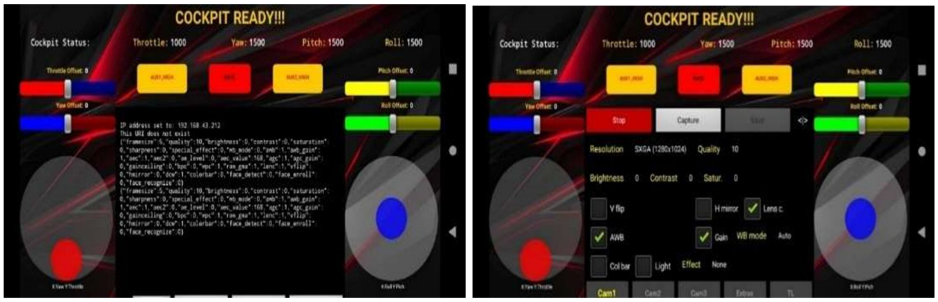

Fig.14 Application Interface at Runtime: Camera starts streaming on Stream button at SXGA quality

Application during runtime at streaming mode is given in Fig. 15.

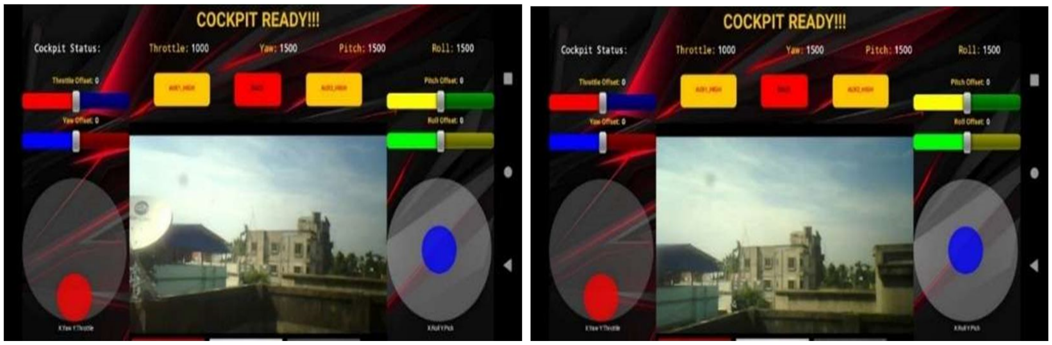

Fig.15 Application Interface at Runtime: Camera Streaming at SXGA quality during Flight

E. Implemented Process Control

The process defined contains many functions. Overview of the process control consists of technical, calculative and methodical steps given below and in Fig. 16. Functions help UAV at flight time includes:

1) MPU6050 Data
2) DMP Data
3) User input for setpoint
4) PID Calculation
5) Output Acctuation
6) Setpoint Setting/Resetting

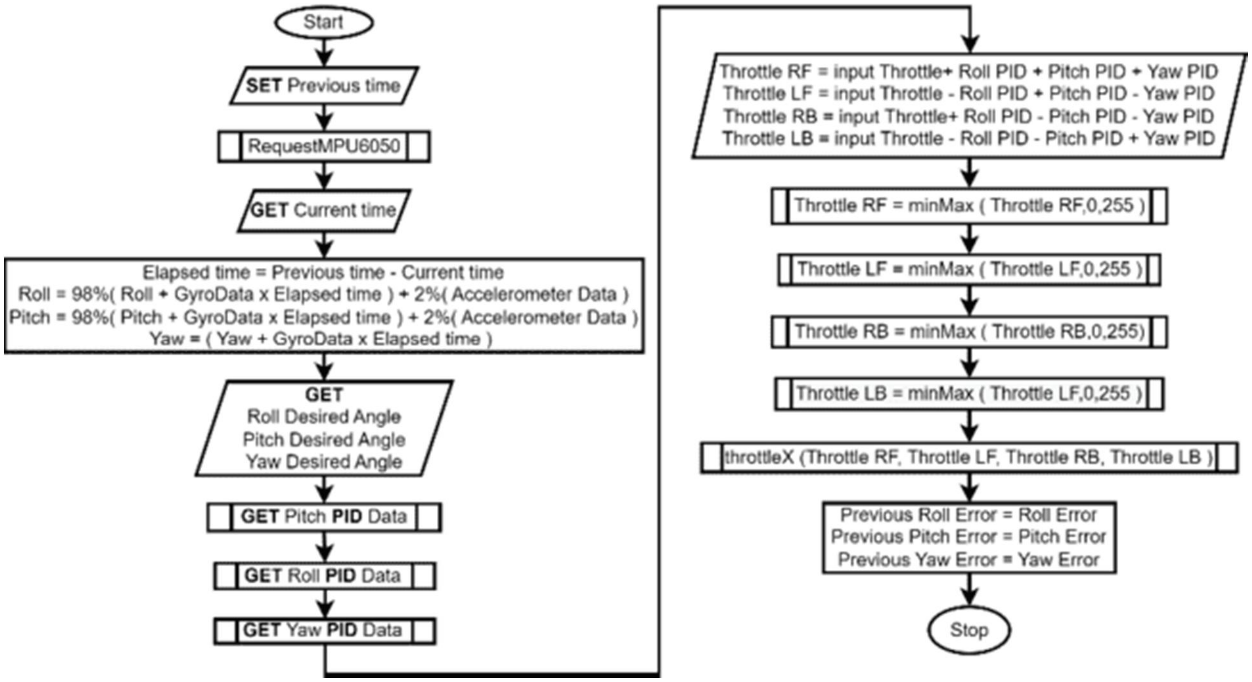

Fig. 16 Process Control

IV. CONCLUSION

Crucial turning points in the development of drones have come when innovations in microelectronics have enabled innovations in physical movement. This is true of the accelerometer and gyroscope data that make it possible for quad copters to maintain stability, and of GPS devices that allow drones to navigate from one point in space to another.

Many of the cargo initiatives plan on such an aircraft that can fly vertically and horizontally so a technically tricky problem to solve hence arises. This is the necessary hump to be overcome if delivery drones are to prove economically viable. Pure quadcopters lack the needed range and endurance; fixed-wing aircraft that can carry a substantial payload need too much space to take off and land. But if delivery drones succeed, they will likely far outnumber all the other uses of drones put together. Drones as observers in the sky will remain important for the indefinite future. They will grow easier to operate. The ease of flying and taking pictures of drones will mask the constraints of tough with higher sensor resolutions, better lenses, cheaper memory counterparts and the greater precision. One of the ideas of this work is to break the system into their fundamental parts in such a way that one can get a detailed study with all pros and cons associated with each unit. This, in turn, will enrich the idea of advancement of open-source work. This work establishes an ease of the reconfiguring dismantle modules along with much-varied library to some extent as a learning model for the future research. However vast scope of future advancement of this work can be recognized by improving in the data reception and extending the boundary limitation of the latitude and longitude and improving the resolution in the data observation part.

V. ACKNOWLEDGEMENT

The open-source embedded processors and integrated development environment (IDE) of Arduino, Esspresif, MIT (Application Development Environment) and EasyEDA tools and others organisation are used due course of this work for which we are highly thankful. Special thanks to New Alipore College, University of Calcutta for providing laboratory support during the development of work.

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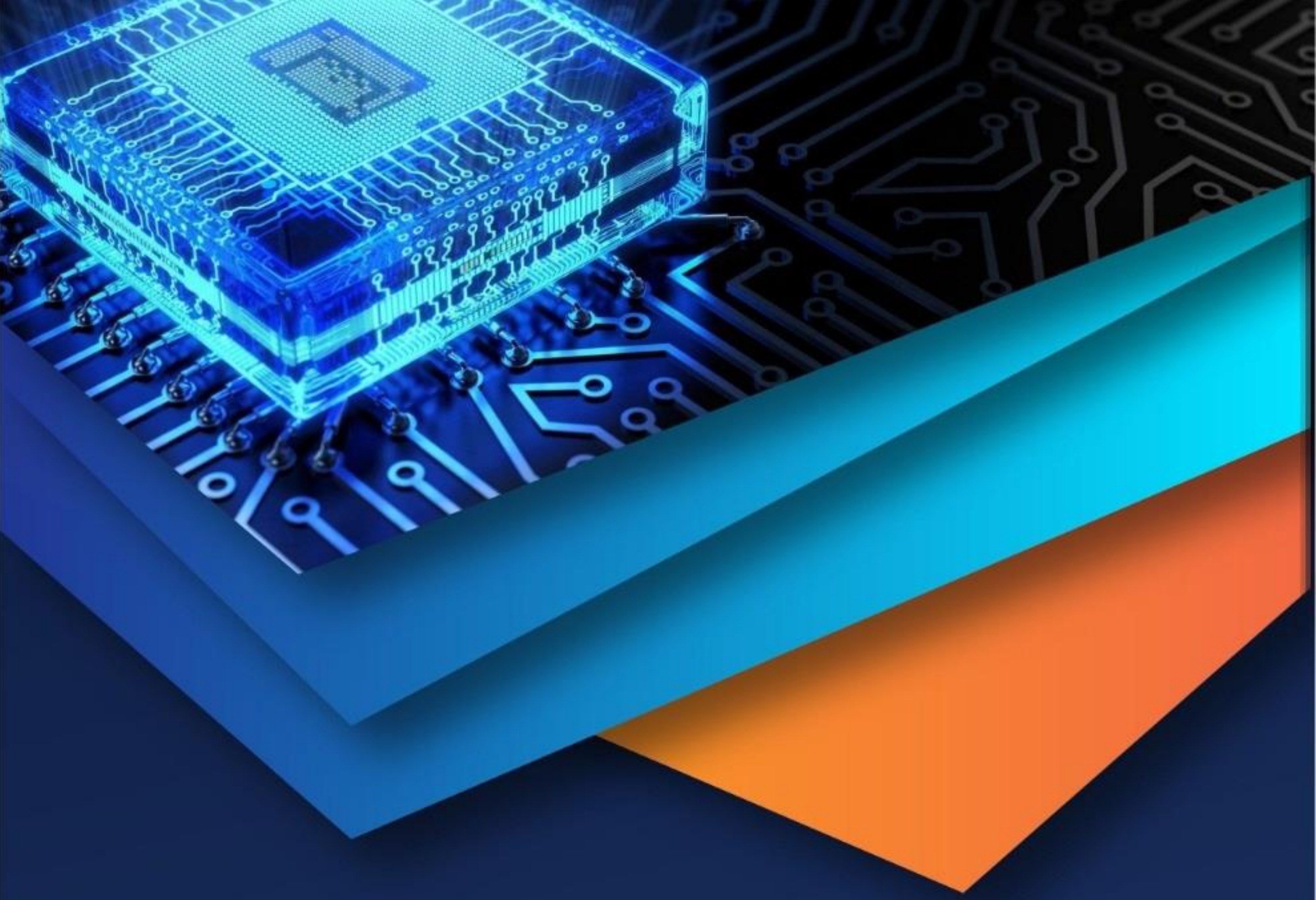

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