Poppins - The Autonomous Weather Balloon

ECE 445 Project Proposal Fall 2020

MARC HARVEY, ARTURO CUEVAS, KATIE STAPLETON

TA: YIFEN

1 Introduction

1.1 Objective

High altitude weather balloons are an essential part of data collecting for many sciences, ranging from weather forecasting to pollution monitoring. Two weather balloons from about 900 sites around the world are launched every day of the year [2]. They consist of a large balloon, usually filled with either helium or hydrogen, and a payload, which often has sensors and computers to obtain data from the heavens. As the balloon and payload float up the air pressure decreases and the diameter of the balloon expands until it pops.

Once it has popped, the payload then deploys a parachute and safely returns to the ground, where the data can be collected. Researchers can predict where the weather balloon will land using calculations, but ultimately, due to outside variables such as jetstreams, they have to rely on GPS to retrieve the payload. Unfortunately, this is an issue when balloons decide to land in hazard as it often results in the data collected, as well as the payload, getting destroyed or lost.

Our solution is to give the balloon a way to guide itself; a system that allows the balloon to reposition or apply tension to certain parts of its parachute to land at a designated GPS location. Our custom payload, including power, heating, navigation, and steering, and weather balloon will have to follow FAA regulations in order to be utilized by other weather balloonists.

1.2 Background

Meteorologists, researchers, and the military deploy these balloons with a diverse and expensive payload of equipment that can exceed thousands of dollars. Besides the financial investment, scientists pour countless hours of work to collect this data that can improve the fields of meteorology, photography and astronomy [3].

The landings of these small unmanned aircraft are also important as they can cause fatal damage. The high frequency of weather balloons and growing urban sprawl are increasing the chance a weather balloon could land in trees, bodies of water, residential areas, or even highways. Due to the nature of the electronic payload, there are cases of crash landings where the payload starts a high blaze [1]. In the wrong situation, these balloons could cause wildfires, destruction of property, or vehicle accidents.

The ability to determine a secure landing location for weather balloon payloads would be an invaluable tool to the scientific community. With just a small amount of overhead, researchers can confidently launch their balloons and ensure it will avoid large catastrophes and losing their precious data.

1.3 High-Level Requirements

- Follows all FAA guidelines. Because of its ability to change direction, it is possible it will be labelled a drone by the FAA. We want to avoid this if possible, otherwise we will need to adhere to drone guidelines and the project will be slightly less useful.
- The ability to steer the parachute payload a full 360 degrees. The is necessary to direct our payload once the parachute deploys and to auto correct when it veers off course.
- If the height of the parachute deployment is 60,000ft, the payload should be able to land itself within 200ft the destination site CONSISTENTLY. This is an acceptable first threshold to achieve because oftentimes weather balloons land 25 or 300 miles away from the launch site [3].

2 Design

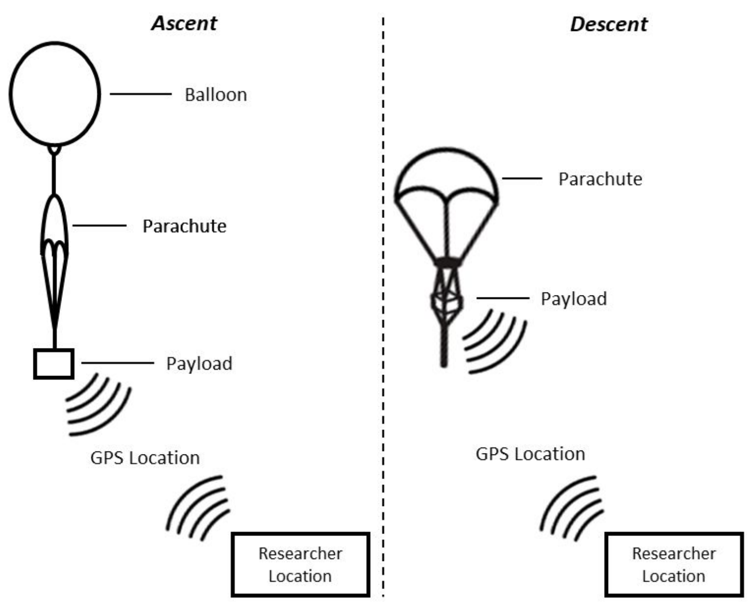

Figure 1. Physical diagram of weather balloon system. Poppins will steer the payload upon descent.

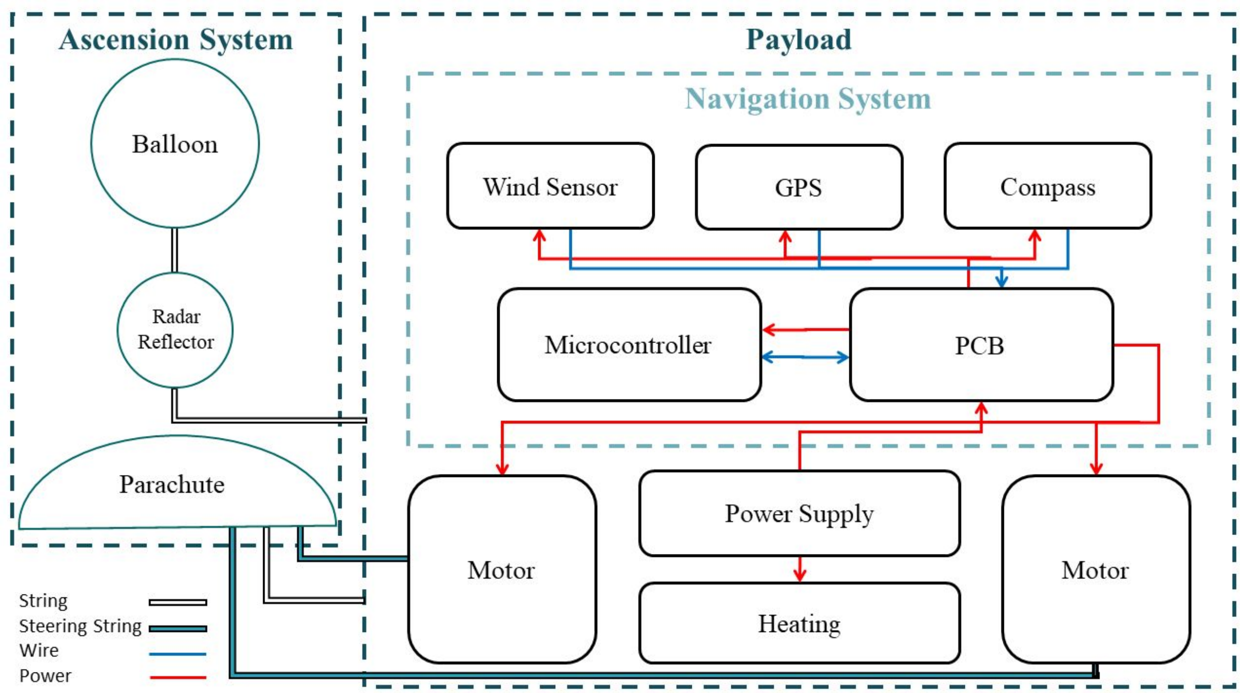

Figure 2. High Level Block Diagram

In the block diagram above, our design will be made up of a mostly conventional weather balloon ascension system and a custom payload. We will be able to achieve our requirement to control the movements of the descending payload to a specified location through the navigation system using a microcontroller, sensors, and motors. Within the ascension system, the parachute will be specifically designed to achieve our goal to steer the payload 360 degrees by being attached to the payload for support and the motors for steering. Each of these block components will be discussed further in the following section.

Payload

2.1 Heating System

The heating system is required because as we approach higher altitudes, the air temperature can reach as low as -69.70 degrees fahrenheit at 70,000ft above sea level [7]. Since most devices, especially the battery, have a minimum operating temperature we need a heating system that can ensure we can still operate our equipment.

This heating system will be in close contact with the other devices and will be connected to the power supply if it is electronic.

Requirements: Based on our devices used, the lowest temperature they can all withstand is about -4 degrees fahrenheit [9]. The heating system chosen must be able to keep the inside of the payload container above that temperature.

2.1.1 Electrical or non electrical heater

This could either be an electronic heating pad or even something as simple as a hand warmer. The decision to do so will depend on the weight and minimum operating temperatures of our other devices in the payload.

2.2 Navigation System

The main deliverable of this project and what allows us to compute the logic for steering and landing requirements is the navigation system. This system will take in input from the various sensors and use a microcontroller to decide how to power the motors to steer the parachute. This system has its data and power wires connected to our custom PCB board, which is powered by the power supply. The PCB also outputs the power calculated by the microcontroller to the motors in the steering subsystem.

Requirements: Out of all the components in the navigation system, the GPS is most important. If the other sensors lose functionality, the controls and landing location will be incorrect, but, as long as the researcher can view the GPS location, the payload can be recovered.

2.2.1 PCB Board

This PCB board will act as the highway for our power and data bus. The board will take in as input power from the power supply, data from all other sensors (GPS, wind, and compass), and the output of the microcontroller logic. As output it will drive all sensor data to the microcontroller and output the final power to the motors in the steering system.

2.2.2 Microprocessor/Microcontroller

The navigation system will need a brain to compute what to do with the input data the sensors provide. Depending on any issues, the microprocessor required could range from a microcontroller to an Nvidia Jetson, although it will likely require something in between such as an Arduino or Raspberry Pi. It should be able to be done on an Arduino unless it requires unexpectedly high computing power or requires some kind of high dimensional machine learning.

2.2.3 GPS Device

The GPS device will be used so that the payload knows its location. We will have to find a good balance between weight, accuracy, and cost. It needs to be lightweight because it is important for the whole payload to not weigh enough to be considered a drone, and it needs to be accurate so that the navigation system will have good information to make decisions based off of [4].

2.2.4 Wind Sensor

For proper navigation it is essential to measure both wind speed and wind direction. Thus we will need both a wind speed and wind direction sensor. Sometimes they are sold as part of the same unit. Alternatively, it might be better for our use case and possibly cheaper to just use four wind speed sensors to determine speed and direction, by having one on each side of the payload.

2.2.5 Digital Compass

In order for the navigation system to know which direction to try and go to, it must first be able to tell which direction it is facing. This can be accomplished with a digital compass.

2.3 Steering System

The steering system will be the main mechanism for accomplishing our tasks of steering the balloon in a full 360 degrees and landing our balloon consistently on a GPS location. The steering system will consist of motors, powered by the microcontroller, that pull on the steering strings of the parachute.

Requirements: The steering system must be able to wind strings based on input from the navigation system.

2.3.1 Motors

The steering system will consist of four separate stepper motors, each connected to a winding mechanism connected to the four strings of the parachute. By activating the motors, we are able to tighten and loosen each string independently by winding them, similar to how one would coil a kite string. By tightening and loosening the strings, the design has the ability to position the parachute in the direction most beneficial towards getting the whole system to move in a wanted direction.

We will use a stepper motor driver to help regulate the current to each motor.

2.4 Power System

Requirements: The power system must be able to power all 4 stepper motors as well as the whole navigation system. The navigation system will be fine with around 7 Volts, and the 4 stepper motors will likely require around 3 Volts.

2.4.1 Lipo Battery

The power system will essentially just be a rechargeable 7.4 Volt lithium polymer battery with around 5000 mAh. 7.4 volts will be necessary to drive the motors in parallel, although two or more might be required to generate enough current, depending on what motors we choose.

Ascension System

2.5 Reflector plate

The reflector plate is a cardboard sphere that is covered in light reflecting tape so it can be more easily spotted in the sky. This is a mandate from the FAA and will be attached to the same support string of the weather balloon.

Requirements: A 12 inch by 12 inch sphere with reflective material [4].

2.6 Parachute

The parachute we need for our project will have to be highly maneuverable and light weight. A small Ram-Air parachute will serve our requirements of being able to carry the payload and have steering strings that can be fed into our internal steering system [8].

Requirements: A 6 - 8 ft Ram-Air parachute that can upload our total payload of at most 12 pounds.

2.7 Weather Balloon

The weather balloon is the main and sole ascentation device. The weather balloon will have to be big enough to carry our 12 pound payload and burst at the altitude we desire.

Requirements: A 1200 gram parachute that can ascent to at least 60,000 ft.

Risk Analysis

The component that poses the most risk to the project is the navigation system. It is easy to program a microcontroller to spin a few motors to wind string, but it will be extremely difficult to make our navigation system such that it knows what strings to wind and when. Since our design completely depends on the will of the wind, it will not be as simple as it is with drones, where simply making certain rotors spin faster can alter position and direction, because if the wind is not blowing in the direction we need it to, the parachute will have tremendous trouble fighting it.

It will be necessary to program the navigation system to use the wind rather than fight it. It will have to be a system capable of accepting failure and making the best out of worst case situations, as there will be many cases in which it will be impossible to overcome the circumstances. The system's goal must not be to get within X distance of a target, but just to get as close to X as possible, given wind conditions.

Even when the wind conditions aren't bad, the problem of moving in certain directions is still very difficult. Sometimes it may be beneficial to tilt the parachute in a non straight direction depending on which way the wind is flowing, and even then the wind direction and speed can change quickly as altitude increases.

3 Safety and Ethics

The success of our project can only be measured if we can follow all safety and ethics guidelines. Conveniently, the United States Federal Aviation Administration (FAA) and Air Traffic Control (ATC) have already established requirements for all aircraft to follow. We have contacted the district FAA office in Springfield, IL and the FAA official requested we send the capabilities of our design in order to determine whether the device is considered a high altitude weather balloon or small unmanned aircraft [5]. If our design is classified as a weather balloon then we only have to contact ATC before flying in an approved air space [6]. If our design is classified as a Small Unmanned Aircraft (similar to a drone) then we are limited to flying under 400 ft in the majority of air spaces. Fortunately, the Springfield official said we could test our "high altitude drone" in their FAA testing field.

Our biggest safety concerns during the construction of our project include working with the high power supply and the motor drive. We need to follow best practices for not blowing out our circuit and ensuring no one is harmed by a motor accidentally turning on.

The accidental issues that can rise during our deployment are the same problems we are trying to solve. These include our device veering off course and causing a crash that would lead to fires, vehicle accidents, or damage to personal property. To limit the probability of these incidents, we have to research the safest launching site for our project.

On the side of ethics, when our device is fully operationally we now face issues with privacy and public safety. Weather balloons are useful tactic devices for military surveillance operations because they do not show up on radar and are silent. Also, the additional capability to land a payload at a GPS location also means this device could be used as a weapon. These concerns will be weighed by both our team and the FAA to ensure we keep the safety of the community and environment in mind [5].

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