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DroneHook

High Level Design

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1 Introduction

Recently, there has been a growing interest in package delivery through the use of drones. Various companies have set out to develop a functioning method that can not only be easily accessible by the general public, but that can also be approved by the Federal Aviation Administration (FAA) . For example, companies like Wing, Flight Forward and Prime Air are leading efforts to find this fully functioning method with the help of billion dollar companies like Google, Amazon and UPS. However, these companies primarily focus on the package delivery side of things rather than package retrieval. Drones are typically viewed as the last link in the supply chain (e.g. Prime Air's vision of drones involves drones flying out of distribution centers and delivering packages to the customers doorstep. Although drones are generally seen as a method for delivering packages, drone package retrieval could be critical in certain scenarios. Examples that demonstrate time-critical retrieval scenarios include the retrieval of test samples from patients who are unable to make it to regional testing centers or the package retrieval of medication from one field hospital to another that has a patient who needs the medication.

2 Problem Statement and Proposed Solution

The problem we are addressing is a fast and energy efficient ground-to-air delivery system for autonomous drones. These factors are particularly important in time sensitive and long range delivery operations such as medical emergencies or rural deliveries. Typically when considering drone delivery systems the easier and more straightforward solution is quadcopter drones. Although quadcopters have high maneuverability which allows for easily securing packages they lack the high speeds and long ranges inherent in fixed wing drones. Keeping this in mind, we are developing an approach for a fixed wing drone to secure a package without needing to lose significant speed or land.

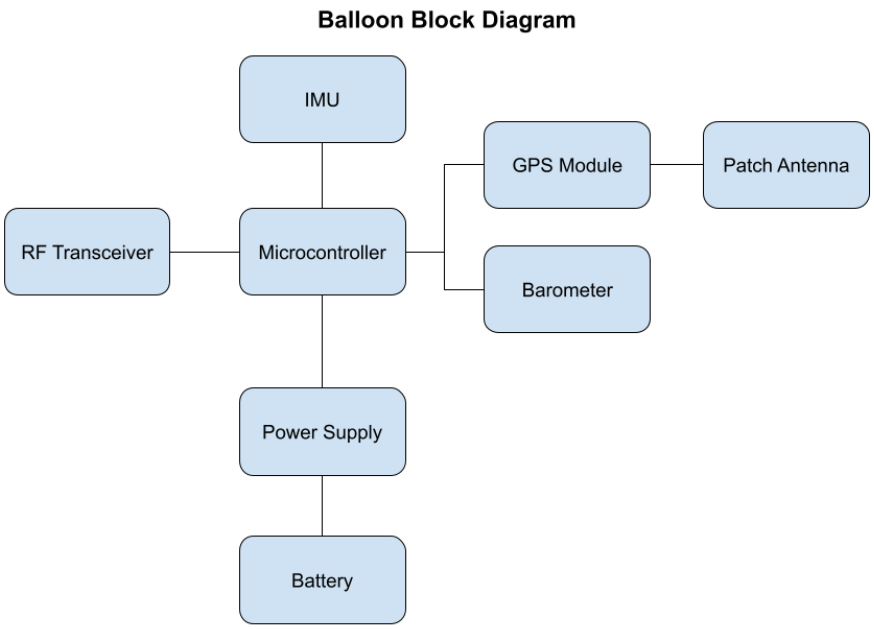
The solution involves a balloon in the air attached to a package by a strong line. The balloon will carry the equipment needed for the autonomous drone to accurately fly towards it in order to secure the line and reel in the package. For this project we will be approaching the balloon close enough for a computer vision system to take over and take a picture of the balloon, thereby showing that our system is capable of accurately tracking the balloon. This would substantially set the stage for future research and work in this direction.

3 Overall System Requirements

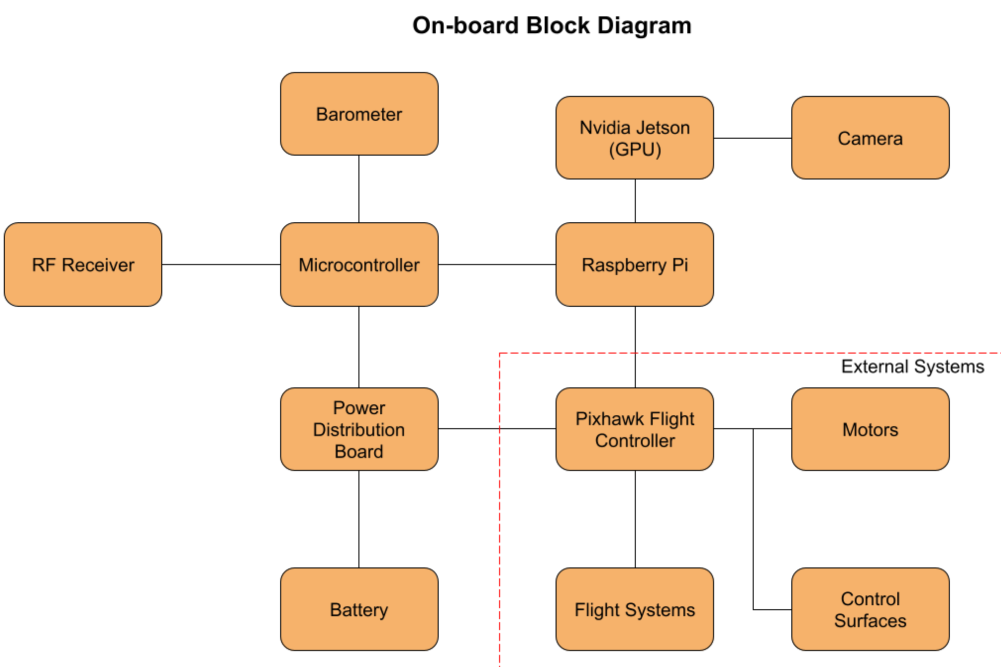
- **OR1.0:** The system shall be able to fly the UAV from beyond visual line of sight (BVLOS) to within 10 feet of the balloon utilizing transmitted data and computer vision system to construct trajectory
- **OR2.0:** The system shall consist of an on-balloon embedded system and UAV system which will interact via a computer vision system onboard the plane and an RF link
- **OR3.0:** The one-way wireless link shall be capable of transmitting sensor data from the on-balloon system to the UAV when the two are separated by a distance of at least 500m
- **OR4.0:** The UAV embedded system must fit within a 5 inch x 5in x 5in volume due to onboard space restrictions
- **OR5.0:** The on-balloon mechanism must weigh less than 250 grams to satisfy the payload limit of 36 inch helium weather balloons
- **OR6.0:** The on-ballon mechanism will have a toggle button by which the user can turn on and off the transmitting and data collection system which will be turned on during deployment
- **OR7.0:** The on-balloon mechanism shall have a two status LEDs by which the user can determine whether the system is on/off, sensors healthy, and transmitter functional
- **OR8.0:** The computation executed by the on-balloon and UAV systems' microcontrollers shall be restricted to serial (i.e. I2C, UART, and SPI) communication with sensors and data aggregation
- **OR9.0:** The on-balloon mechanism shall possess a footprint smaller than 3 inch by 3 inch so that it can be fully encased in a lightweight TPU case
- **OR10.0:** The system shall be capable of operating in environments with winds speeds of 5 miles per hour (i.e. breezy conditions)
- **OR11.0:** The on-balloon system shall be packaged such that light sprays of water do not interfere with the operation of the data collection and transmission electronics
- **OR12.0:** The UAV embedded system shall consume no more than 5% of the energy stored in the 6S 2P 15,000mAh bank of lithium polymer (LiPo) batteries used to power the systems onboard the fixed-wing
- **OR13.0:** The computer vision system shall be capable of resolving the balloon against shades of backgrounds ranging from dark blue to light gray
- **OR14.0:** The on-balloon and UAV embedded systems shall be capable of operating at a temperature range of 0 F to 110 F with optimized performance at moderate temperatures (i.e. 50 F)
- **OR15.0:** The RF-transmitted and computer vision generated balloon data shall be updated at a rate of at least 64 Hz to maintain safe generation of control sequences seeing that the cruise speed of the aircraft is roughly 16 ft/s (i.e. ~4 data points per every foot traveled in space)
- **OR16.0:** The wireless link between the on-balloon and UAV system shall support adequate error checking in the form of a cyclic redundancy check or checksum to ensure passing of uncorrupted data
- **OR17.0:** The UAV embedded system shall weigh below 90 grams such that its installation does not interfere with the balancing of the airframe

4 System Block Diagram

4.1 Overall System



Power Supply will also provide power to RF Transceiver, IMU, GPS, and Barometer



Power Distribution Board will also supply power to motors, control surface servos, Raspberry Pi, Nvidia Jetson, Camera, RF Receiver, and Barometer

4.2 Subsystem and Interface Requirements

- **SR1.0:** The on-balloon embedded system shall transmit relevant sensor data as described in **SR2.1** to the UAV so that the balloon can be located and flown to
    - **SR1.1:** The system shall be powered by a Li-Ion battery
        - **SR1.1.1:** The battery shall be capable of powering the data transmitter system referenced in **R1.2**
        - **SR1.1.2:** The system shall stay full functional for a minimum of 10 minutes on a single fully charged battery
        - **SR1.1.3:** The battery shall not exceed 50 grams
    - **SR1.2**: The data transmitter system shall include:
        - **SR1.2.1:** An RF transceiver for long range, rapid transmission of on-balloon data
        - **SR1.2.2:** A barometer for gathering accurate altitude data
        - **SR1.2.3:** An inertial measuring unit (IMU) for calculating the volatility of the balloon's position resulting from adverse weather conditions (e.g. wind) containing:
            - **SR1.2.3.1:** Accelerometer
            - **SR1.2.3.2:** Gyroscope
            - **SR1.2.3.3:** Magnetometer
        - **SR1.2.4:** A GPS module for gathering two-dimensional coordinate data (i.e. x and y axes) with a resolution of at least 20 feet
    - **SR1.3:** The balloon itself shall be a distinct and unnatural color which can be easily recognized by the computer vision system against the background of the various shades of the clouds and sky
    - **SR1.4:** The system shall possess a microcontroller that fuses the data from the various on-balloon sensors and transmits via an RF transceiver
        - **SR1.4.1:** The microcontroller shall possess serial interfaces to accommodate the devices specified in **R1.2**
        - **SR1.4.2:** The microcontroller shall be low power and robust to operate in various weather conditions as specified in the overall requirements **OR10.0**, **OR11.0**, and **OR14.0**
- **SR2.0:** The on-board embedded system shall receive relevant sensor data from the balloon and on-board computer vision
    - **SR2.1:** The relevant received data shall be the x and y coordinates from the GPS module, the altitude or z-coordinate from the barometer, and volatility data from the IMU.
        - **SR2.1.1:** An on-board Raspberry Pi or similar single board computer (SBC) will be responsible for the onboard handling and computation of the above data.
        - **SR2.1.2:** The Raspberry Pi shall utilize this data to compute an autonomous flight pattern and control sequence.
    - **SR2.2:** Autonomous flight control shall be responsible for implementing this autonomous flight pattern and control sequence and controlling the motors and other flight control features to realize the approach towards the balloon.

- **SR2.3:** The drone will carry a camera for close range locating of the balloon
  - **SR2.3.1:** The camera will interface with a computer vision algorithm for detecting the balloon and calculating a new trajectory and corresponding control sequence.

4.3 Future Enhancement Requirements

- **ER1.0:** Actual snagging of the package. The ultimate goal of this project would be to actually secure the package from the ground. Given more time and resources we would want to implement this. This would work by having a foldable frame which could expand when approaching the balloon to bring the line inside this frame. This frame allows us a margin of error for the approach trajectory. Once inside the frame the line would be fed to a motor which would then reel the package from the ground, and into a carrying compartment aboard the plane. We would then have a mechanism to cut the line near the package and the drone would then be able to fly away towards the delivery site with the package aboard.
- **ER2.0:** Increased range: Currently we are planning on testing the system over a range of less than a mile. If this product was brought to market we would want to have a much higher range. This would require higher power supplied to the RF transmitter and therefore a larger battery. This would likely lead to a larger balloon to maintain positive buoyancy.
- **ER3.0:** Implementation of redundancy aboard the balloon by potentially using multiple GPS modules and IMUs. By having multiple IMUs and GPSs we would be able to obtain more robust data and create the trajectories and flight paths with more confidence.
- **ER4.0:** Operation in lowlight conditions or at night would necessitate the incorporation of a camera with a lower of additional features on the UAV system such as the potential addition of a camera with a substantially larger aperture. Additionally, the use of a light detecting and ranging (LiDAR) system could be considered due to its relatively high resolution and ability to operate in darkness. Special coatings of the balloon or a low power illumination apparatus could be also explored to increase contrast and visibility to the computer vision system.
- **ER5.0:** Operations in adverse weather conditions where the volatility of the objective balloon and inbound UAV increase substantially (i.e. the path of the UAV is no longer smooth and easily predictable) due to rapid changes in wind magnitude and direction. Among other modifications to the overall requirements, accommodation of such conditions would likely necessitate a higher update rate for transmission of sensor data from the balloon. Likewise, the inclement weather may substantially lower visibility. As such, the option of a sensory method not impaired by extreme weather such as high resolution RADAR should be considered.
- **ER6.0:** Minimization of the on-balloon mechanism's cost would be a non-functional requirement that would need to be implemented following the successful implementation of a first iteration prototype. Commercialization of the overall system would likely require a unit cost for the balloon mechanism under 35 dollars.

5 High Level Design Decisions

On-Balloon System
The decisions on the balloon systems will mostly be based upon two factors: The diameter of the balloon, and the amount of weight able to be carried by the balloon. In order to be recognized by the UAV camera system, the balloon needs to be of sufficient radius (around 1.5 feet) in order to make sure the camera will recognize it. We also need to make sure that the balloon can carry any cargo necessary to operate. This includes the actual package and any on-board microcontrollers. These should be relatively light.

On-board Microcontroller: For this we are leaning towards using a microcontroller in the PIC32 family, specifically the PIC32MX320F032H. Our rationale for this is that the PIC32s are lightweight and have low power usage, while giving us some key functionality such as I2C. This particular PIC32 has a small amount of memory, but it will prove adequate because there are no computations occurring on this module.

I2C bus: because of the number of data collection modules we will be implementing we are leaning towards using I2C because we would only need a single I2C bus to send the information from the barometer, IMU, and GPS to the RF transceiver. Another feasible option would be to use SPI but we are leaning towards I2C because it has the key functionality we need and is also more familiar.

Airborne System
The airborne system will be required to receive the position data being transmitted from the balloon and use it to locate the balloon and fly within ten feet of it. Once the aircraft is within the range for the visual tracking, the visual tracking will take over to guide the aircraft to the balloon. The RF receiver will receive the data being transmitted from the balloon and used by the microcontroller onboard to adjust the flight path with comparison of the position data with the aircraft positioning. The aircraft positioning will be given by the GPS module and barometer. I2C interface will be used for communication between the GPS, barometer, and microcontroller.

The visual imaging will be processed by a Nvidia Jetson due to its high computing power. The Jetson will be connected to the Raspberry Pi as the companion computer for computing the transition to visual tracking. The Pi will also be computing the updated flight path that will be connected to the Pixhawk 4 flight controller to physically change the flight path of the aircraft.

Coding component: Software will need to be written which can decode the raw data received from the On-Balloon System into a functional trajectory. Additionally we will need code to process the visual feed from the camera system and convert that into a functional trajectory. This data will need to be fed into the flight controller.

6 Open Questions

- Procedure for turning the raw data into a control sequence on the Raspberry Pi?
- What should our testing distance(s) be?
- How much will inclement weather affect the quality of our results?
- How quickly will we be able to transmit and process the data with the microcontrollers?
- What power setting on the transmitter (on-balloon) and receiver (on-drone) will result in optimal balance of battery lifetime and transmission range?
- Which frequency is optimal for energy efficiency and clear signals?
- Will the system experience channel saturation/overloading on the selected transmission frequencies?
- What height should the balloon be set at?
- What would be the optimal speed at which to snag the balloon (e.g. closer to maximum throttle or stall speed)?
- What should the thrust and trajectory sequence be following the snagging of the objective balloon (e.g. full throttle with 30 degree pitch upwards)?

7 Major Component Costs

We have previous funding from NASA for this project so we will be using those funds to purchase equipment and drive development.

Item	# of Items	Expected Cost	Total ($)	Notes
RF Transciever	2	$20	$40	
IMU	1	$25	$25	
Microcontroller	2	$6	$12	
Battery	3	$7	$21	
GPS Module	1	$0	$0	WILL USE FROM UAVND CLUB
Patch Antenna	1	$7	$7	
Barometer	2	$5	$10	
Balloon	1	$10	$10	
Camera	1	$0	$0	WILL USE FROM UAVND CLUB
Pixhawk 4	1	$0	$0	WILL USE FROM UAVND CLUB
Nvidia Jetson	1	$60	$60	
Airframe	1	$0	$0	WILL USE FROM UAVND CLUB
Motors	2	$0	$0	WILL USE FROM UAVND CLUB
ESCs	2	$0	$0	WILL USE FROM UAVND CLUB
Plane LiPo Battery	2	$0	$0	WILL USE FROM UAVND CLUB
Raspberry Pi	1	$75	$75	
Board Design	2	$50	$100	

Total	$360

8 Conclusions

Our design allows for autonomous package retrieval but also permits the average user to be able to leave their package within a specified range. Companies have been so focused on the delivery side of this market and have not been focusing on the retrieval side, leaving a completely untapped market. Our design allows us to utilize designs that have come recently from companies like Amazon and Zipline but also utilize a design that came during World War Two in order to tap into this market and be that solution. Our solution is fairly simple and easily adopted as the technology already is being used for package drop off. Utilization of our solution allows for low cost retrieval of packages and can be used for pickup of returns and donations in a low cost manner.