Overview of Building a Multi-Drone system

For autonomous drone-based delivery

By

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Executvie summary:

UAVs which are commonly known as drones are completely revolutionizing many industries. This paper will take a deep dive in to potential of building a multi-drone system for more efficient workforce. The paper will discuss about building an autonomous UAV for delivery purposes and ultimately design a multi-drone system to complete the entire mission. The paper will also look into fundamental of UAV technology including history, design types, basic aerodynamics, energy, mission planning. The paper has also discussed about the importance of using hybrid- VTOL drone for the task.

Introduction:

A drone system, commonly referred to as an unmanned aerial vehicle (UAV) system, consists of an aircraft that is controlled either remotely or autonomously, along with its associated technology. Drones have transitioned from being primarily utilized in military roles to fulfilling a wide array of functions across multiple industries, such as agriculture, logistics, photography, disaster response, environmental monitoring, and beyond.

With the rapid advancement of the industry drones or UAVs are developing and evolving for more complex tasks in near future.

1.Fundamentals of UAV:

Unmanned Aerial vehicle also known as UAV is commonly introduced as a drone. They are remote controlled, semi-autonomous or fully-autonomous aerial vehicles that are being designed for specific task/mission. They are being designed with basic aerodynamics concept to fulfill their mission efficiently.

1.1 History:

Although the modern designs began recently, the actual historical background goes back to more than a century. It is commonly known that human always wanted fly. So, several inventors, engineers and scientists did run several experiments and theoretical designs throughout the history.

The first theoretical design concepts of UAVs appeared in mid 1850s. During the 18th century ballons were used during the battles. In 1849, amid the conflict (refer to Table 1) between Austria and Venice, unmanned balloons carrying explosives were employed. The Austrian military deployed approximately 200 incendiary balloons, each containing bombs weighing between 11 kg and 14 kg. The first experiments of unmanned aerial vehicles did start just after te first successful plane ride of Wright brothers. In 1907, an early development of this technology appeared, called the quadcopter configuration. □at year, Louis Breguet (Figure 1) and his brother together with the help of French physiologist Professor Charles Richet (Figure 2), developed a gyroplane, the forerunner of the helicopter. It should be noted that in 1905 Louis Breguet with brother Jacques and under the guidance of Charles Richet began work on a gyroplane, the forerunner of the helicopter [1]. During 1930s, Walter Wrighter did design and create a remote-controlled aircraft model called 'OQ-2'. Then US navy developed further developed these planes as remote-controlled drones. During the 1950s, the U.S. was still developing the manned SR-71 Blackbird spy plane, and spy satellites were not yet prepared for use. There was a need for specialized UAVs to securely collect information in controlled regions. The SR-71 Blackbird was a strategic reconnaissance aircraft designed and built by Lockheed Martin Corporation, known for its long range and high-altitude capabilities. US army began to start building the modern UAV program to build a not-expensive drone that have many capabilities including faster mission completing. They also built the first-ever solar powered air-craft. Then over the years, UAVs have been developed by implementing several advance technologies.

The most recent technological implementation is Artificial intelligence. AI is being actively used to build intelligent fully-autonomous drones.

1.2 Fundamental aerodynamics:

The fundamental aerodynamics of Unmanned Aerial Vehicles (UAVs) adhere to the same principles as traditional aircraft, concentrating on the interaction between the UAV and the airflow to produce lift, manage flight, and counteract drag. Nevertheless, UAVs possess distinct design factors, as they are generally smaller, lighter, and may incorporate specialized structures tailored for different purposes (such as fixed-wing, rotary-wing, or hybrid designs). There are several aerodynamics concepts that can be used for UAV flight.

1.2.1 Force of Flight:

For an object that is airborne (such as UAV or Airplane), there are several internal and external forces that are working on the aircraft. They are:

1. Lift: This is the lifting force that is being created by rotating wings (rotors) against the total weight (mg). When the lift force is higher than weigh, the unbalance between two forces will be the cause for lifting the aircraft.
2. Weight: This is the downward force that is being created due to force of gravity by earth.
3. Thrust: Thrust is the total upward for forward force that has been created by rotating wings and propellers to move the aircraft in a certain direction.
4. Drag: This is basically the resistance force that is being created on the aircraft against the movements of aircraft and caused by the friction.

1.2.2 design type:

UAVs has mainly two design types.

1. **Fixed wing:**
   Their design concept is similar to the a moder airplane and the lift force is created in moving direction (forward direction). They can be used in longer range mission due to the energy efficiency.
2. **Multi-rotor:**
   They are helicopters (one rotor) and other copter types with 4 or more rotors, that can perform vertical take-off or landing (VTOL). VTOL and hoovering are signature functions for UAV which fixed wing drones cannot perform.
3. Hybrid VTOL:
   Recent developments in drone technology have come to the point of mixing the main physical features of both fixed wing and multi-rotor to build a hybrid version of UAVs.

1.2.3 **Stability or Efficiency:**

There two main aspects that needed to be addressed when it come to the stability and efficiency.

1. **Lift-to-Drag Ratio:**
   In order to fly for extended periods of time with little energy consumption, fixed-wing UAVs strive for a high lift-to-drag ratio.
2. Hoover:
   Instead, then focusing on long-distance efficiency, multi-rotors are designed for maneuverability and stable hovering. Compared to gliding flight, hovering UAVs use more energy per unit of time, hence power management is crucial.

1.2.4 Battery power:

UAVs mainly use electrical energy as the energy source. The weight and effectiveness of the battery and propulsion system have an impact on their aerodynamics. In order to maximize flying time and minimize energy usage, aerodynamic efficiency is essential.

Previously mentioned are the basic aerodynamic concepts that are being considered when designing a new aircraft. They are the primary considerations for improving efficiency and productivity.

2.Mission Requirements:

The proposed multi-drone system is being designed for autonomous delivery drone system. The main carriage drone is being used for carry 2-4 small delivery drones near their delivery destination. Also, the need for Vertical take-off and landing capability is a major requirement. Hoovering under one position is also a major requirement.

3.Hybrid VTOL Drone design:

Hybrid Vertical Take-off and landing UAV is the newest evolution of UAV technology. The main advantage of hybrid versions is that they can be designed to have both features.

3.1Background:

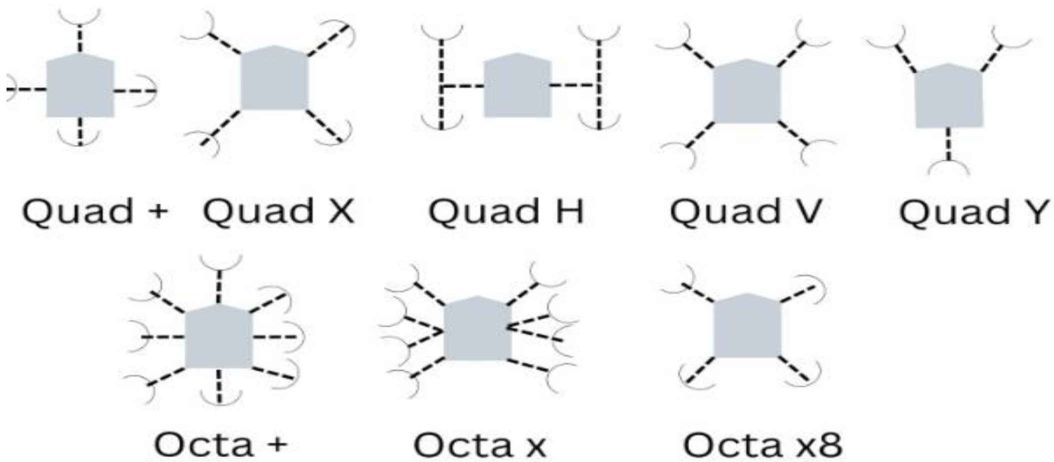
When it comes to efficiency, endurance and productivity, the fixed wing UAVs perform way better than multi rotor designs. But multi rotor drones can perform vertical lift-off and landing and also the mid-air hoovering functions. So, engineers were trying to build a advanced aircraft that has both capabilities.

3.2design:

Designing a Hybrid VTOL drone is neither simple nor complex. The basic idea is to work as both a multi-rotor and a fixed wing drone. So, there will be two structures that can be achieved in same UAV design.

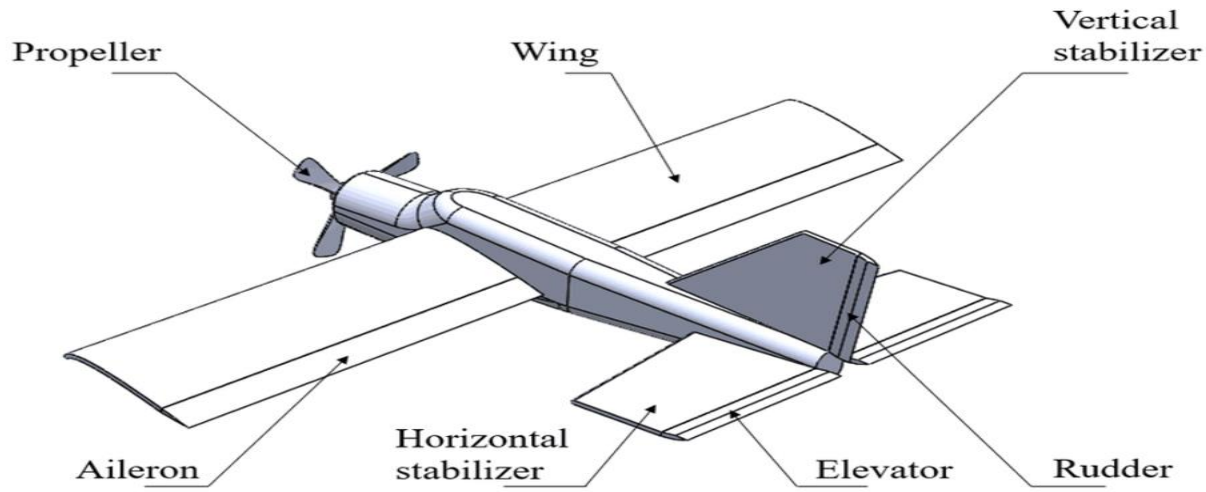
In a fixed-wing drone structure, the main design is to have rotors in a horizontal angle and toward the moving direction. So, mostly while the aircraft is airborne the fixed wing structure will be activated. This will only change while hoovering under one position mid-air.

In the multi-rotor structure, the main purpose is to vertical taking-off or landing the drone. so, it is important for rotors to face the vertical direction according to aerodynamics. Also, it is important to have at least 4 rotors and should be one of following shapes.



As shown in the previous graph, there are several multi rotor designs mainly based on the number of rotors. for a UAV that need to carry more weight, it is recommended that the hexagon and octagon are the preferred shapes since they have more rotors to generate thrust to create more lift force.

Fixed wing drone shape is more complex than a multirotor drone design. Following figure shows the basic structure of a fixed wing UAV.



As shown in the figure, there are many physical components that allow the aircraft to move upper direction or lower direction by changing lift force on the vehicle body or turn on a right or left direction by changing the lift force on the body according to basic concepts using the ailerons and Elevators. Beside these features, there are one or two rotors to generate a thrust force toward moving direction.

So, there are multiple aerodynamic concepts to consider when it comes to designing a hybrid drone. There are several components to consider when building the design.

4.1Electric propulsion:

Using electricity as the propulsion is frequently experimenting on implementing in many vehicle working processes. Electric propulsion technology already being used in electric cars and hybrid cars. For unmanned aerial vehicles, it is most using propulsion method. Specially, small and medium drones that use electricity as the power source. Lithium-polymer or Lithium-ion batteries can be used since they are rechargeable. According to studies, 350-mAh per kg is the standard battery usage. But in modern day, Lithium-polymer offer up to 370mAh per kg while Li-ion battery can offer up to 38mAh per kg. Also, futuristic Lithium-oxygen and Lithium-sulfur batteries can make a Hugh impact in near future.

The electric motor plays a crucial role in electric propulsion. Currently, lightweight brushless direct current (BLDC) electric motors with power ratings under 360 kW can be found in the market. Simultaneously, multi-copter UAVs are gaining popularity due to maneuverability, controllability, and VTOL characteristics.

Electric propulsion is important since the proposed charging station is designed to use solar energy.

4.2 Brushless motors:

Brushless motors are more advanced motor types than traditional brushed motors. Followings are some of the key advantages of using brushless motors.

1. efficiency

2. less-maintenance issues

3. more working life span

4. more size to power ratio

5. lower noise

6. more safety and customizability

5. Mult-Drone System architecture:

Here is an explanation on my proposed design of multi-drone system for autonomous-drone delivery. The system contains two different drones.

1. Larger carriage drone
2. Smaller delivery drones.

5.1 Workflow for main carriage drone:

The proposed workflow for the larger carriage drone is not a complex process. As a VTOL drone, the taking-off and landing processes are being controlled by vertical multi-rotors as well as the hoovering over one position. While airborne, the entire mission is completed by the horizontal fixed-wing rotors. The two types won't work simultaneously since the forces generated wouldn't be able to follow concepts of aerodynamics. The drone is carrying 2 – 4 smaller carriage drones that act as delivery systems.

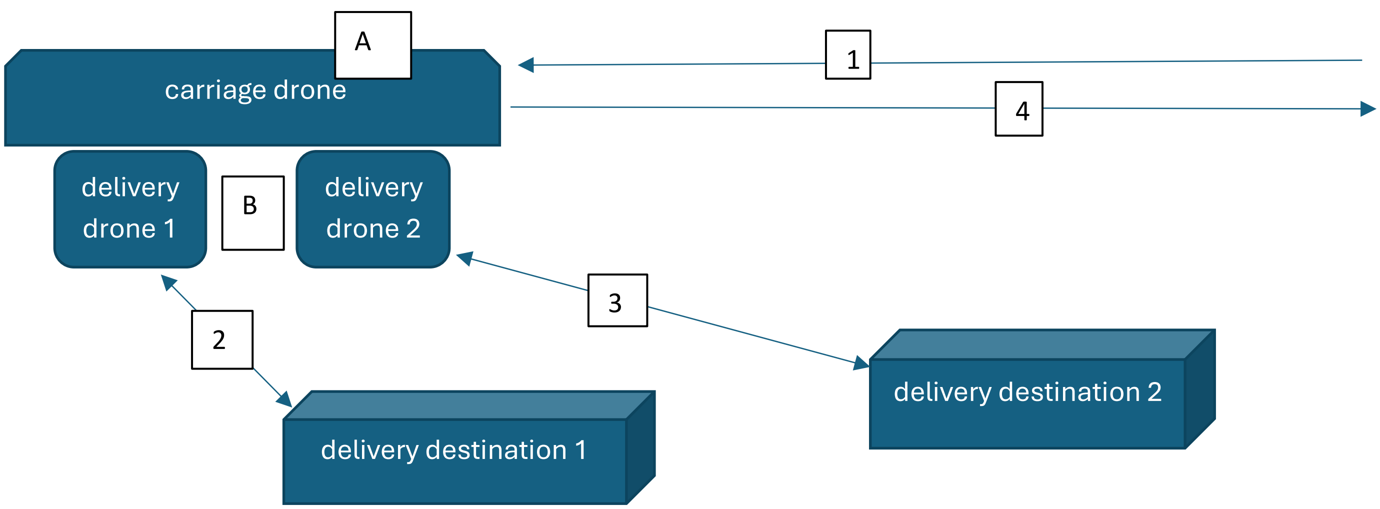
5.2 workflow of smaller drones:

In the proposed multi-drone system architecture, the smaller drones are being created with the sole purpose of work as delivery systems. Drone only contains the characterizes from multi-rotor design. The drones will be built as fully autonomous drones for safer and faster contactless delivery process.

5.3 Autonomous UAV:

Autonomous UAV or drone is referred to an UAV design that can perform each and every target in mission status including taking-off, waypoint tracking, mission planning, obstacle avoidance, task management, landing and safety measurement by itself without a human operator intervention. One major advancement of an autonomous drone is including an intelligent flight computer in addition to the fundamental flight controller unit.

5.4 combined workflow:



The proposed full workflow on the multi-drone system is follows. All the UAVs that are designed for the multi-drone system have the fully or semi-autonomous capability. This will help for the mission planning and faster delivery options.

A. **Carraige drone:** Carriage drone will be responsible for the handling the mission from taking off from the ware house to reaching destination area and returning to warehouse. The main task is to complete a safer and faster mission while airborne.

B. Delivery drone: Delivery drone is responsible for the delivery process. This drone is fully autonomous drone that can complete automated delivery process with safer and comfortable maneuvers.

The entire mission will can be divided into 4 parts.

1. The carriage drone will take-off from the ware house autonomously and human operator will include the destination address into UAV mission planner. Then mission planner computer will generate the easiest and safest route by using google map API. Then the drone will autonomously start the mission by start the movements towards the end destination.
   Maximum altitude for carriage drone: 200ft – 400ft
   Maximum weight(total): 25-30kg

Drone Size	Payload Capacity	Description
Mini Drones	Up to 100g	Smallest category of drones, typically for recreational use.
Small Drones	100g to 1kg	Used for recreational or light commercial tasks, easy to maneuver.
Medium Drones	1kg to 5kg	Used in professional fields like photography, surveying, and agriculture.
Large Drones	5kg to over 30kg	Designed for industrial inspections, cargo transport, heavy-duty photography.
Heavy Lift Drones	30kg to 220kg or more	Specialized for heavy lifting, used in construction, agriculture, and emergency response.

   Previous figure is the current UAV maximum payload capacity based on the drone size.
   Maximum payload capacity = delivery drone weight * n (number of drones) + total weight of packages
   Maximum payload capacity: 20 kg
   UAV shape: hexagon or octagon
   Number of propellers: 6 or 8
   Number of rotors: 6 or 8
   Battery: rechargeable Li-Po battery
   Capacity: based on the maximum drone weight and duration / 40,000mAh – 20-22V

2. When the drone system reaches the desired destination, the carriage drone will stop the movement and start hoover in the position of end/last waypoint. Then delivery drones will activate and start the rotor by signaling speed controllers (ESC). Then the drone will detach from main carriage drone and start to plan the safest and easiest path for delivery destination. 2 types of sensors will be used to collect data; Lidar and Ultrasonic. Also camera system will monitor the surrounding and perform active obstacle avoidance, most of the obstacles that are non-moving (resting) obstacles. So, they are being categorized as predictive obstacles. Once the drone is near ground level, the two ultrasonic sensors will activate and measure the distance from drone delivery package to ground level. This distance measurement will decide the safe delivery procedure. The delivery package carrier has an automatic mechanism for keeping and releasing purposes. The mechanism

will automatically trigger when the drone is in safer distance by using ultrasonic sensors and release the parcel to the ground.

3. There is multiple delivery drones attached to the main carriage drone. So, all the drones will follow previous mission plan to complete their end goal.
4. Returning to ware house is last part of the mission planning. The delivery drones will return and attach to the carriage drone once the delivery process is complete. After every drone is attached to main drone, the drone will automatically activate the return flight path. Most of the time, drone will memorize the path taken before and make a reverse path planning with similar way point tracking.

6.Conclusion:

- The proposed system is multi-drone system that are a set of fully autonomous drones that have difference specific purposes.
- Building an autonomous drone will require significant amount of hardware and software design gathering.
- Artificial intelligence will play a key role in the future of drone-based delivery.
- Drones will require at least 3 difference input devices such as cameras, Lidar sensor, ultrasonic sensors.
- This paper is discussing about using an multi-drone system to create an autonomous drone delivery process.
- Electricity is major energy source and converting solar energy into electricity will be revolutionary idea for environmental friendly services.