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Design and Implementation of an Autonomous Logistic UAV for Last-Mile Delivery

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Abstract
This research paper proposes the concept of creating an Autonomous Logistics Unmanned Aerial Vehicle (UAV) that is able to transport medical equipment or other small parcels quickly and safely. It is of great value in case of an emergency or in an area with bad roads where transportation is slow. This drone has a flight controller that maintains the stability and balance of the drone during flight. In addition to this, there exists a Raspberry Pi 4, which can be used to handle more advanced and intelligent functions. The UAV can travel independently by utilizing the GPS and waypoint navigation technique. It can travel through its desired path automatically without being controlled by human intervention all the time. With the route planning technique, it can plan the best route to its destination. For improved safety, the drone will possess ultrasonic sensor, which will be used to sense obstacles and avoid them when flying. The drone has a wireless telemetry system. This allows the operators to operate the drone using real-time control using software Mission Planner. The drone has a secure system to transport the payload. Furthermore, the drone has a battery system that monitors the battery usage. However, the paper states specifications of components, developing procedure, testing, and result of working model.
Keywords: *UAV, Pixhawk flight Controller, Raspberry pi, RVNC, Clockwise Anticlockwise mechanism.*

1. Introduction
The Autonomous Logistics UAV is an unmanned aerial vehicle that will be used for the efficient and safe transportation of goods. The proposed system will be able to carry a payload of up to 1 kg. The proposed unmanned aerial vehicle will be designed with the following components: high-speed motors, propellers, a stable frame structure, a battery management system, a GPS module that will enable accurate positioning and navigation, multiple sensors such as ultrasonic sensors that will enable obstacle avoidance, and the capability to enable real-time monitoring and communication through the use of telemetry. The proposed unmanned aerial vehicle will be designed for the efficient and safe transportation of goods. The proposed system will be able to carry a payload of up to 1 kg. The proposed unmanned aerial vehicle will be designed with the following components: high-speed motors, propellers, a stable frame structure, a battery management system, a GPS module that will enable accurate positioning and navigation, multiple sensors such as ultrasonic sensors that will enable obstacle avoidance, and the capability to enable real-time monitoring and communication through the use of telemetry.

2. Literature Review
Abhishek Sharma, Sagar Chaudhari, and Aakash Tiwari (2025) point out the challenges in the drone delivery system and propose a solution to reduce them by integrating advanced AI, which enables drones to navigate complex surroundings, optimize routes, and handle deliveries. This invention holds great promise for transforming last-mile delivery, reducing business traffic, and lowering carbon emissions. Limited battery life, environmental obstacles, and rainfall conditions are some of the limitations that need to be overcome through wide renunciation.[1].

Pannee Suanpang and Pitchaya Jamjuntr (2024) state the challenges in last-mile delivery due to the rise in e-commerce, which include high cost. They studied the previous method and challenges in the delivery system and also looked at urban micro-depot operations. They conclude that there is not enough evaluation of technologies in terms of environmental and commercial aspects. [2] Mrs. Vijaylaxmi S. Sadlapur and Mrs. Jyothi Wadgeri (2018) explore how the delivery and surveillance sectors are impacted by autonomous drones. AI-based navigation and real-time data analysis can greatly improve logistics and emergency management. The authors also point out that issues such as security risks, public safety concerns, and a lack of consistent international regulations are still to be addressed for widespread use of the system.[3] Kalani Gunaratne, Amila Thibbotuwawa, Alex Elkjaer Vasegaard, Peter Nielsen, and H. Niles Perera (2022) studied about the Sri Lankan vaccine cold chain as a case study and look after UAV's address to last-mile logistic issues in Healthcare supply chains in low-income countries. They showed how a drone-based delivery system can have low operational cost, speed up delivery time, and be harmless to the environment in terms of carbon emissions as compared to a traditional road-based system.[4] Khin Thida San, Sun Ju Mun, Yeong Hun Choe, and Yoon Seok Chang (2018) developed a model of a delivery drone that can lift up to 700 g of weight. The research states the proper specification of each component along with its functions and performance parameters. The authors provide all detailed calculations used to develop the model. Before flight, during flight, and after flight, conditions are traced, and according to these conditions, how the model works is pointed out in this paper.[5] Jack Saunders, Sajed Saeedi, and Wenbin Li (2021) provide a review of autonomous aerial vehicles for package delivery. From managing payloads to mapping roads, they point out the major technical challenges to keep control and stability while functioning. Design, environmental and regulatory factors are also considered in the paper. Overall, the study states the need for integrating system-level solutions to ensure safe delivery, maintaining secure and scalable system performance. [6] Fang Li and Oliver Kunze (2023) proposed the review of Air drones (UAV's) and Delivery Bots (SUGVs) for Automated last mile home delivery. In their research, they provide a comparison of different components used by different industries to develop UAV's. The study also considers direct drone delivery: single stop, multiple stops, along with indirect drone delivery via multiple mini hubs in remote areas, providing deep knowledge about route mapping and planning. The paper states a new concept of SUGV delivery via public transport. [7]
In their 2021 study, Taha Benarbia and Kyandoghere Kyamakya state a review of drone-based package delivery logistics systems and their Implementation Feasibility. The paper addresses the comparative study between literature sources, problem addressed, contribution, modelling and analyzing method, and its limitations, which provides an overview of previous research. Adapting some of the models stated by authors to the real world would be a valuable contribution to industry and academia for drone-based parcel delivery. This review of existing studies and theories on drone delivery systems in logistics might be used to develop a conceptual framework that defines the key concepts to design a system in cost effective way.[8] Kaya Kuru, Darren Ansell, Wasiq Khan, and Halil Yetgin (2019) analyzed and optimized swarm technology in a logistic drone delivery system where multiple drones are integrated in between and can communicate. It is similar to fleet management technology, which is normally used in ground vehicles. The Authors focused on these technologies to provide a wide view of an intelligent delivery platform. The paper states that swarm technology introduces factors like time saving, cost-effectiveness, and several loads at a time in the logistic drone delivery system.[9]

3. Methodology

3.1.Components used and their justification

- The Q450 frame refers to a quad copter frame which is a 4 rotor frame. The frame is used to build drones. The frame's motor placement extends 450 mm from one motor to another. The frame has three essential qualities of being lightweight and durable while offering simple assembly. The system achieves its optimal performance through its precise

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combination of dimensions and maximum weight it can transport. The system includes sufficient room for installing both batteries and controllers.

- The motor uses electrical energy from the Li-Po battery to produce mechanical power which drives the propeller rotations. 1000 KV provides moderate RPM with good torque which ensures robust flight, good capacity to carry the load and efficient power usage. The system has instant responsiveness to changes made by the flight controller.
- The Electronic Speed Controller (ESC) is an electronic device used for controlling the speed, direction, and in some cases, the braking of an electric motor. ESC is used in drones, RC cars, electric bikes, etc. The ESC works on the principle of controlling the power supply from the battery to the motor. In the case of a brushless DC motor, the ESC regulates the DC voltage from the battery and supplies a three-phase AC voltage for the smooth running of the motor. The speed of the motor is also controlled by the ESC. It receives a command and adjusts the speed of the motor accordingly. In simple words, the ESC is the "Throttle Control" of an electric motor.
- The 1045 propeller, also known as a 10×4.5 propeller, is widely used in quadcopters and small unmanned aerial vehicle (UAV) applications. In this numbering system, the value 10 represents the propeller’s diameter, which measures 10 inches from one blade tip to the opposite blade tip.
- The value 4.5 represents the pitch of the propeller. Pitch describes the theoretical forward distance the propeller would travel in one complete rotation if there were no air resistance. In simple terms, it indicates how far the drone can move forward with each full spin of the propeller.A 10×4.5 propeller provides a suitable combination of thrust and efficiency, making it ideal for medium-sized drones. It is capable of producing sufficient lift to carry the drone while maintaining stable and smooth flight performance. These propellers are commonly manufactured from materials such as nylon, ABS plastic, or carbon fiber. Carbon fiber versions are generally stronger and lighter, which can improve overall performance and durability.
- The 1045 propeller is available in two rotational directions: clockwise (CW) and counterclockwise (CCW). In quadcopter systems, both types are used together to counteract motor torque and maintain flight stability. This balanced rotation prevents unwanted spinning and helps the drone remain steady during operation.
- Pixhawk is an open-source flight controller that is used in various unmanned aerial vehicles such as drones, fixed-wing drones, and VTOL aircraft. Pixhawk is used as the central processing unit of the drones. Pixhawk processes all the information from various sensors such as gyroscopes, accelerometers, magnetometers, and barometers. Pixhawk boards are based on an STM32 ARM Cortex microcontroller. Pixhawk boards are capable of using various communication protocols such as UART, I2C, SPI, CAN, and PWM. Pixhawk boards can be connected with GPS devices, telemetry devices, RC devices, cameras, and various other sensors. Pixhawk boards can run various open-source flight stacks such as ArduPilot or PX4. Pixhawk boards can perform various complex operations such as autonomous flight, waypoint navigation, altitude hold, return to launch, and mission planning. Pixhawk boards are widely used due to their modularity and high reliability. Pixhawk boards are widely used in academic and research projects as well as for various professional drone development projects
- The anti-vibration mount made of rubber is employed in order to minimize the amount of vibrations resulting from the motor. The anti-vibration mount will be positioned between the motor and the base in order to ensure that the shock and the resulting vibration are absorbed.

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- Telemetry is a data acquisition and transmission technology used for the remote monitoring of physical parameters such as voltage, current, temperature, speed, and environmental conditions from a distance or hard-to-reach places. Telemetry is an integral part of the automation industry, smart grids, health care, aerospace, and IoT technologies. In this paper, the architecture, principle, components, communication technologies, and application of the telemetry system in modern engineering fields are presented.
- The M8N GPS module is one of the most commonly used satellite navigation modules, based on the u-bloxNEO-M8N chipset. It is called a multi-GNSS module, which means it receives signals from multiple satellite systems, including GPS, GLONASS, Bei Dou, and sometimes Galileo. These satellite systems are based in different countries, including the USA, Russia, China, and Europe. This allows the M8N module to lock satellites quickly and provide accurate location information. It provides an accuracy of 2-3 meters in open sky conditions. It supports communication through UART, also known as serial communication, where the output is in NMEA format. It usually operates between 3.3V to 5V. It usually comes with an active ceramic antenna built-in, along with a backup battery, for hot starts. It is commonly used in drone technology, robotics, vehicle tracking systems, and microcontrollers like Arduino and Raspberry Pi.
- A 2200 mAh lipo battery is a rechargeable battery which can be charged again and again. It is a light weight and delivers high power. It delivers 2200 milliamps. This type of batteries are designed with voltage rating 3S (11.1 volts) and 4S (14.8 volts). S represents the number of cells in series. The discharge value can range from 25C to 40C. Lipo batteries are designed with a balanced charger.
- A B3 charger is a basic balance charger that can be used to charge 2S or 3S LiPo batteries. It provides a standard charging current of 0.8A to 1A. To calculate the charging time of a 2200 mAh or 2.2Ah LiPo battery, we use the following formula:
- Charging Time = Battery Capacity / Charger Current
- Therefore, using a 1A current, the charging time will be 2 to 3 hours when the battery needs to be charged from a low level. As discussed, it is a basic balance charger that provides safe charging by balancing each cell of the battery.
- Power Module: The power module is essentially the link between your battery and your electronics. It regulates the voltage that comes out of your LiPo battery. The voltage that comes out of a LiPo battery is usually too high for your flight controller. The power module steps down this voltage so that your flight controller and other electronics can use it. For example, if you're using a 3S 2200 mAH LiPo battery, which has a voltage of 11.1V, the power module steps this down to a safe voltage of around 5V for your flight controller. It also monitors the amount of voltage and current your battery is using. This prevents you from over-drawing current from your battery. The current that a power module can handle ranges between 30 and 60 amps.
- The Fly-Sky FS-i6 is a widely used radio transmitter that operates in the 2.4 GHz band and is designed for controlling remote-controlled aircraft such as drones, quadcopters, helicopters, and airplanes. The radio transmitter has a total of 6 channels and can be used for controlling different parameters of the aircraft. The radio transmission technology used in this product is FlySky AFHDS/AFHDS 2A technology. This technology minimizes interference and provides a reliable link between the transmitter and the receiver. The radio has a transmission range of about 500 meters and above. It requires four AA batteries for operation. The product is known for its low cost and ease of use. It has an LCD display

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and can be widely found among students and hobbyists who are developing drones and other remote-controlled aircraft.

- The Tower Pro SG90 micro servo motor is a small and lightweight micro servo that finds application in robotic, RC car, airplane, and electronic device projects. It requires a 4.8 to 6 volts power supply and rotates up to 0 to 180 degrees. It has plastic gears and provides a torque of 1.8 kg.cm, making it appropriate for robotic arms, RC car steering, and airplane flight surfaces. It uses Pulse Width Modulation signals to operate the micro servo, usually from microcontroller devices such as Arduino. It is a popular micro servo among students and hobbyists due to its low price, small form factor, and simplicity of use. In this research it is used as release mechanism while dropping the parcel.

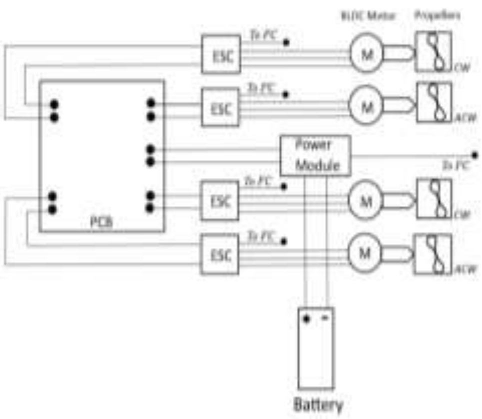

Figure 1 **Direction of the Propellers**

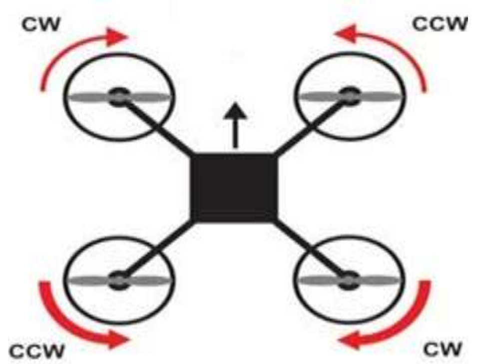

Figure 2 **Direction of the Propellers**

The above diagram shows the power and control distribution system of a quadcopter drone. It shows how the energy flows from battery to motors including connection to the printed circuit board (PCB) and how flight controller communicates with propulsion system. It is a schematic representation of exact connections of power distribution system of drone. The PCB is integrated circuit board which comes along with Q F450 quadcopter frame body which consists of 5 connection points (positive and negative) from which 4 are for ECS connections and 1 is for power module. Its job is to distribute power out to the 4 ESCs. The respective ESCs are solder to terminals on the PCB. Each motor has its own ESC to control the speed as per variations. These ESCs translates instructions into movements. Two distinct inputs: Raw DC power from PCB and specific speed commands by signal wires connected to flight controller. These ESCs generates three phase output which creates a rotating magnetic field within BLDC motors to induce mechanical rotation. The three pins of ESCs are directly connected to motor and its connection decides the direction of motor i.e clockwise or anticlockwise. The power module is the primary gateway for electrical flow between battery and rest components. It features connection to the battery to raw power, which it then passes through the PCB to feed motors. Finally, these motors turn the propellers to generate thrust. The propellers are connected to motor as per the direction. Fig shows the alternate connection of propellers i.e clockwise and anticlockwise. The working principle of this model basically depends on simple conversion of chemical energy from the Battery into controlled mechanical thrust. The scheme of operation is based on two working embedded subsystems: Raspberry pi 4 and Pixhawk flight controller when integrated together the system transmit from the basic remote-control drone to autonomous setup. The overall controlling of all the components is done by flight controller.

3.2.Calibration with software

The Software used in this research is Mission Planner where communication, data planning, simulation, and configuration with hardware components is done. The type of frame is to be selected to continue calibration. Firstly the acceleration calibration is done by positioning drone in various poses which are tail up, tail down, front, back to ensure the stability and pass commands to navigate in any position during flight. For compass calibration the drone is to be rotate in each angle so it could catch coordinates in any position. In radio calibration the transmitter and receiver is to be bind first and then perform each movement of switches on transmitter to set the channel commands on software. Here we are using dc sevro-motor mot parcel release mechanism so the fixed unit of transmitter switch(channel number) is connected to servo output. The next is ECS calibration where all four esc are controlled and passed mission to control speed as per the instructions from software. Further the Battery level is to be set and discharge limit is given so that on that level of battery the drone will return to launch pad. On holding the safety switch for 3 sec, it shows the blue colour which states the calibration is done successfully. The data plan will show the drone is “Armed” which means it is ready to take flight. Propellers are connected as per the direction and drone is set for testing.

3.3.Integration of flight controller and raspberry pi

- **Headless Pi OS Setup:** The Raspberry pi was configured in headless mode to eliminate the need for external peripherals such as monitor, keyboard, and mouse. The Raspberry pi OS image was flased onto microSD card using Raspberry pi Imager tool.
- **Libraries Installation:** Software libraries were installed to enable communication and control. It enables pi to rune python program.
- **Raspberry pi Config:** The Raspberry pi was configured to enable hardware interfaces essential for drone operation. The serial communication interface was enabled to allow communication conflicts.
- **Pixhawk and Pi Connection:** The Pixhawk flight controller was interfaced with the Raspberry pi using a serial communication link through telemetry port. It was established using MAVLink protocol.
- **Servo and Pixhawk Connection:** Servo motor is connected to output channel of flight controller via Pulse Width Modulation (PWM) signals generated by Pixhawk. This servo mechanism was utilized for payload delivery, enabling controlled release of packages in logistic application.
- **Python Script**: A Python-based control script was developed to implement autonomous drone operations. The script includes overall functioning and navigation of route.

3.4.Communication Structure

The proposed system uses a Remote Visual Monitoring and Control (RVMC) based on Virtual Network Computing (VNC) for communication between drone and user. The VNC sensor is run by Raspberry pi which is mounted on drone. The user can connect to this server through mobile or laptop using VNC viewer over Internet or Wi-Fi network.

```
def my_mission():
    arm_and_takeoff(3)
    goto_location()
    drop_parcel()
    time.sleep(2)
    print("Returning to Launch")
    vehicle.mode = VehicleMode("RTL")
```

The implemented mission function demonstrates the ability of drone to navigate to a predefined GPS location. After take-off, the function “goto_location()” provides the target latitude and longitude to navigate system. These coordinates act as the destination point for the drone. The Raspberry pi sends this location data to the flight controller using the Mavlink protocol. The successful execution of the “drop_parcel()” functions after the navigation step serves as an indication that the drone has arrived at the required coordinates.

4. Result

Payload Capacity: The drone successfully carried and delivered a payload of up to 1 kg with stable flight performance.

Flight Range: The system achieved an effective delivery distance of approximately 1–2 km under normal operating conditions.

Navigation Accuracy: GPS-based navigation provided an accuracy of about 2–3 meters, suitable for practical delivery applications.

Return-to-Launch (RTL): The drone reliably executed the RTL function, autonomously returning to the take-off location after mission completion.

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Figure 2 Model structure

Conclusion

This Research Proposes an Autonomous Logistic UAV which would perform a mission of carry 1kg load from launch pad to provided location for distance of 1-2 km, navigation accuracy of 2-3 m and return to launch pad. This mission will be carried out autonomously by providing google map location co-ordinates in RVNC viewer. The development of this autonomous illustrates a significant advancement in solving the "last-mile" delivery challenge through integration of Raspberry pi 4 and Pixhawk flight controller. This dual- processer allows for a critical division of labour: The Pixhawk manages low level task- keeping drone level, managing motor speeds, and processing sensor data in real time while Raspberry pi 4 handles high level task that requires more processing power. The Research proves that by using low-cost hardware the last-mile delivery mission can be passed by bypassing traffic and reducing carbon-emitting delivery system at some proportion.

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