

Repurposing an Iridium Network Satellite Modem into a Two-Way Balloon Tracking and Communications System

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An undergraduate student project to track high-altitude balloon payloads using an Iridium network satellite modem to send and receive data from a payload at up to 90,000 ft. Ground station software was created to facilitate two-way communication with a webserver and database system set up to receive and store data. This information is then plotted on a Google Maps overlay and updated dynamically allowing anyone to view the location of the balloon via a website on the internet.

Nomenclature

<i>APRS</i>	=	Automated Packet Reporting System
<i>ATC</i>	=	Air Traffic Control
<i>BOREALIS</i>	=	Balloon Outreach, Research, Exploration, and Landscape Imaging System
<i>FAA</i>	=	Federal Aviation Administration
<i>GPS</i>	=	Global Positioning System
<i>MSGC</i>	=	Montana Space Grant Consortium
<i>SBD</i>	=	Short Burst Data
<i>VOR</i>	=	Very High Frequency Omni-Directional Range

I. Introduction & Motivation

THE MSGC BOREALIS program allows undergraduate students from any discipline to design, test, fly, and analyze scientific or engineering experiments during high altitude balloon flights. Located at Montana State University in Bozeman, Montana, the program runs throughout the entire school year with an internship opportunity during the summer. BOREALIS students are encouraged to use a hands-on approach with their projects with an emphasis on experimentation and failure analysis.

During the 2013-2014 school year we developed a hardware and software system to track and control balloon payloads with an Iridium network satellite modem. This project came together to address several needs of the BOREALIS program:

- provide near real-time balloon position reports to the FAA and local ATC
- recover payloads and experiments
- communicate with and control experiments mid-flight
- overcome issues with the previous amateur radio based tracking system

The primary purpose for near real-time on-line position reporting of the balloon is to provide the FAA and ATC rapid updates of the balloon location for aviation safety reasons. While contact is still made with the FAA to file flight plans and flight position updates, it is common for their technicians to already have the tracking website up and to comment on our flight progress. The second most important aspect of tracking the balloon throughout its flight is for recovery of the science payload after it lands. The tracking of our science payload currently has triple redundancy with the satellite modem, an amateur radio system using APRS, and a SPOT satellite beacon.

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Iridium satellite modems allow two-way communication with the balloon payload. This allows remote control of scientific or engineering payloads or control of the balloon itself. Our balloon payload currently uses this ability to activate a helium vent valve for altitude control and also to actuate servo motors integrated into our flight termination system.

Like most ballooning groups our primary means of tracking and communicating with our payload relied on amateur radio equipment, such as that shown in Fig. 1. Line-of-sight with the payload is required for radio communication from the ground which can become a problem during the last minutes of flight. In contrast, as long as the satellite modem has an open view of the sky data can be sent to or from the system. Control of BOREALIS payloads mid-flight using the amateur radio equipment has previously been inconsistent and is no longer used to activate critical systems.



Figure 1. Amateur radio based communications system

II. Satellite Modem

The satellite modem being used is an NAL Research 9602-LP as seen in Fig. 2. This modem is marketed primarily to the asset tracking industry, where one would attach the device to high-value equipment to monitor its status and location. The modem operates by communicating with both the Iridium and GPS satellite constellations. The GPS constellation consists of 32 satellites orbiting at an altitude of 12,600 miles. This constellation provides the modem with an exact fix of its location on or above Earth's surface. The Iridium constellation consists of 66 satellites orbiting at an altitude of 485 miles. The Iridium constellation provides the modem with two way communication capabilities from anywhere on earth.



Figure 2. NAL Research 9602 satellite modem.

The 9602 modem utilizes a special dual-band antenna to receive GPS data and receive/send data over the Iridium network. The antenna is sensitive from 1610.0-1626.5 MHz for the Iridium network and 1575.42±13 MHz for the GPS. Settings are updated on the 9602-LP modem using software running on a PC, which is then communicated to the modem using a serial port. Every setting can also be adjusted in-flight by sending specially crafted data packets to the modem via email. Settings may include reporting rate, output pin states, type of GPS sentence to send, etc. A data packet from the modem is called a SBD message. Service for the modem is charged per-SBD message sent or received, much like a text message on a mobile phone.

III. Software

Software communications with the satellite modem presented numerous challenges which included: how to interpret incoming data from the modem, how to store the data (latitude, longitude, altitude, etc), how to display the stored data in a meaningful way, and how to communicate with the payload during flight.

To solve the first challenge of interpreting incoming data, a plugin was used to adapt the incoming data to a more usable form. The plugin runs through a service installed on a server running in the BOREALIS lab. The service and plugin convert incoming data to an XML formatted file. A Java program was then written to read certain data elements from the XML file when it is created. A typical location report in XML format is shown in Fig. 3.

Once the Java program interprets the incoming data file, a storage location was needed to make the data easily accessible for future use. A custom MySQL database was created to store the

```
<type>NAL GPS Report 5</type>
</meta>
<nalGpsReport5>
  <time>2013-07-31T15:10:49.5Z</time>
  <lat>46.3612667</lat>
  <lng>-109.0443833</lng>
  <alt>21820</alt>
  <gndVel>18.36</gndVel>
  <course>294.10</course>
```

Figure 3. Example XML data packet

incoming data for later use, and the Java program was adapted to place information into this database in real-time.

To display the location information in a meaningful way we created a website for displaying data. Two methods were used to display information: a continuously updating table of information and a live map view showing the moving location of the balloon payload.

To implement the two methods of delivering information via the tracking website various scripts and code segments were written and run on the webserver to read and interpret information from the MySQL database. The Google Maps application programming interface was utilized to plot information onto a topographical map using a marker for each data point received (Fig. 4). The website can also detect when it is viewed on a mobile device (Fig. 5) to improve performance by decreasing update frequency and number of graphical items on screen.

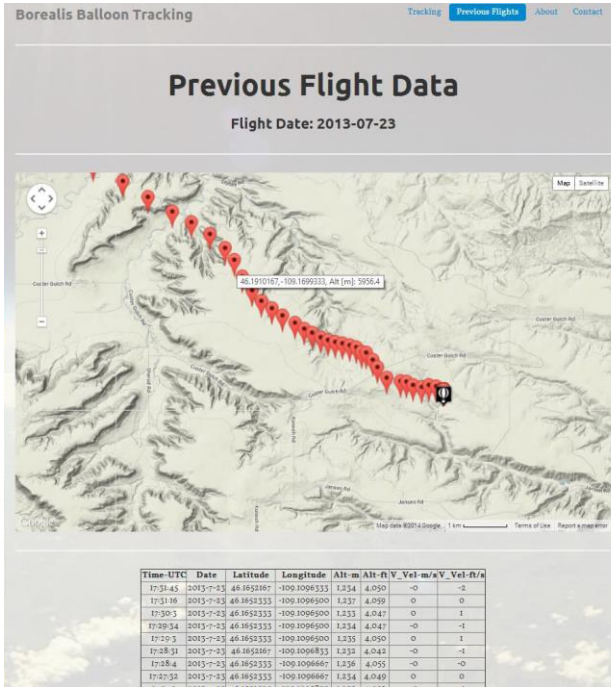


Figure 4. Tracking website displaying historical data.

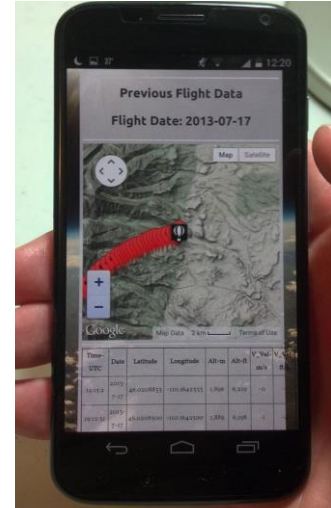


Figure 5. Tracking website displayed on a smartphone.

Finally, a control system consisting of an Arduino microcontroller with a GPS shield was interfaced with the satellite modem (Fig. 6). A set of three output pins on the 9602-LP modem were connected to digital input pins on the microcontroller. Code running on the microcontroller then determines what action to take depending on the pin state of the modem. Commands can be emailed to the modem mid-flight to perform various tasks. To date the microcontroller controls a helium vent valve to establish neutral buoyancy flights, and a flight termination system actuated by a servo motor.

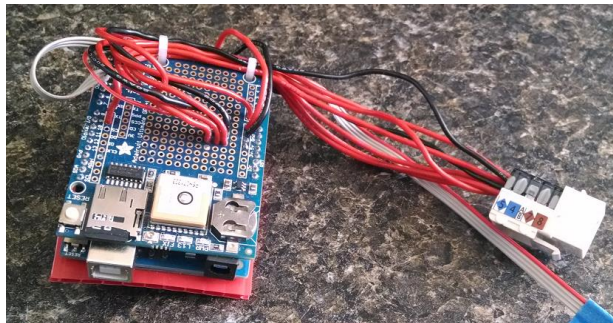


Figure 6. Arduino microcontroller with GPS shield attached.

would not compromise the campus network. Throughout the project the processing load of the webserver was monitored for performance to ensure reliable operation.

IV. Webserver

To accomplish the tasks listed in the software section above, a custom webserver was required to host the code and database used by the tracking website. The webserver allows the tracking data to be displayed on any internet browser. An Apache webserver was configured along with a MySQL database host on a BOREALIS lab computer. We then worked with the campus information technology department to open up certain internet ports in the campus firewall. Various security concerns were investigated and addressed to ensure the webserver

V. Future Work

We intend to continue to develop and enhance the functionality of our website. Several future goals include: integration of aviation sectional maps overlays onto the flight maps, automatic plotting of the projected landing site, and web-based control of the payload. A graphical overlay of aviation sectional maps onto the tracking system would aid the FAA in tracking the location of our balloon. This feature along with displaying the balloons bearing and distance from a reference VOR site will make our position reporting consistent with that currently employed by the aviation sector. Currently the system only displays location information on a topographical map of the area. An automated landing site calculator is also being developed. It will continuously predict where the payload would land should the flight be terminated at any point and plot that location on a map in real-time. This feature will help inform the decision making process about when and where to terminate the balloon flight. Further work could allow for a web-based interface for sending commands directly to the modem instead of sending email messages with embedded commands.

VI. Conclusion

Integration of an Iridium network satellite modem has allowed the BOREALIS team at Montana State University to reliably control, track and provide on-line position reports of our high altitude balloon payloads in near real-time. The tracking website allows the FAA, ATC and other interested observers immediate access the balloons current position. The website also serves as an archive for any flight data collected using the satellite modem. To date, the system has successfully flown on seven flights.

In-flight communication to an on-board microcontroller has also been successfully demonstrated. Commands are uplinked through specialized messages sent via email. On the previous two flights the satellite modem allowed our team to successfully control a helium vent valve and flight termination system. This combination has allowed our team to achieve neutral-buoyancy flights where the balloon payload loiters at a specific altitude.

VII. Acknowledgements

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