Directional Camera Control on High Altitude Balloons

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The research reported in this paper examined the design and control of a gimbal for solar eclipse tracking and video recording. The gimbal design required 3 axes of rotation to allow for full range of motion. Utilizing individual brushless motors for each of the axes ensure minimum rotational requirements on each axes. In controlling the gimbal, both a mathematical and visual method were utilized. The mathematical method is a modified version of what is currently used for solar array pointing. The visual method looks at where the position of the sun is within the image and determines what angle changes are required. Utilizing a combination of these methods helps to eliminate error that accumulates within the onboard gyros due to the erratic behavior of balloon motion during flight. Elimination of this error ensures accurate video recording of the solar eclipse.

I. Introduction

In 2017 there is a solar eclipse that is in a prime location within the United States to view. For this eclipse, however, it will be viewed in a different way then typically done before. Using high altitude balloons it has become possible to record and stream the eclipse from upwards of 100,000 feet in altitude (MSL). This paper reflects upon the gimbal and gimbal control for pointing at the Sun.

A. Gimbal

Balloon flights are not typically stable platforms. So in order to record or transmit quality video it become paramount to utilize a gimbal for stabilization. Due to the flight characteristics of a balloon it is important to have gimbal be able to orient itself in all 3 axis. These axis include Yaw Pitch and Roll.

B. Pointing

One of the main aspects that needed to be addressed for this flight was the necessity for gimbal control and pointing. There are two main methods of pointing that were investigated for the gimbal. The first method was through mathematically determining the location of the sun using azimuth and zenith angles. This method has long been utilized for pointing solar arrays.[2] The second method uses a small black and white camera (with a filter) or a Sun sensor to determine where the center of the Sun is and what orientation change is required to move the center of the Sun to the center of the camera.

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II. Method

A. Gimbal

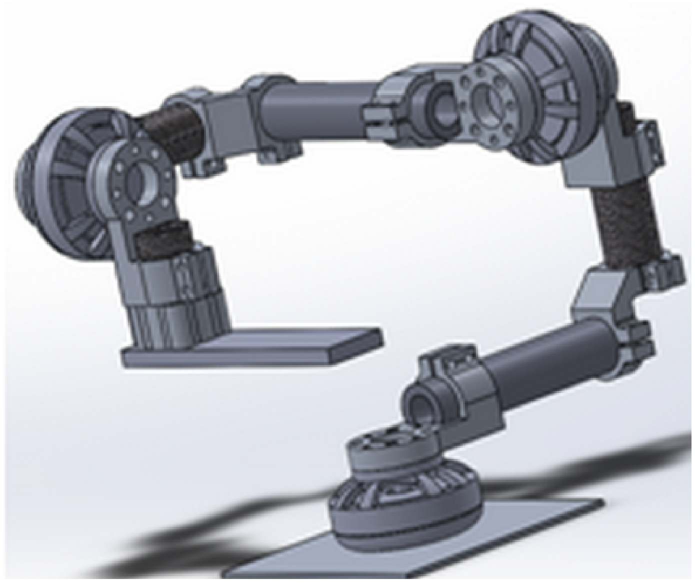

Figure 1.

To fulfill the needs of the gimbal it was important to identify what types of motion would be encountered during a normal flight. Through past flights it was determined that prior to burst the payload typically rotates about its Z axis. Payloads also typically incur pendulum like motion throughout flight. Due to the nature of the flight the gimbal would only have to counter flight motion up till burst. This is because it is nearly impossible for the gimbals to compensate for full tumbles.

With a firm understanding of what would be required of the gimbal it became possible to look at the design requirements of the gimbal. When talking about gimbals an important aspect is the range of motion. By looking at typical flight conditions each of the axis were analyzed to determine what range was required.

1. Pitch

This axis controls the cameras zenith angle. During normal flight this axis only compensates for pendulum motion. Since this motion should never create and angle of greater than 90 degrees at maximum amplitude, this axis should never need to move more than ± 90 degrees from horizontal.

2. Roll

This axis behaves very similarly to pitch. Roll, like pitch, only has to compensate for pendulum motion. This means that the axis should never need to move more than ± 90 degrees from horizontal.

3. Yaw

This axis is responsible for control of the azimuth angle for the camera. During normal flight yaw does not need to compensate for pendulum motion, however, it does have to compensate for any rotation around the Z axis. This means that it must have a greater than 360 degrees of motion. Ideally this axis would have an infinite degree of motion. Our first design failed to accomplish this, however in the future work section a method is described that accomplishes this goal.

Using these design requirements the gimbal design in figure 1 was developed to fit the needs for the solar eclipse flight. This design employs 3 motors: one for each axis. 2 of them have 180 degrees of motion and the third, yaw, has 360+.

B. Electronics

1. Gimbal Controller

For the control of the gimbal it was decided to go with an off the shelf option in order to reduce time and cost of the system. Through research it was determined that the storm32-BGC[1] would accomplish the needs of the system. The developed firmware for the controller allowed for a multitude of input including PWMbng:80bk which we used as our angle input method.

2. RFD900 with ChipKit

It was determined for testing purposes the best way to give inputs to the gimbal controller was by manually sending them from the ground. To accomplish this an RFD900 was added to the payload and a ChipKit decoded the data sent to it. Then if the checksum on the data stream checked out the angels sent via the ground station would be sent to the gimbal controller.

C. Pointing

As mentioned before two methods where explored for tracking of the sun. The first being an analytic method and the second through imaging.

1. Analytic

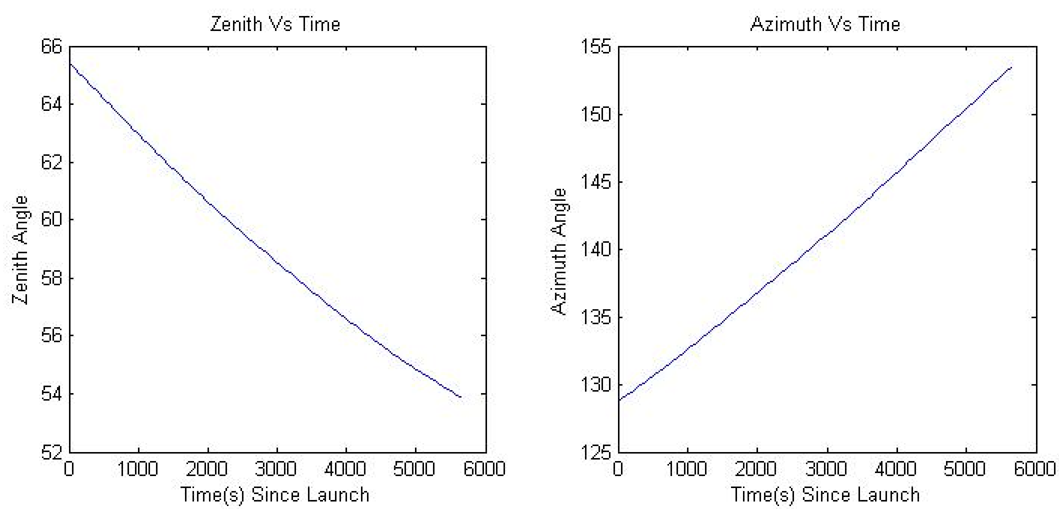

Figure 2. This shows the Sun's position in respect to the balloon during a simulated standard duration flight

This method was originally designed for solar arrays. Given a time UTC and location in latitude and longitude, the program returns an elevation and azimuth angle. These angles are than given to the gimbal via the RFD900 link.

2. Imaging

An imaging system has not been flown yet, however significant work has been started on it. The primary goal of this method is to maintain the view of the sun as it travels across the sky. So when on the ground the payload camera would be initially pointed at the sun. Then as the balloon flies the azimuth and zenith angles are adjusted based off of the location of the sun in the image. The issue with this lies in the fact that much of the sun will be covered up during the solar eclipse. This is fixed by only using an arc of the Sun to determine the center. The arc that is used is constructed off of the bight pixels in the image. These bright pixels are found using simple software based filtering algorithms.

III. Conclusion

A. Manufacturing

A vast majority of the required parts for the gimbal were able to be purchased off the self due to their growing use in photography. The only issue that what initially ran into with the construction of the gimbal was the adapter plates between the elbows and the motors themselves. The elbows had different size screws and threads then the motors and they where placed in different locations. This then meant that the adapter plates had to be precision machined in order to properly work. Once these plates where machined and the gimbal was assembled, the gimbal had to be balanced. To do this the length of the gimbal arms needed to lengthened or shortened depending on what was needed to get the center of gravity through the 3 axis of the gimbal.

B. Testing

During testing some issues started to arise due to the large amount of cables going to the camera from the main payload. It quickly became abundantly clear that there was going to be a limit on how many turns the yaw axis would be able to take.[a] For the first flight it was decided that having the gimbal unwind itself periodically would be sufficient, however future work would be needed to prevent the required unwinding. Overall the ability to send the azimuth and elevation angle to the gimbal worked fairly well as long as there was enough slack given to the gimbal cables. Improving this system again pointed back to finding a better way of managing the cables.

C. Flight

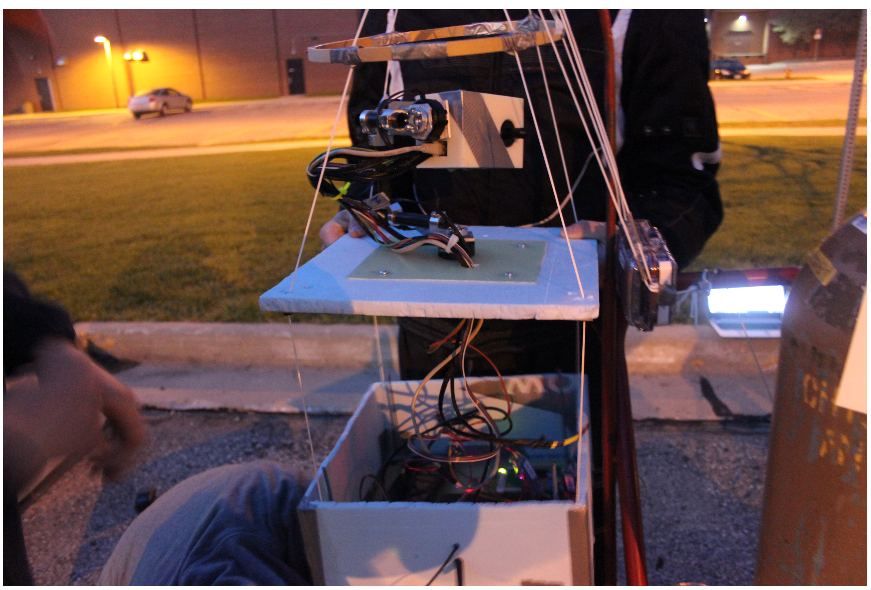

Figure 3.

The flight was good in the fact that it helped to point out a few of the other flaws in the system. One of the issues again points right back to cables on the gimbal. When the temperatures get as cold as it was on the early spring day the cables did not bend well when the gimbal tried to compensate for any movement no

[a]It is important to note that this limit was not just limited to the yaw axis, but also to the pitch and roll axis, however they do not need the same range of motion that is required for the yaw axis.

matter how small. This lead to the gimbal having to work harder then it should to even maintain a single position. This lead to the eventual timeout of the gimbal controler.

IV. Future Work

A. Gimbal

One of the main issues with the gimbal is its inability to have an unlimited degree of motion on the yaw axis. To solve this it is necessary to look at what cables are required to go up to the camera housing, since the cables are what limit the movement. Once it was determined that it wasn't possible to reduce or remove all of the cables it became necessary to look at where the yaw axis was place. This brought about the idea that it might be possible to put the yaw axis below all of the electronics. This would mean that there would be a box containing all electronics that is attached to the yaw arm. Then the yaw motor would be attached to the bottom of the box containing the electronics. At this point the the motor has an unlimited degree of motion. In order to counteract the moment of inertia of the box it is important to attach a moment arm to the motor. This moment arm or arms are then attached to the guide lines for the balloon which are then attached to the primary tracking payload. This system will be able to remove many of the issues that the cables caused during the flight.

B. Pointing

To create a system that is reliable it is important to be able to do all pointing from the payload so that there is no concern about losing connection with the RFD900. To do this it will require a 2 part pointing system. As talked about before it is possible to point using both an optical method and an analytical method. The primary way for tracking the sun is through the analytical method, however due to sensor drift there is a need to be able to adjust where the gimbal points. So the fix for that is using the optical method to determine the amount of drift that is incurred during the flight. Since the optical method uses an arc of the sun and determines the center of the sun from that it will still be able to locate the center even during the eclipse itself.

Acknowledgments

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References

[1]OlliW, *STorM32 BGC: 3-Axis STM32 Brushless Gimbal Controller*, http://www.olliw.eu/2013/storm32bgc/ (accessed December 1, 2014)

[2]Roy, V., *sun_position.m*, http://www.mathworks.com/matlabcentral/fileexchange/4605-sun-position-m (accessed November 20, 2014).