Geosynchronous Balloon Control Solution

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Abstract

For their Senior Design Project, Jesse Bramble, Lee Mondini, Hani Naqvi, and Matt Peppo are conducting a feasibility study to determine if it is possible to control a high altitude weather balloon for sustained flight in near space. To start their research, the team investigated similar projects and their control techniques. The only comparable project to the Geosynchronous Balloon Control Solution team was Google's Project Loon. Inspired by the control algorithm used for Project Loon, our team is aiming to implement a control technique that will allow the user to specify GPS coordinates causing the balloon to try and stay stationary at the given coordinates in 3D space. After some research, we have concluded that this result can be achieved by manipulating the altitude of the balloon causing it to float in different directions with the wind. Our simulation has concluded that using an ideal balloon, as if the balloon was a point, our control algorithm is capable of guiding the balloon to a specified point in space and sustain the flight.

Introduction

Project High Flight (PHF) is a program lead by Bob Setlock. This project is offered as a course at Miami University in which any student can enroll. Each class plays a different role in the project. PHF has had several balloon launches to date. Currently, the students launch a high altitude balloon under Bob's supervision, the balloon flies up to near space (100,000+ feet) and then pops due to the change in air pressure. The payload then falls towards the Earth achieving speeds of over 100 miles per hour. A parachute on the payload ensures safe landing and a GPS tracker is used for retrieval of the payload.

Last semester, we researched possible methods of controlling a high altitude balloon. We conducted research of wind patterns at different altitudes and determined that a sustained flight is plausible if we can control the balloon's height. We were scheduled to work in conjunction with another team to build a small scale prototype to prove the possibility of sustained flight. Towards the end of last semester, we realized that we would not have a physical prototype available to us in time so we changed our goals for this semester to build a simulator to determine the feasibility of the project instead.

This semester, we spent all our time building and refining the balloon simulator. The simulator uses real wind data collected by the United States government and published to the public to simulate wind patterns at different altitudes. Since we do not have a physical balloon or a mechanism, we used a point to simulate an ideal balloon that can jump between wind levels at every iteration of the code. We left room for modification to make the program more robust by modifying the data to change the balloon's rate of ascent and descent.

Background

For this project, our team is working very closely with the Project High Flight team, which is a program on campus run by Professor Bob Setlock. Project High Flight is a developmental program that focuses on building-up creative, innovative, and leadership abilities in students through a process called Creative Centered Leadership. This is a four year program that includes classes and projects that are made to help instill these skills in students. One of the projects that the Project High Flight students have been working on is sending balloons up into the atmosphere. Once the balloons have reached a certain altitude, the pressure is too much for the balloon and it proceeds to pop. It is also very hard to control what path the balloon will follow due to the draft from the wind. Data from these balloon launches would be much better if there was some way to control the balloon once it reached a certain point in the atmosphere where the winds are more consistent. In theory a balloon should be able to maintain a certain radius around a "home destination" by changing altitude to catch the drift of different wind currents. Some companies have started projects to achieve this objective, most notably Google. For this project we have started taking the steps to solve the lack of control of these balloons.

We have developed a simulator to test this theoretical assumption. The simulator is designed using Java and Processing programming languages. Java is used for the computing and Processing is used for the visual presentation. The simulator is capable of showing a map in the background showing the position of the balloon over a map. There is also a slider bar that shows the current altitude of the balloon. The balloon is represented as a dot and moves around the screen with the magnitude and direction set by the wind data provided by the United States government.

Objectives

Our objective is to determine whether a sustained flight of a high altitude balloon is possible. In order to design an accurate simulator, we need to know many parameters that are not currently accessible. For this reason, we built our simulator based on an ideal balloon that has no weight and can jump between wind shears every iteration of the loop. To get more accurate results, we would like to know parameters such as the maximum and minimum heights the balloon needs to stay between, the rate of ascent and descent of the balloon, and the mechanism that will control the height of the balloon among other things.

Literature Research

For this project, the research required was not very extensive. To control a high altitude balloon, some key topics of research include existing similar projects, wind patterns, the balloon itself, and the control algorithm best suited for the purpose of this project.

We investigated existing projects as a preliminary step towards our goal. There are many enthusiast groups that release high altitude balloons equipped with cameras for near space photography. After reaching a certain point, the balloon succumbs to the pressure and the payload falls back to the Earth. A safety parachute is equipped to ensure safe retrieval of the payload. Since the goal of this project is to actually control the balloon, we did not spend too much time researching existing projects that did not have a control algorithm.

The project we found that aims to control the flight of a high altitude balloon is Google's Project Loon. Project Loon started as an experiment in the Google labs in 2011. After some initial testing, the experiment was announced as a full fledged project in June 2013. Since the project is so young, there are not too many details available to the public yet. We did, however, conclude that imitating Project Loon's method of control would be the best approach for our project as well. The way Google is controlling their balloon is by manipulating the height of the balloon to catch winds in different directions. This discovery lead to our next topic of research; wind direction.

We discovered the website for the National Environmental Satellite, Data, and Information Services (NESDIS), hosted by the National Oceanic and Atmospheric Administration (NOAA) almost immediately. The publicly available database located on the government website contains records of pressure, temperature, geopotential height, dew point depression, wind direction, and wind speed at various altitudes ranging from altitudes of about 1000 feet to over 120,000 feet. We later discovered that this is the same database that Google is using to design their test simulations for Project Loon.

Once we had acquired the wind data, we looked for any available reference books for assistance in analyzing and animating the wind data. With no such luck, we resorted to using our knowledge of MATLAB to analyze the data. We discovered that wind has a very steady pattern at higher altitudes. We decided to use this predictable wind pattern as the basis of our animation software.

Our final research was to decide which programming language to use for our high altitude balloon simulation. We discussed the pros and cons of using MATLAB, C++, or Java for this simulation. We decided that as a group, we were most comfortable with programming in Java. While we were developing our simulation in Java, we received a tip to investigate a program called "Processing". Processing is a subset of Java that was made by artists, for artists, making it very simple to program with the trade off of computing power. For our initial simulation, we decided we did not need extreme computing power.

We are still currently researching and experimenting with different control algorithms to minimize the movement of the balloon while it tried to remain stationary it at given coordinates. The algorithm we are currently using is called the "Greedy-First" or "Best-First" algorithm. This algorithm works on the principle that the algorithm searches a graph and chooses the most promising node to move to. For our simulation, we are using the wind data provided by the NESDIS database. When we implement the algorithm in the actual balloon, we will have the NESDIS database as a reference along with data that our balloon will collect while on its journey.

State of the Art Review

Part of the research we did was to find similar projects others have done already with high altitude ballooning. Some of the projects we discovered have closer goals to ours than others. There were several near space photography projects utilizing high altitude ballooning, such as 1337arts and Near Space Ballooning: Stratospheric Photography. However, these did not accomplish our goals, because there is no control of any kind on the balloon. The balloon is launched and it simply climbs until it pops, and then it parachutes down with the photographs to wherever it happens to land.

The California Near Space Project is a little closer to what we are trying to accomplish. They currently hold the record for longest distance traveled by an amateur balloon, which flew across the Atlantic Ocean. To do this, they have some degree of control, keeping the balloon at a cruising altitude, with valves and highly sensitive flow meters to keep the volume and lift precise. Although they are capable of long flights by avoiding burst altitude, meeting our first goal, they do not meet our second, since they are going for distance, and we want to stay in the same relative place.

Google Project Loon has achieved the closest thing to what we want to achieve. Loon's mission is to provide wireless internet to rural, remote, or disaster areas of the world by a network of near space balloons. These balloons hover over the area up in the stratosphere, catching different wind currents of different directions by changing their altitudes. The balloons themselves are 15 by 12 meters, and Google claims they can stay in the air for about 3 months, although they have not had a test that long yet. They are controlled by a combination of remote control and automation. The balloon automatically vents gas to prevent bursting and uses algorithms to choose its wind currents, but position can be adjusted at mission control. Meeting both of our goals, Loon is the most closely related project to ours.

Design Proposals

In its current state, the simulator is capable of projecting the path of the balloon while keeping it in the range of 60,000 feet to 100,000 feet and aiming for a home point in 3D space. To further improve this design, we propose to add parameters to account for the rate of ascent and descent. We also propose to further investigate methods to make the balloon rise or fall.

One method could be to have a two way motor capable of adding helium (or another light gas) to make the balloon rise and to extract the helium and store it in a compressed form to make the balloon descend. While this solution would raise and lower the balloon, it requires massive energy to pump the helium making this solution not very feasible.

Another method could be to design a system that can change the size of the balloon. If the balloon is squeezed and the air is pushed out, the surface area and the weight of the balloon will decrease and cause it to rise while increasing the surface area again would fill the balloon with air and make it heavier, causing it to fall. This solution seems more feasible and requires further investigation.

Analysis of Alternative Proposals

When deciding on our design for this project, it was important to take into account all of the possibilities so that we could decide on what would work best with our goals. For the simulator, it was important to pick a programming language that most of the team felt comfortable using, so that we could help each other out when necessary. We also had to choose a language that was capable of doing everything that we wanted it to do. We decided to use Processing in Java, because it was the easiest way to create visuals and it was capable of producing everything that we wanted out of our simulator. MATLAB and C++ were other options that we took into account, but Processing in Java was the best for our goals and programming background.

When deciding on prototype, we thought about many different designs including a control steering device, a device that worked off of the idea of a sailboat and its sails, and finally a device that raises and lowers to catch different wind currents. The control steering device would have the most control, however, it would not allow for the balloon to stay afloat for a very long time because it would use a lot of energy to navigate around, especially if it was working against a strong wind current. It would be too much weight attached to the balloon to keep it afloat for the control steering device. The sailboat idea was based off of the idea that the balloon could actually use the wind current and work against it using a sail that is smaller at the top and larger at the bottom. The problem with this design is that sailboats have rudders that allow the sail to use the force required in the opposite direction. Our balloon would not be able to have a rudder that would be used as a force to work the sails against. That is why we chose the idea of raising and lowering the balloon to drift with wind currents.

Design Implementation

After all of our brainstorming and idea collecting, it was time to bring our balloon simulator to life. We created a list of features we wanted our high flight balloon simulator to include. These were things like, a basic three dimensional map of the airspace, visualization of the balloon for whoever will be using the simulator, a way to move the balloon on screen to a specific point, some sort of algorithm to simulate a balloon moving freely through the air, and some sort of algorithm to simulate a balloon being pumped up and down, catching wind currents, and circling around a certain point. We started by building the 3D map by representing it as a simple array in Java. Next the control algorithms were coded and put into use. We ran into problems when it came to handling edge conditions. The decision had to be made what would happen when the balloon got to a point beyond our map. We have currently implemented a complete stop when the simulated balloon reaches an edge, but this choice will most likely be changed in the future, although the choice will not matter much for our balloon should theoretically remain in a small and safe cycle.

After creating the "brain" of the simulator, we needed a user-friendly way to display what was going on behind the scenes. This took a good portion of our time. We researched a few options for a graphical user interface that would allow for real-time movement and measurements, along with the ability for the user to interact and alter the simulation's behavior. Processing, a programming language developed by Casey Reas and Benjamin Fry, was the easiest way, we decided, to create the kind of visual display we had in mind. Processing was a programming language created for artists who did not want to deal with the overhead that comes with programming a graphic interface; this allowed us to use our time more efficiently, and keep a weekly flow of forward progress. Processing also had the capability to mesh with the Java code we had already written.

Discussion of Alternative Solutions

In terms of alternative solutions, we were fortunate enough to not have come up with many. We started with a general plan and worked out most of the details as we went. Having informal discussions frequently, bouncing ideas off one another, allowed for a low stress environment, and allowed for consistent progress. Our solution thus far may be an alternate of the exact image we first pictured, but the simulator we have created exceeds the initial ideas, and better suits our needs. There were specific cases when a certain code structure would return poor results so such structures were changed to alternates. We were not sure what exactly would work best, since none of our team had ever worked on creating a simulator.

Evaluation and Analysis of Final Product

At the end of the first semester, we had studied the wind data and discussed possible solutions for controlling the balloon. We had also developed the base of the project by generating random values for wind speed and direction to create a 3D space to test the balloon in a random environment.

During the second semester, we refined our simulator by using real wind data collected by the United States government instead of randomly generated vectors to determine the path that our virtual balloon will take in order to get to the target “home” location. Our simulator has a map in the background showing geographically which place the balloon is hovering over. Since we could not get information for actual product, we assumed the balloon was ideal and used a point to simulate the balloon. With the ideal conditions, our simulator indicates that a sustained flight using high altitude balloons is feasible.

Ethical, Social, Economics and Other Issues

Our project is to focus on creating a working simulation software to design and test a control algorithm that will be used to control a high altitude balloon in near space. While all our work is in the virtual world, we investigated some additional issues and topics related to high altitude balloon launches.

When the balloon is launched, it is filled with gas and is about five to six feet in diameter. As the balloon ascends, the gas inside expands while the outside pressure drops, causing the balloon to inflate. The balloon generally inflates to about twenty to thirty feet in diameter before finally exploding and dropping the payload.

There is a pretty complicated system that is used worldwide to define airspace. The airspace is classified depending on the locale and altitude. Since these balloons fly to an altitude that is much higher than class A airspace, where most airport traffic is, a high altitude balloon flight requires clearance from Federal Aviation Administration (FAA). This ensures safety for the party launching the balloon and any potential planes in the air.

In its current form, high altitude ballooning is mostly used by the government for data collection and by hobbyists for near space photography. Our goal is to give high altitude ballooning more purpose. Google is trying to provide wireless networks in remote areas. We could extend the list of uses and use the balloon for providing Global Positioning System (GPS) signals or as a surveillance system. The balloon can be virtually undetectable by even the most sophisticated radars due to its small size and high altitude. We can also use this system during emergencies, such as major floods or earth quakes, to provide communication when local towers are down. In short, there are countless applications this technology can be used for and we are very excited to work on making it a possibility.

Future Work

The simulator could use many improvements and updates. Currently, the simulator uses real wind data provided by the United States government, but it is a static file. We would like to program the simulator to access the government website and parse the information automatically as the information gets updated twice a day. It would also be great to have the map in the background be dynamic and represent actual coordinates.

Furthermore, we would like to be able to access the wind data for any geographical region in the United States automatically. The user should be able to input the location of interest and the simulator should find the data for that city and simulate the balloon trajectory based on information for that city.

Finally, we would like to build a small scale prototype to test our algorithm in a controlled environment. Upon successful testing, we would like to see a full scale launch in the future.

Conclusion

Project High Flight is a program lead by Bob Setlock. Team High Flight has had several successful high altitude balloon launches in the past. The balloons fly up indefinitely until they succumb to air pressure and pop. A GPS signal from the payload is used to track and retrieve it.

For our senior design project, we are implementing a way to control the flight of the balloon. We aim to not just prevent the balloon from popping, but also to be able to specify coordinates that the balloon would then hover around. Research indicated that the most effective method to accomplish this would be to control the altitude of the balloon and use the wind currents to steer the balloon in the desired direction.

The control algorithm that we are developing uses the greedy-first method for calculating whether the balloon should rise or descend. In this kind of search, the system is always calculating the next step and assessing the best choice to reach back to the desired location. Since it is not feasible to test our algorithm on the actual setup, we are developing a software based simulator for preliminary tests. Once we are satisfied with our simulator results, we will implement the algorithm on the live balloon.

In its current state, the simulator is able to implement a greedy first algorithm using wind data provided by the United States government for an ideal balloon. In the future, we would like to add parameters to the balloon to make it more realistic and provide tangible results. Based on our simulations, we believe a sustained flight for a high altitude balloon is possible and the scope of the project is huge. This technology can be used to launch cheap temporary satellites to provide internet or GPS in remote locations. It can even be used for spying and other military purposes.

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