FIVE-STAR DRONE RAPID RESPONSE

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Abstract - This paper presents a novel system for rapidly responding to emergencies using drones. It is designed to rapidly assess and respond to natural disasters, building fires, and search and rescue operations. The system has a PI controller, a GPS, and a camera that transmits live video over Wi-Fi. The PI controller is responsible for the stability and control of the Drone during flight, and the GPS provides the Drone's live location. The camera, connected to the Drone via Wi-Fi, captures a live video feed that first responders and command centers can access in real-time through a mobile application and web server. The mobile application and web server allow for real-time monitoring and control of the Drone, enabling fast and informed decision-making. This approach reduces response time and improves situational awareness, thus increasing the safety of first responders. The system has the potential to revolutionize how the emergency response is conducted, making it faster, more efficient, and more effective.

Keywords - Drone, Rapid Response, PI Controller, UAV

I. INTRODUCTION

Humans have always been fascinated by flying objects. This has led to the development of flight theory and a series of inventions that have revolutionized how we travel worldwide. Humans decided to start working on Unmanned Aerial Vehicles (UAVs). It is an aerial vehicle that does not require a person's physical presence and can be remotely controlled or fly autonomously using software-controlled flight plans in their embedded systems. Depending upon the type of wings, they are divided into three main categories: Fixed-wing, Rotary wing, and Flapping wing UAV, among which the rotary wings, commonly known as Drones, are the most common type [1].

Multi Rotor Drones are classified on the number of motors attached to them. Drones are rated from one star to five stars based on various characteristics: Flight time, flight range, repairs, camera resolution, stabilization, GPS, and speed are the contributing factors [2]. With their significant abilities of maneuverability, compact size, and speed, drones find applications in the military and non-military fields. Practical non-military applications in different industries include agriculture surveillance and crop spraying [3], media coverage, and disaster response [4]. It is also used for weather monitoring, firefighting [5], search and rescue, surveillance, and traffic monitoring [6].Similarly, drones have been introduced since their advent, and much work has been done in this field.
Global Hawk is an efficient drone that is the first variant developed for National Security and Drug Prohibition [7]. Predator, its successor initially built by General Atomics, is the most combat-proven Unmanned Aircraft System in the world and has a flight time of approximately 40 hours. As far as non-military applications are concerned, drones have been deployed for both commercial and emergency crises. In case of a medical emergency, a rapid response is expected. In the 2010 earthquake in Haiti, Matternet delivered medication to the affected areas. Matternet also has begun the first urban network of drone base stations in Switzerland's hospitals and labs [8].

Amazon prime air was the first to propose using drones in the delivery field in 2013. And in 2022, they launched their first Drone to provide air shipping [9]. In 2016, DHL's third-generation Parcelcopter tested the delivery of over 130 parcels of urgently needed medicines or sporting goods between automated Skyports in two Bavarian Alpine villages [10]. CyPhy introduced a drone to deliver an asthma inhaler to a remote summer camp on a children's island. The Drone released the inhaler, which was inside a capsule after it landed. The time saved could be critical if a child has a severe asthma attack [11]. Despite all these already present and tested drones, work is underway to make this response as rapid as possible to save time in critical conditions.

The overall working diagram of a Drone is described in Fig. 1.The flight controller gives instructions to the Electronic Speed Controller (ESC)after taking inputs from GPS, camera and sensor modules. ESC controls the speed of motors and ultimately controls drone maneuverability based on the instructions it receives from the microcontroller [12, 13, 14].

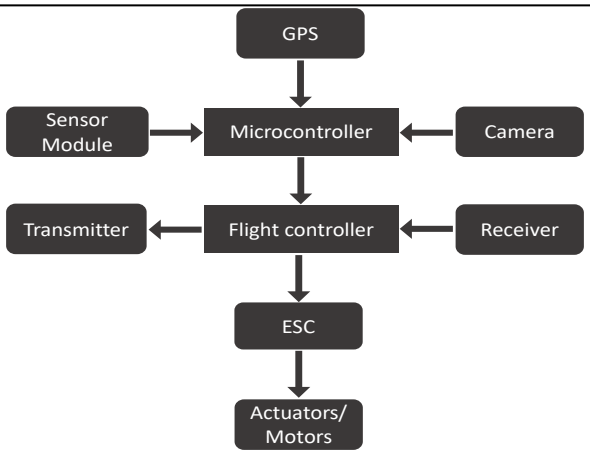


Fig. 1.Block diagram of drone working

Section II of this paper discusses the methodology adopted to design the proposed system. The designing of the controller is done in section III. Section IV discusses the communication system for live feed and location tracking. The working prototype is discussed in section V. Section VI concludes the paper.

II. METHODOLOGY

Rapid response refers to using drones to respond quickly to and address emergencies, natural disasters, and other incidents. Drones can be equipped with various sensors, significantly improving the speed and efficiency of response efforts. Cameras can be attached to drones, allowing them to gather real-time data and images of the situation on the ground, providing valuable information to responders [15]. They can also quickly deliver supplies, such as medical equipment and food, to affected areas. It will eventually result in saving lives and minimizing damage.

Previously, PID controllers were applied to the drones and results were drawn [16]. In this paper, a new method is introduced, which will contribute to the rapid response of the Drone whilst maintaining the Drone's stability. A PI controller is introduced, which helps improve drone flight stability and accuracy. It involves proportional and integral control to accurately regulate the position and speed and adjust in realtime to account for external factors such as wind, rain, or altitude. The basic block diagram of the proposed PI controller is shown in Fig. 2.

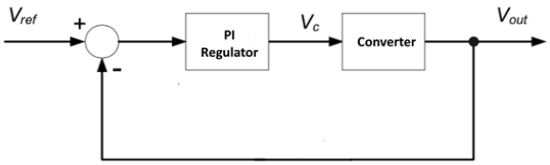


Fig. 2. Basic block diagram of PI controller

Similarly, to keep in check the stability and movement of the Drone, a modified version of the communication system is introduced, which comprises the live camera feed and location tracker. This data is accessible through a mobile application and is accessible over the cloud.

III. CONTROLLER DESIGN

The flight time of a drone depends on various factors, such as the size and weight of the Drone. While designing the optimized design of a drone, the choice of a battery matters a lot. It is required to be of maximum efficiency and less weight. It potentially contributes to increasing the Drone's flight time by allowing it to use a higher voltage power source, which could result in more efficient operation and longer battery life. A boost converter is introduced to tackle this situation, which will help to balance the low-voltage battery.

A. Boost Converter

At first, a simple switch-based boost converter is implemented. The switch is turned on and off at a high frequency, and the inductor in the circuit stores energy during the on-period and releases it during the off-period. This results in an output voltage that is higher than the input voltage. The Simulink model of a simple switch-based boost converter is shown in Fig. 3.

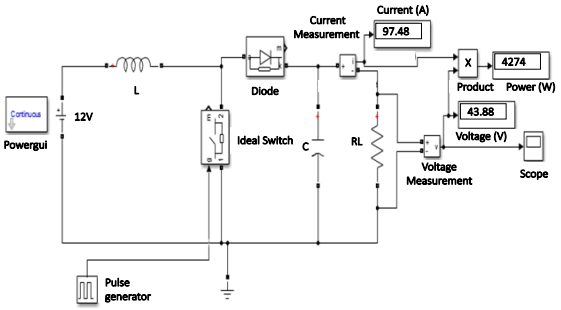


Fig. 3. Boost converter with the ideal switch

While looking at the size and weight constraints of the Drone, in the boost converter, the switch is replaced by a MOSFET. It will act similarly but has more advantages than the simple switch, including lower on-resistance, higher switching speeds, and higher efficiency. This makes them more efficient and suitable for motors used in drones [17]. The Simulink model of this setup is shown in Fig. 4.

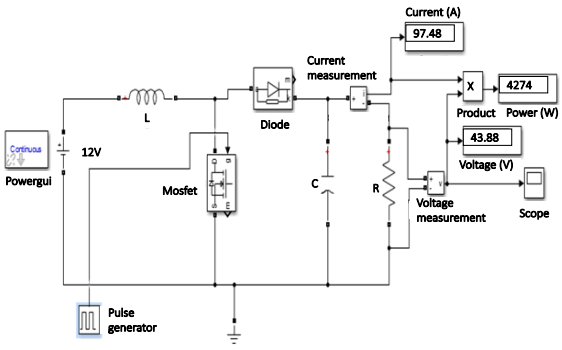


Fig. 4. Boost converter with Mosfet

B. PI Controller

The Proportional Integral (PI) Controller is introduced to minimize the variability of control error and to maintain stability and accurate control of their position and other variables during flight. It is a closed-loop feedback control system to continuously adjusts the control signal based on the difference between the desired and actual output of the system. The proportional gain factor (K_P) adjusts the control signal proportionately to the error between the desired and actual output. The integral gain factor (KI) uses the integral of the error to adjust the control signal.

The Simulink model of implemented PI Controller with Mosfet as switch is shown in Fig.5.

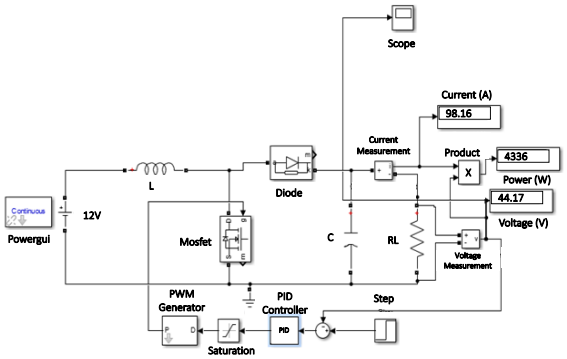


Fig. 5. PI controller with Mosfet as a switch

On different values of K_P and K_I, different responses are observed. The resulting responses are unstable, the settling time is too high and has an abnormal overshoot. The response of output voltage for K_P = 0.00001, K_I = 0, K_D = 0 is shown in Fig. 6.

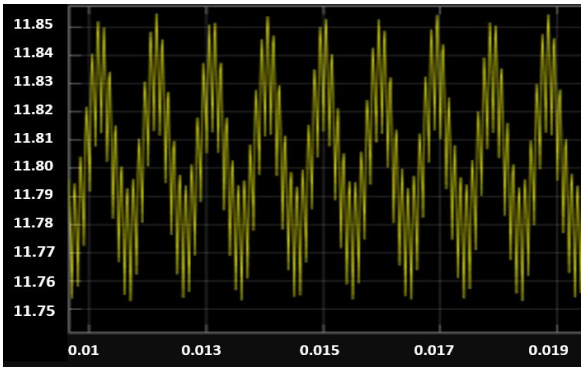


Fig. 6. Output voltage response at K_P = 0.00001, K_I = 0, K_D = 0

Ziegler–Nichols proposed a rule of determining values of K_P, K_I, and K_D after experimentation based on the transient response of the plant. The values of KP and KI involved in the PI controller are calculated after the experimentation based on the transient response of the plant using Ziegler-Nichols Method. The basic steps are as follows.

- First, set all the K_P, K_I, and K_D to zero.
- Begin with a smaller value of proportional controller K_P for your closed-loop system.
- Increase K_P until you get steady-state oscillations. This value of K_P is called K_U.
- Find the period T_u at K_U and then find T_I.

It was observed that the output voltage becomes stable at K_P = 0.005 (K_I = K_D = 0). This value of KP is considered K_u. The value of the time period is observed from Fig. 7.

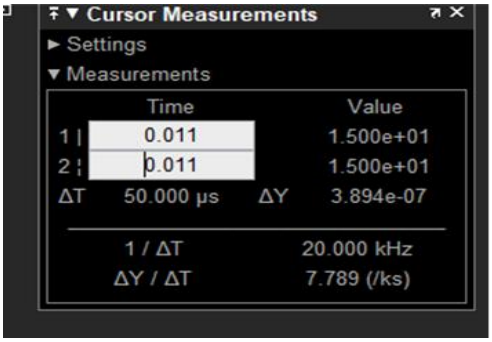


Fig. 7. Time-period for output voltage for K_P = 0.005, K_I = 0, K_D = 0

Parameter	Value	Description
K_u	0.005	It is value K_P at the stable response
K_P	0.00225	$K_P = 0.45 \times K_u$
T_u	50us	From Fig. 7.
T_i	41.7us	Tu/1.2
K_I	54	$0.54K_U/T_U$
K_D	0	PI model is used

Table 1. PID parameters calculated by Ziegler-Nichols method

The values of all parameters of PID as per the Ziegler–Nichols Tuning Method are calculated in Table1. The response of the boost converter with PID controller output as per the values in Table 1 is shown in Fig. 8.

The Derivative Control is omitted because there is a risk of overshoot, which will slow the system. Thus, making it dangerous for the Drone will eventually negatively impact the rapid response.

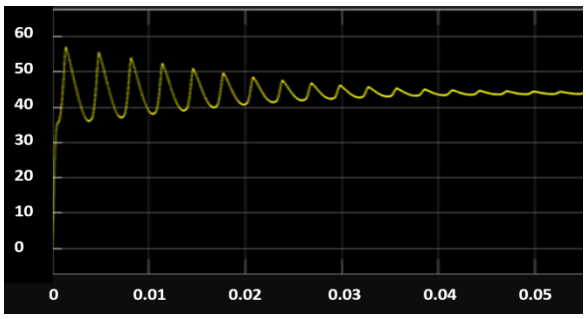


Fig. 8. Output voltage response at K_P = 0.00225, K_I = 54, K_D = 0

IV. COMMUNICATION SYSTEM

A. Live Feed over Wi-Fi

A live feed of a drone over Wi-Fi is necessary to remotely view the video and data captured by a drone in real-time, using a Wi-Fi connection. For this purpose, Wi-Fi communication is used for short-

range video transmission without an internet connection. A camera is installed on the Drone, and IP webcam android software for video transmission has been used. It provides a live video stream accessed via local and global computers. For local communication, it uses Wi-Fi communication. The mobile device and the onboard computer must be connected to the same Wi-Fi network. On the other hand, Ivideon cloud streaming is supported for instant global access. In addition, two-way audio transmission is also possible in this software.

B. Live Location Tracker

A GPS receiver is installed on the Drone to track the real-time location of the Drone. The functional architecture of this module is shown in Fig. 9.This live location architecture works in such a way that it acquires the data from the GPS module mounted on the Drone, this will then be sent to the microcontroller. Eventually, this location data will be sent to the application. Now, this data will be sent to the webserver. Also, simultaneously, the user can view the coordinates of the Drone on his smartphone. For displaying data using Google Map API v3, it draws a red line through each point it has travelled.

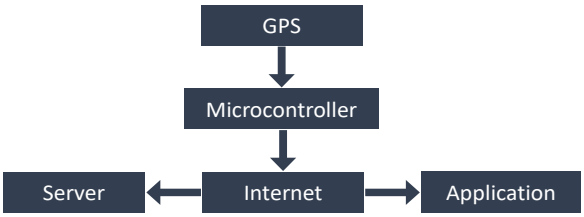


Fig. 9. Flow diagram of live location tracker

In addition, it records data on when it starts its journey and stops and displays the average speed and distance based on this data. The computer can also access this data anywhere since it is stored on the server. For the test purpose, we have built a website in an accessible hosting server that can be accessed from mobile and computer.

V. PROTOTYPE

The following section shows the parametric study related to weights, layouts, and components, which can be used to deduce the load-lifting capability of quadcopter design. For calculating total weight to calculate the thrust required ultimately, the parts of the Drone are to be selected.

A. Components used

The quadcopter assembly consist of the following parts.

- BLDC Motor and Propellers
- Frame
- Electronic Speed Controller
- LiPo Battery
- Flight controller
- Radio system
- Battery Checker or Voltmeter
- NRF Wireless module and Arduino

B. Altitude and flight time

An average drone's flight time is between 10 minutes to 30 minutes. Flight time is not an independent parameter. Rather it depends upon payload, altitude, and other environmental factors. The drone system proposed in this work is targeted to have a maximum flight time of 35 minutes hovering at a maximum height of 2000 meters.

C. Weight specification

The estimated weights of the components selected are,

- Frame Weight = 382 g
- Weight of 4 ESC = 30 × 4 = 100 g
- Gens Ace LiPo Battery (Voltage = 11.4 v) Weight = 349 g
- BLDC Motor (920 kV) Weight = 96 × 4 = 384 g
- Miscellaneous (Propellers, GPS unit, Flight Controller, etc.) = 350 g approx.
- Total weight = 1565 grams

D. Thrust calculations

The thrust generated by the propeller must be greater than the weight of the UAV. Otherwise, the Drone will not fly. The RPM value is given for thrust calculation by multiplying the motor KVA rating by the battery voltage.

$$RPM = 920 \times 11.4 = 10488$$

Thrust force can be calculated using the numerical method proposed by Gabriel-Staples.

$$F = 13.72\ N = 1398.57\ g$$

This value is for 100% efficiency, calculating 'F' for 70% efficiency as budget motors are assumed to have efficiency around 70%.

$$1398.7 \times 70/100 = 979\ g$$

This falls within the range given by the manufacturer, so theoretical calculations are correct. For four motors

$$F = 979 \times 4 = 3916\ g$$

As a thumb rule, calculating thrust at 50% throttle for dynamic quadcopters.

$$979 \times 4 \times 0.50 = 1958\ g$$

Finally, subtracting the weight of all the quadcopter parts to determine the load lifting capacity of the quadcopter other than its weight,

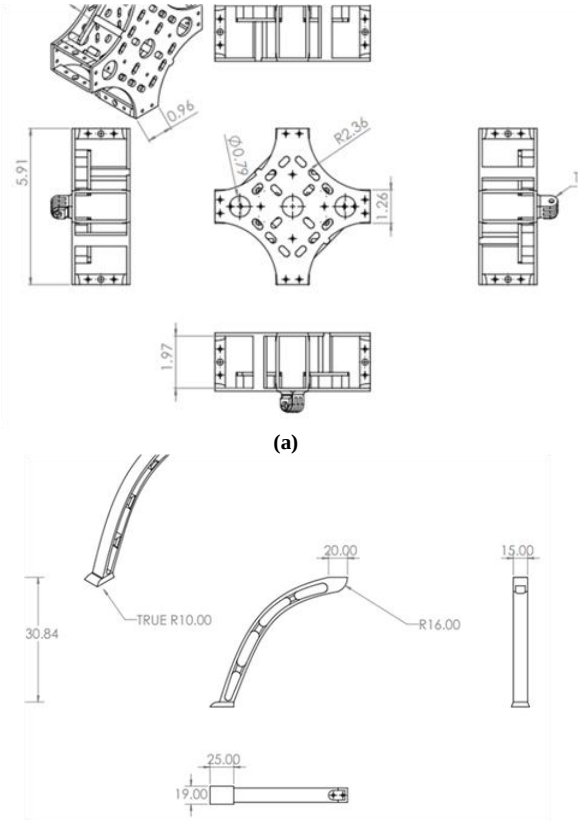
$$\text{Payload Lifting Capacity} = \text{Thrust} - \text{Total Weight of the quadcopter}$$

$$\text{Payload Lifting Capacity} = 1958 - 1565 = 393\ g$$

The cooperative payload-lifting capability depends upon the payload configuration. If the payload is directly beneath the two quadcopters and has evenly distributed mass, the assembly could lift twice the lifting capacity of a single quadcopter. Thus, based on the current design, a single quadcopter can lift 393 grams of weight.

E. CAD Model

The frame has a top plate, a bottom plate (with an integrated power distribution board), and four arms. The Solidworks model of the frame selected is shown in Fig. 10.



(a)

(b)

Fig. 10. (a) Drawing of the main base, (b) Drawing of legs of quadcopter

After manufacturing/procuring various parts, the final Drone assembly was made. A successful test flight of a Drone was the first benchmark. So, after the complete manufacturing of the Drone, it was initially tested for structural integrity. The working of the motor and propeller were checked. The functioning of all control surfaces in accordance with the radio controller was checked. The final drone assembly is shown in Fig. 11.



Fig. 11. Prototype of Drone

VI. CONCLUSION

The main aim of this project was to develop a five-star rated drone that can be used in quick response applications and delivering lightweight products. The 2.4 GHz radio frequency transmitter, receiver, microcontroller, electronic speed controller, brushless DC motor and servo motors were used to control the Drone. A PID controller with a boost converter was designed and tuned for the system to adapt automatically. Live location tracking architecture was proposed for advanced navigation. Live location tracker and live feed output was also incorporated into this Drone, thus, improving the efficiency and contributing to the rapid response of the Drone in time of crisis.

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