Design and Development of a UAV-Based Delivery System for Disaster Relief Operations

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Abstract: **In many disaster-prone areas the responders team faces several issues like transportation, communication and networking which intern results in the delay of essential supplies and services. This work presents the design and development of an Unmanned Aerial Vehicle (UAV) based delivery system that is used for disaster response application. This proposed UAV is integrated with autonomous navigations, GPS based way points tracking and wireless communication media for long range operations. This system mainly consists of a lightweight air frame, optimized payload capacity and an electro-mechanical dropping mechanism which ensures efferent transportation and safe delivery of medical kits and essential supplies to the disaster-prone areas.**

Key words: Unmanned aerial vehicle, Autonomous navigations, GPS based way points tracking, Wireless communication, Electro-mechanical.

I. Introduction

Natural calamities such as earthquake, landslides, can often cause disruption to transportation and communication networks which makes it difficult to deliver essential supplies to the affected population. The conventical logistics are often slowed down due to the damaged infrastructure, hence we need an autonomous and reliable system that can be operated in inaccessible environments.

The unmanned aerial vehicles (UAV) is an emerging solution to address these challenges. Some of the capabilities of the UAV's are vertical take-off and landing, follow autonomous flight paths and access to remote areas or hazardous locations which make them highly suitable for disaster relief operations. More over these UAV's can be deployed immediately with minimal ground support which signifyingly reduce the responders time during emergencies.

The UAV based delivery system that is developed in this study has been indigenously designed and fabricated which emphasizes both structural efficiency and autonomous functionalities. The quad copter platform is equipped with Pixhawk 2.4.8 as its flight controller, which serves as the main core of the control and navigation system. This controller also integrates the data from the on-board sensors like barometer, inertial measurement unit (IMU) and GPS module for flight stability and précised way-point based missions. The UAVs system consists of four 920KV brushless motor which is driven by an electronic speed controller (ESC), providing the necessary thrust and maneuverability for stable flight under varying payload conditions. Power is supplied by a rechargeable Li-Po battery optimized for endurance and weight balance.

A custom-designed servo-actuated payload release mechanism is integrated into the drone to facilitate accurate and safe delivery of relief materials. Upon reaching the designated coordinates, the servo motor is triggered by the Pixhawk through pre-programmed commands, ensuring smooth and controlled release of the payload without disturbing flight stability. This design enables precise drops even in constrained or uneven terrains, making it suitable for real-world disaster response scenarios.

II. Related Work

In [1], This study aims to develop a quadcopter with a paint spray system for precise aerial marking. The goals include systems integration, drone testing, and component selection. Important calculations such as lift, thrust per motor, and a multitude of other parameters critical for stable flight, motor efficiency, and operational purpose-driven effectiveness are fundamental in the methodology. Undoubtedly the most significant practical result of the study is the addition of a paint spray unit to the UAV interfaced with a PC for construction layout marking and other site supervision functions that demonstrate purposeful use of UAV technology. The preservative mechanical allocation hypotheses also tacitly solve some of the design problems of the vertical flight machines.

In [2], the study describes the design of a UAV that is used for healthcare application. It aims to provide faster and safe delivery of medical emergent supplies to remote areas. It also consists of an OTP-based verification system, and a live telemetry to ensure secure and a contactless delivery. The customer authentication framework is build using a firebase to store user data and delivery OTPs. The system also consists of a camera that captures the recipient's image for the confirmation of the delivery. It also provides the information about the capabilities of the quad copter that is capable of delivering a payload of 200 grams across a distance of 250 meters.

In [3], the study describes about the analysis of 325 electronic speed controllers (ESCs) from 18 different manufacturers which are focusing on various field such as control systems, design, cooling mechanisms and overall performance of UAV. The UAVs performance is analysed by various methods such as traditional PWM and various moder protocols like DSHOT and CAN interface. The ESCs analysis is based on software platform that are used for its configuration and hardware analysis is done by the architecture that is used in it. Some of major types of architecture is sandwich, case and carrier PCB. The research provides a detail on performance optimization of UAV which includes balancing, heat dissipation, power density, and circuit board efficiency through multilayer PCBs and advance cooling systems.

In [4], this study describes the application of an UAV in the domain of disaster management. It talks about an innovative UAV-based evacuation guidance system designed to assist in disaster relief scenarios, particularly where conventional ground infrastructure or sensor networks may be compromised When communication with an evacuee's mobile terminal is possible, the UAV transmits evacuation routes directly. Otherwise, a small UAV is deployed mid-air to guide the evacuee to safety. This dual-UAV strategy enables effective guidance without reliance on ground-based IoT devices, making it resilient against infrastructure failure. Simulation results validate the system's ability to reduce evacuation completion times and ensure scalable, autonomous operation in large-scale disaster zones.

In [5], the study describes the application of UAV in the domain of surveillance and security. It presents the design and implementation of an autonomous surveillance drone system aimed at real-time video monitoring in areas where human access is difficult, dangerous, or delayed. The system integrates a flight controller with GPS, ultrasonic sensors for obstacle avoidance, and a Raspberry Pi module with a camera for live video streaming. The drone follows a pre-mapped waypoint path using telemetry control and utilizes a Wi-Fi-enabled Raspberry Pi to transmit real-time video feeds through a browser-accessible IP interface. This architecture allows remote observation of disaster zones, critical infrastructure, or security-sensitive regions. The drone autonomously navigates between target coordinates, streams live footage during surveillance stops, and returns to base without manual intervention. The project effectively demonstrates the utility of UAVs as cost-effective, efficient surveillance tools in both civilian and emergency applications.

III. METHEDOLOGY

The development process of the proposed UAV based delivery system is carried out in multiple stages. These stages play a prominent role in the development of the system these stages are

- Design and structural development
- Hardware integration
- Software configuration
- Payload Mechanism

Each stage was carefully planned and executed to ensure flight stability, accuracy and reliability in real world disaster scenarios.

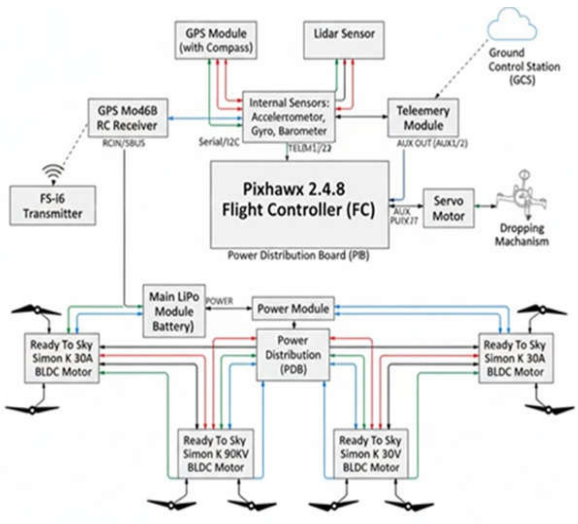

FIG 1: Overall Block Diagram

1) Design and structural development: This section mainly deals with the structure, aerodynamics and the motion of the Unmanned Aerial Vehicle. The quadcopter used in this study is indigenously designed and fabricated which mainly focuses on achieving balance between the payload capacity, flight stability and the structural integrity. The air frame is built using glass fiber and Polyamide-Nylon to ensure high rigidity and low weight which minimizes the power consumption during the flight. The air frame design follows an 'X' configuration where the four arms are symmetrically positioned at an angle of 90° which ensures equal thrust distribution and improved roll and pitch control.

Each arm is equipped with a Brushless DC (BLDC) motors paired with high efficacy propellers to generate lift. In these four motors, two of them rotate in clockwise (CW) direction and the other two of them rotate in counter clockwise (CCW) direction, to provide lift, stability and control of the drone. They play a prominent role in maneuvering and keeping the copter air born.

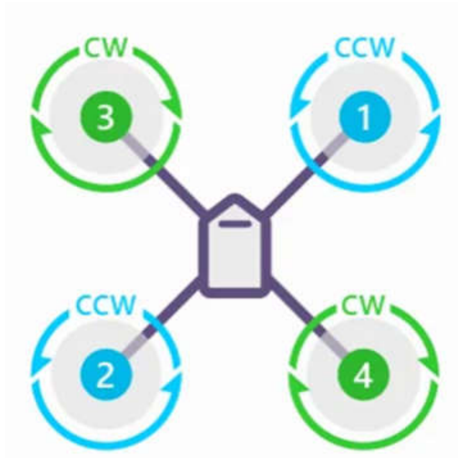

FIG 2: Direction of the Motors to provide lift

Throttle (Lift): The total upward thrust is controlled by increasing or decreasing the speed of all four rotors simultaneously. When the combined thrust equals the weight of the UAV, it hovers steadily; higher thrust results in ascent, while lower thrust causes descent.

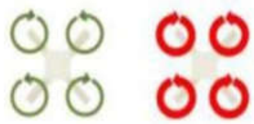

Fig 3: Move down Move up

Pitch Motion: The forward and backward movement is achieved by changing the relative speed of the front and rear motors. Increasing the speed of the rear motors while decreasing the front causes the drone to pitch forward and move ahead, and vice versa to move behind.

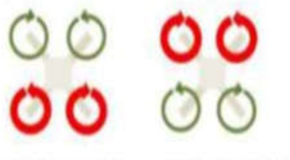

Fig 4: Move forward Move backward

Roll Motion: Lateral motion (left or right) is produced by varying the speeds of the motors on one side relative to the other, allowing the UAV to roll and move sideways.

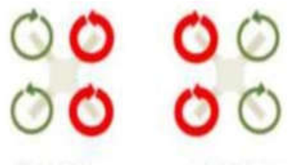

Fig 5: Bend left Bend right

Yaw Motion: Rotational movement about the vertical axis is controlled by adjusting opposite motor pairs in counter directions, creating a torque differential that enables the UAV to rotate left or right.

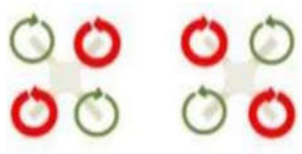

Fig 6: Rotate left Rotate right

2) Hardware integration: The hardware integration plays a significant role in ensuring stable flight, accurate navigation and reliable pay load delivery. The system integrates multiple subsystems like propulsion, control, power distribution, communication and payload mechanism. All these systems are coordinated with the help of Pixhawk 2.4.8 as the flight controller. Each sub-system is designed for a specific operation in real time decision making and executed during flight operation.

The Pixhawk 2.4.8 serves as the central processing unit of the UAV, responsible for receiving sensor inputs, processing flight data, and generating appropriate control outputs for the motors and actuators. It supports multiple communication protocols such as PWM, I2C, UART, and CAN, enabling a robust interface with the peripheral components. The flight controller is also equipped with an internal Inertial Measurement Unit (IMU) consisting of a 3-axis accelerometer, gyroscope, and magnetometer, which continuously monitor the UAV's orientation, angular velocity, and heading. The barometric pressure sensor aids in altitude estimation and the GPS module provides real-time positioning and navigation data essential for autonomous flight.

Pixhawk also communicates with the ready to sky 30A SimonK electronic speed controller (ESC) that regulate the BLDC motor speeds based on the control commands provided by the flight controller. Each motor–ESC pair is connected through PWM channels with feedback process in real time to maintain attitude stability and thrust balance.

The integration of a customized power distribution plate ensures that electrical power from the 11.1V Li-Po battery is efficiently distributed to all components. The Battery Eliminator Circuit (BEC) provides a regulated 5V and 3.3V power rails for low-voltage peripherals such as the GPS module, telemetry system, and sensors.

The telemetry module operates typically at 433 MHz frequency band which enables two-way data between the drone and the ground control station (GCS). This communication is essential for monitoring flight parameters, updating mission waypoints, and observing real-time feedback such as altitude, battery status, and system health. The telemetry plays a crucial role in failsafe mechanism and returns to launch (RTL) in case of signal loss, low voltage, or system anomalies.

For autonomous payload deployment, a servo motor-based drop mechanism is integrated into one of the auxiliary output channels of the flight controller. The servo motor is triggered through mission commands or manual input from the GCS to release the payload at a designated location. The mechanical clamp used for the drop system is designed to hold the package securely during flight and release it accurately upon command, ensuring minimal vibration-induced disturbances.

3) Software configuration: The software configuration of the UAV system mainly focuses on the flight stability, mission planning and autonomous payload deployment. The integration of both onboard firmware and ground control software which ensures seamless interactions between hardware components. The operator can enable fully automated or semi-manual flight operations.

The Pixhawk 2.4.8 flight controller operates on Audio Pilot firmware, which is an open-source platform which is widely used in research and application field for multi-rotor system. The ardupilot provides a robust flight algorithm for altitude stabilization, sensor data fusion, way point navigation and fail safety handling. Upon installation of the firmware on the flight controller it is configured by using Mission Planner software which also acts as the Ground controller station (GCS) for the UAV. It also offers an inclusive interface for parameter tuning, calibration and mission setup.

During the system initialization of the system the firmware is flashed into the Pixhawk 2.4.8 through USB connector. The radio calibration procedures are performed to map the transmitter channels to the corresponding control axes like throttle, roll, pitch, and yaw. The ESC calibrations are conducted to synchronize the throttle range across all four motors which ensures uniform thrust response. Then the accelerometer and compass are calibrated to align the IMU sensors and eliminate magnetic interference to maintain stable flight and accurate heading control.

The GPS module is configured through Mission Planner software to establish a stable satellite lock and provide real-time position of data for navigation purpose. The failsafe parameters are programmed to trigger the Return-to-Launch (RTL) or automatic landing in cases of low battery voltage or loss of communication link. The PID control loops are fine-tuned based on the drone's weight, motor thrust, and environmental conditions to optimize for attitude response and minimize oscillations during the flight.

In case of autonomous operations mission waypoints are created using the Mission Planner's map interface. Each waypoint included altitude, speed, and action commands, allowing the UAV to perform pre-defined tasks such as take-off, waypoint traversal, hovering, payload release, and return-to-home. The servo-based payload release mechanism is configured using the auxiliary output channel which is controlled by Mission Planner software and activates the servo at a specific mission stage.

4) Payload mechanism: The payload mechanism is an important subsystem of the UAV delivery platform. It is designed to ensure carriage and precise release of relief materials in disaster-affected areas.

The design employs a servo motor–driven release mechanism, which controls the actuation for holding and releasing payloads. The payload clamp is a lightweight, high-tensile structure fabricated using 3D-printed PLA plastic to minimize the mass while maintaining structural strength. The clamp operates through a rotational latch system, in which the servo arm actuates the gates that locks the payload during flight and releases it upon receiving an electronic signal from the flight controller.

The servo motor used in this system is Tower Pro MG 90S which is connected to the auxiliary output channels on the Pixhawk 2.4.8 flight controller. The control logic to the mechanism is fed through the mission planner in which a specific PWM value is corresponded to the lock position and another value that corresponds to the release position. This type of configuration allows both manual control from the ground station and automatic tracking during way-point based mission.

In case of automatic dropping mechanism, the Pixhawk monitors the UAV's position using onboard GPS module and executes the payload release command once the aircraft reaches the designated delivery way point.

IV Implementation

The implementation phase of the proposed UAV based delivery system is focused on transforming the conceptual design into a fully functional and operational prototype what is capable of autonomous flights and précised pay load deployment. This process involves careful assembling of hardware components, integration of electronic modules and configuration of control system to achieve a full fledge operational UAV.

The mechanical structure of the UAV is designed using a glass fiber with Polyamide-Nylon that offers both durability and aerodynamic efficiency. The frame is configured in an 'X' layout to ensure thrust distribution and stabile flights characteristics. Four Ready To Sky 920kV BLDC motors are mounted symmetrically at the arm's end, each of these motors are connected to Ready To Sky 30A SimonK ESC. This type of configuration provides the required thrust and smooth motor response for stable hovering, maneuvering and altitude control. All these ESCs are programmed for rapid response and are synchronized with the flight controller to efficient speed modulation and torque balance during flights.

The core of system uses Pixhawk 2.4.8 as the main processing unit which is responsible for maintaining all flight operations. It is also responsible for processing the sensor data, control motor speed and execute all the flight commands. This controller also has an inbuilt IMU and barometer which helps the UAV to determine its attitude and altitude. A NEO 7M GPS module with integrated compass is interfaced with the Pixhawk for précised geolocation of the UAV and achieve way point navigation during autonomous missions. The UAV is also equipped with the fly sky i6 transmitter and receiver that is used manual flight operations. It also offers a two-way communication interface and also allows manual overriding of parameters.

The electrical and communication systems are wired with the power distribution plate that supplies and regulates power to all active components. The power is supplied by an ABSD 2200 mAh Li-Po battery which also acts as the main power source for the UAV. All sensitive components such as the flight controller are mounted on a vibration isolator to reduce the signal noise and improve the stability. All components are arranged in the center of the structure to maintain the center of gravity that is close to the geometric center which ensures consistent balance and control during maneuvers.

The process of software configuration the firmware is flashed into the flight controller and calibrated using mission software. The calibration process consists of making the ground positions of the IMU sensors like accelerometer, gyroscope and compass to ensure that all components are aligned and oriented. The ESCs are calibrated to ensure all four motors are synchronized to run at the same speed and time. The PID controllers are tuned repeatedly to achieve smooth flight performance. Waypoint and autonomous flight paths are programed in the mission planner enabling the drone to operate without the manual input using the transmitter and maintain stability and course accuracy. The telemetry provides real time-flight data that includes altitude, position, battery status and to allowing it for adjustments during field testing.

The payload release mechanism is designed to deliver relief supplies to accurate locations. A servo motor-based release clamp is installed below the drone and ensure the center of gravity is balanced properly. The clamp is controlled by through an auxiliary channel connected to the Pixhawk 2.4.8 flight controller. The servo is programed to activate at a specific point in the mission that ensures that the payload is released only at the predefined dropping coordinates. This mechanism is tested under various conditions to verify the reliability, response and to minimum disturbance.

V Results

The developed UAV-based delivery system underwent a series of controlled field tests to evaluate its flight stability, navigation accuracy, payload handling capability, and overall system performance. The testing was conducted under moderate weather conditions to simulate realistic operational environments that is encountered in disaster-prone regions. The primary focus of the evaluation is to verify its autonomous flight control, waypoint tracking, and précised payload deployment.

During the initial flight trials the UAV was highly unstable due to improper PID tuning and low response. Later on proper PID tuning the UAV exhibited high stability. The quadcopter also achieved smooth vertical take-off and hover stability at various altitudes, maintaining position hold with minimal drift. The PID tuning proved effective orientation control even under light disturbances. The system is capable of hover for a time of 18–20 minutes under a standard payload of 500 grams.

Fig 7: Stable operation of the UAV

The navigation system performance is evaluated by executing autonomous missions that are programmed through Mission Planner. The Neo 7M GPS module provides an accurate positional data, maintaining a deviation of less than 1.5 meters from the desired waypoints during the flight. The UAV successfully followed predefined flight paths and returned to its take-off point autonomously using the Return-to-Launch (RTL) feature, which confirms the reliability of its GPS-based navigation and waypoint management system. The integrated compass ensured accurate heading control and reducing orientation drift throughout the missions.

The payload delivery system the performance of the servo-operated release mechanism functioned with high reliability and precision. The payload is successfully released at the assigned drop zone with an average positional error of less than 1 meter which demonstrates the accuracy of the delivery system. Multiple tests have confirmed that the actuation timing and release sequence are consistent and unaffected by minor flight vibrations. The mechanical clamp held the payload securely during the flight path and preventing premature release or oscillations.

The communication and telemetry system have also performed efficiently. The FS-i6 transmitter and receiver have ensured strong signal stability during manual control operations, while telemetry data transmission between the UAV and ground control station remained uninterrupted during the test flights. The Real-time monitoring of altitude, battery voltage, and positional data allowed continuous supervision and quick response to flight variations.

In the overall system evaluations have confirmed that the implemented UAV can effectively perform autonomous missions by maintaining stable flights and deliver payloads with high precision. The integration of the Pixhawk 2.4.8 flight controller with Ready to Sky propulsion components, and GPS-based navigations have yielded a reliable aerial platform that is suitable for emergency supply delivery. The system demonstrated consistent performance across repeated trials, validating its design and functionality for potential deployments in disaster relief and remote logistics applications.

VI References

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