Altitude Control Methods for High Altitude Balloons

Introduction

High altitude balloons offer unique capabilities for Earth observation and monitoring. Their low cost and long loiter time is beneficial for several situations where aircraft, satellites, or terrestrial infrastructure cannot accomplish mission objectives, such as natural disaster sites or remote locations. A common requirement of these applications is station keeping, in which the balloon loiters over an area for an extended period, in some cases weeks. For balloons to maintain position, they often are required to change and hold altitude with tight tolerances, as air currents at different altitudes travel in varying, yet predictable, directions. This paper reviews several commercially available altitude control methods, their underlying technology, and specific implementations of those technologies.

Commercial Applications of Altitude Control Systems

Weather balloon altitude control systems have existed for several years; however, they have been relatively crude, mechanical devices. Within the last ten years, electronic controllers have been developed to use a combination of digital sensors and remote user input to control mechanical actuators control the height of the balloon. Examples of these actuation methods include releasing ballast or adding/removing gas from the balloon. X Development LLC (a subsidiary of Alphabet, which also owns Google) is one of the most publicized companies producing these control systems with their Project Loon. Their balloons are designed to provide internet connectivity to rural areas and are based on large zero-pressure high altitude balloons [1]. X's balloons have loiter times approaching 6 months. Unfortunately, their balloons are expensive with a unit cost which X has described as "tens of thousands of dollars [2]."

Another alternative is Stanford Student Space Initiative's ValBal project, which is based on a latex weather balloon. It is targeted as a low-cost control system with a parts cost which is less than $1,000 [3]. Their controller recently achieved a world record for time aloft (for a latex balloon) with 88 hours 40 minutes of time [4].

Technology of Altitude Control Systems

Several methods exist for altitude control of balloons, one of the simplest was implemented by NOAA's smart balloon, which merely uses an on-off control methodology to modulate a control valve on a gas cylinder which fills the balloon [5]. This algorithm, although effective, prematurely uses the expendable gas, limiting flight duration.

Alternative methods include that implemented by the ValBal controller, which monitors altitude, its rate of change, and the altitude change since the last action. These values are then combined with a weighted sum to compute "incentives" which must be above a certain cut-off to trigger a control action, such as the release of ballast or gas. This method was designed to conserve ballast and gas as much as possible as each represents limits on the duration of the flight. However, this solution had greater variability in altitude as a result [3].

The third method of control attempts to predict future changes by monitoring additional atmospheric variables which can affect the balloon’s altitude such as temperature and wind direction and speed. Specific corrections can be calculated to minimize the use of non-replenish able resources. [6-7].

Implementation of Altitude Control Systems

Altitude control systems have been implemented in various ways including with mechanical interlocks and embedded microcontrollers. The electrical implementations vary based on cost with lower cost systems typically using smaller off-the-shelf microcontrollers. Larger systems, such as Project Loon, may use cloud computing infrastructure to calculate control inputs with the balloon’s onboard hardware primarily acting to perform that mechanical actions necessary to control the balloon [6].

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[6] J. Mathe, C. O. L. Boyce, and K. Bonawitz., “Optimal Altitude Controller for Super Pressure Aerostatic Balloon,” U. S. Patent 9,237,816, 3 May 2016.

[7] S. Saleh, “Floating Performance Analysis and Extended Lifetime for High Altitude Zero Pressure Balloon,” *International Journal of Modeling and Optimization*, vol. 6, no. 4, pp 199-205, 2016.