Implementation of Multimodal Tracking Capabilities for High-Altitude Ballooning

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Successful ballooning tracking is a challenging task for many ballooning teams. Several methods of ballooning tracking are known to the ballooning community. In this paper, we present a concept of dual-modal tracking payload integrating an RF radio operating at ~900 MHz and a cellphone-based tracking system operating at ~2 GHz. In particular, we describe how we combined the RF-based and cellphone-based methods to function properly as an integrated module. As part of the implementation details, we also present a processing mechanism implemented on a microcontroller to detect when the payload has landed and turn on the cellphone after landing.

I. Introduction

IN high-altitude ballooning, tracking is of paramount importance to properly chase and recover the payloads. There are various ways to realize balloon tracking capabilities but most common options have been based on satellites, Automatic Packet Reporting System (APRS), or cell phones. Each of these options requires a network of its kind and the end-user needs to have access to the Internet so that a tracking device on a balloon system can deliver its position information to the network. The end-user then retrieves this position information from the network via the Internet. While each of these options offers the benefit of being able to track the balloon, it also suffers from limitations (for more info, see [1]). In addition, 900 MHz radio frequency (RF)-based tracking systems have also become available, e.g., [2]. To ensure a successful recovery of the payload after a balloon flight with a variety of landing scenarios, more than one option is often utilized together on a balloon system, either in a single payload or in separate payloads.

During the 2017 solar eclipse, we have participated in the nationwide ballooning initiative as one of the teams from Pennsylvania. The main objective of the nationwide eclipse ballooning project [3] was to capture videos of the spectacular natural event of the solar eclipse along the eclipse path from west coast to east coast, and live-stream to the ground and also on line. Specific to our needs to sustain a ballooning program at the University, our secondary objective of the project was to build and test a more robust balloon-tracking system with or without access to the Internet during flight.

In the following, we provide an overview of our dual-modal tracking payload and describe some design specifics for integration of a 900 MHz RF radio and a cellphone into a single payload. This dual-modal payload was used along with a separate payload of the Iridium-based tracking during our solar eclipse ballooning. The dual-modal payload can be further expanded to a trimodal payload when an APRS transmitter is integrated into the payload [4].

II. Overview of the System

Error! Reference source not found. shows an overall functional diagram of the multi-modal tracking system (MTS). It consists of two main parts, 1) a tracking payload, MTS-Tx, on the balloon system and 2) the mobile stations with an MTS-Rx. A 900 MHz RF radio [5] on the tracking payload transmits directly to its peers on the mobile stations in a form of point-to-multipoint communication. A line-of-sight is required to maintain a reliable communication link between them. To ensure redundancy, we have implemented two mobile stations such that both mobile stations receive the same signal from the 900 MHz radio on the payload and retrieve the GPS coordinates of the tracking payload at each mobile station. The GPS satellite signal is received by a GPS receiver on the payload, and GPS coordinates are

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extracted by a microcontroller and passed onto the 900 MHz radio for transmission to the mobile stations. The cellphone on the tracking payload has its own built-in GPS receiver and communicates with a cellphone tower to deliver its position information to a web server. We have used AccuTracking [6] for the web server and its tracking software to configure the cellphone. Adhering to the FCC regulations [7], a control mechanism is devised such that the cellphone is powered on to operate only when a preset logical condition is met, which does not occur during ascent or flight but occurs after landing.

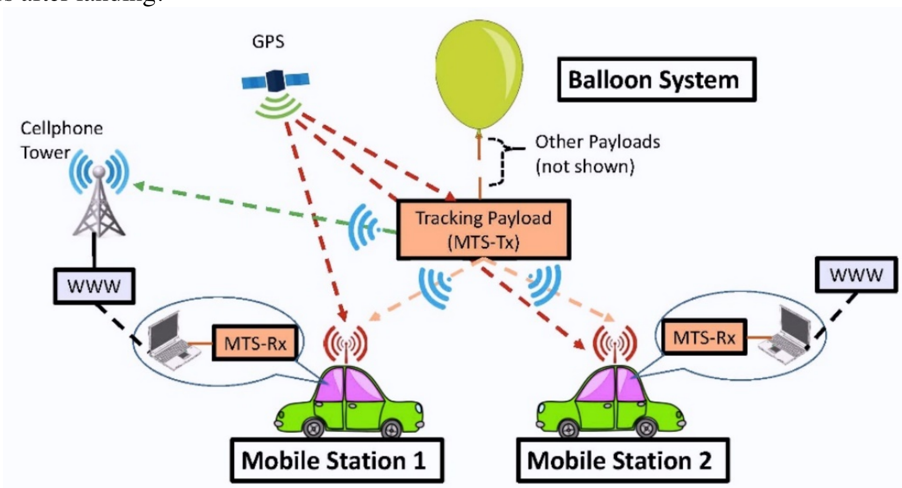

Fig. 1 Overall functional diagram of the multi-modal tracking system (MTS).

Each mobile station is equipped with 1) a directional antenna mounted on a 5" plastic-coated magnet antenna base and connected to a 900 MHz RF radio, 2) a laptop with a mobile hotspot device to gain access to the Internet, and 3) a power inverter to convert 12V DC to 110V AC for the laptop. The directional antenna is powered by the battery of the vehicle via a cigarette power outlet and the RF radio is powered by the laptop. The laptop displays the payload position sent by the cellphone on the online map from the AccuTracking and the payload position sent by the RF radio on the Microsoft MapPoint locally available on the laptop. The RF-based tracking is used during a balloon flight for real-time tracking. As the RF radios have a limited range, the mobile stations should stay within the range to be able to receive the GPS coordinates of the payload.

III. Implementation Details of the Subsystems

Error! Reference source not found. shows a more detailed block diagram of the dual-modal tracking payload. The payload was initially developed for the RF-based tracking and then later integrated the cellphone components. The two blocks for the cellphone-based tracking are highlighted in yellow in the block diagram. The microcontroller handles the tasks for extracting GPS strings and flipping the electronic switch to turn on the cellphone.

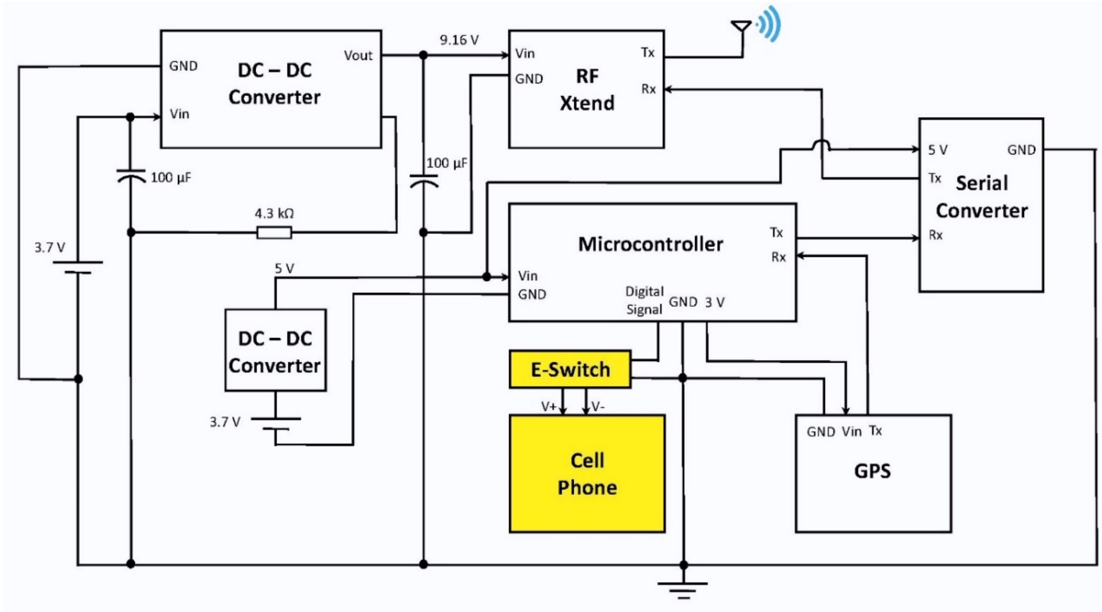

Fig. 2 Block diagram of a dual-modal tracking payload.

A. RF-based Tracking

For the 900MHz communication link between the payload and the mobile station, XTend 900 MHz RF radios are used [5]. The radio on the payload is connected to a ChipKit MAX32 microcontroller. The microcontroller reads the GPS string from a GPS receiver via a 4800-baud serial connection. An Inventek Systems ISM300X GPS receiver [8] is used since it is specifically designed to function at altitudes of up to 135,000 feet and over the wide temperature range required for balloon applications. Most commercial GPS receivers have a maximum altitude range of only 60,000 feet. The microcontroller parses the National Marine Electronics Association (NMEA) GPS string to extract the GPS coordinates (latitude, longitude, and altitude), and transmits the coordinates in the GGA string format via the RF radio. The parsing is performed every 10 seconds. An overall functional flow in the microcontroller is shown in Fig. 3. The last block highlighted in yellow is for the power-up procedure of the cellphone and will be further described below.

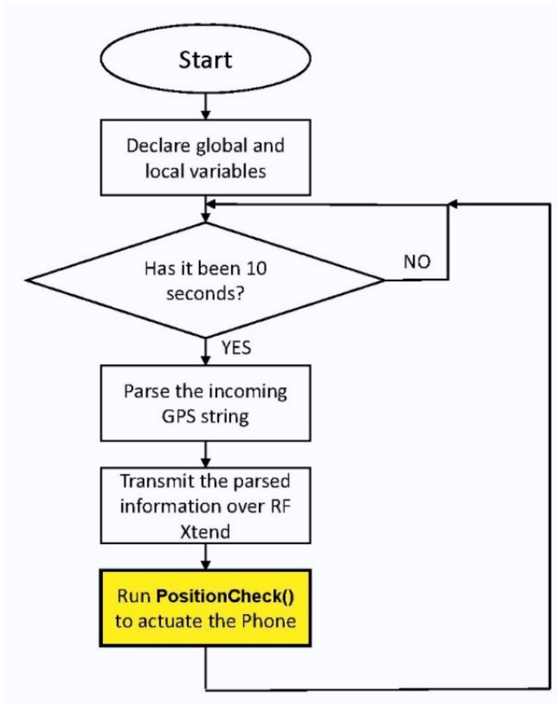

Fig. 3 Overall flow chart for the operation.

Due to incompatibility of the physical signals between the microcontroller output (i.e., TTL/CMOS signals) and the input (i.e., RS232 signals) to the RF radio, a Max233 serial converter [9] is used. Also, to power all components in the payload with 3.7V 2200mAh Lithium Ion batteries, a wide output-voltage DC-DC boost converter [10] is used that produces its output voltages ranging from 5V to 15V, suitable for the RF radio requiring 9.16V and the microcontroller requiring 5V.

B. Cellphone-based tracking

Most current cellphones can report their position from anywhere as long as cell service is available to them. For the purposes of this project, we have used a ZTE Maven 2 phone running the Android operating system because it was inexpensive and had an easily accessible battery. As shown in **Error! Reference source not found.**, an electronic switch is used to control the phone's power-up procedure. For implementation of the e-switch, an external relay was inserted to open/close the circuit between the phone's main circuit board and the phone's battery. We chose this approach instead of supplying the DC power to the cellphone directly from the microcontroller since cellphones may require a higher current than a DC output from a microcontroller could supply. The guiding principle for devising the control algorithm is based on changes in altitude during a balloon flight. Once the payload has landed, the GPS coordinates will stop changing.

When the microcontroller detects and determines with confidence that the payload has landed, it will switch the power relay to turn on the phone. When powered on, the phone is configured to automatically start AccuTracking, a cellphone application software, which transmits the GPS coordinates of the phone to its web server maintained by the software vendor.

For more details, **Error! Reference source not found.** shows the flow chart of the processing performed in the microcontroller to turn on the cellphone sometime after landing. This routine, `PositionCheck()`, is a part of the iterative loop for the whole system processing shown in Fig. 3. Receiving the GPS coordinates every 10 seconds, the routine first checks whether or not the payload is in a situation indicating the payload has landed by comparing the current location coordinates with the ones stored from the previous iteration. During the flight, the difference in altitude is expected to be more than the tolerance in a 10-second interval, e.g., an ascent rate of 1200 ft/min (or 20 ft/sec). With the tolerance for the difference preset to a sufficiently small value (e.g., +/-10 ft), the counter designated for this comparison is reset to 0 unless the difference in altitude is within 10 ft. Then, the counter value is compared with a preset maximum count value (e.g., set to 5) which is intended to replicate the condition several times repeatedly to ensure that the payload has indeed landed. When this comparison results in FALSE (i.e., "NO" in the flow chart), a variable denoted as `flag` is set to 0. The `flag` value of 1 is one of the two requirements to turn on the cellphone.

Next, the current altitude is compared against a preset maximum altitude value determined for possible landing locations in reference to the sea-level. Only when these two requirements are met is the cellphone turned on and the value of `majorFlag` set to 1; until then, the value of `majorFlag` remains unchanged as initially preset to 0 or once set to 1 first time, it keeps the new value in order not to repeatedly turn on the cellphone in subsequent iterations. This mechanism prevents the cellphone from being accidentally turned on during the lift-off or initial ascent, especially when the power-on procedure is only based on a threshold of the maximum altitude.

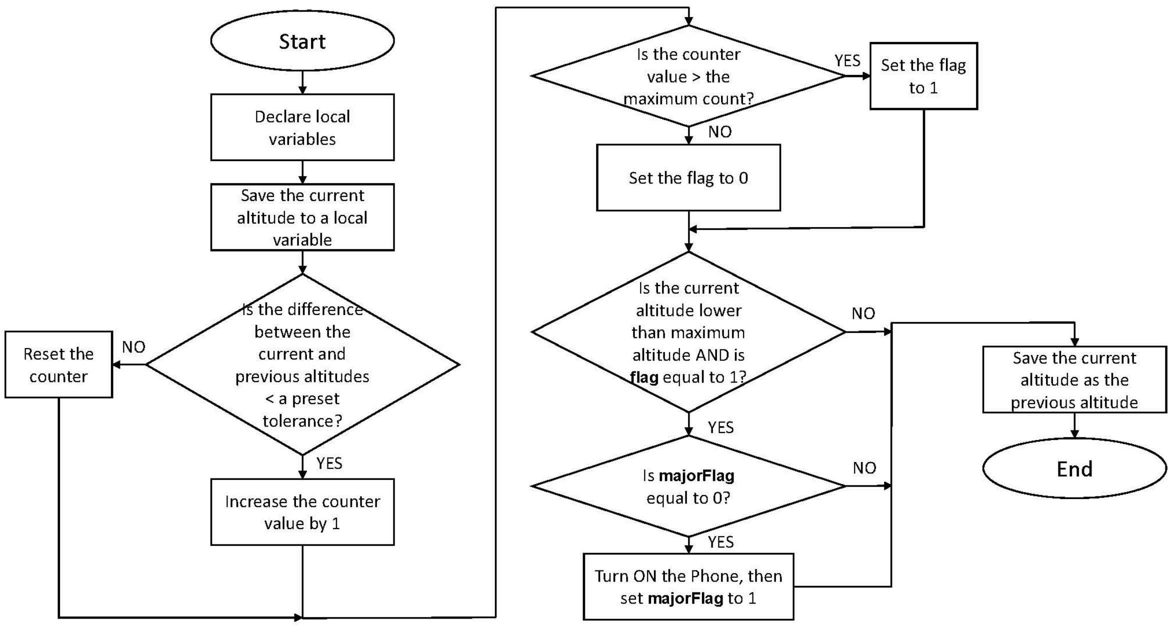

Fig. 4 Flow chart of PositionCheck() to turn on the cellphone.

During flight, the processing flow is expected to continue with FALSE at all comparison stages. Although there might be abnormal situations where the difference in altitude at the first comparison shown in **Error! Reference source not found.** results in TRUE ("YES" in the flow chart) at a point in time, it is not expected for such abnormal situations to occur continuously in a set of consecutive iterations to be able to set `flag` to 1. Even with that, the comparison of the current altitude with a preset maximum altitude prevents this algorithm from accidentally turning on the cellphone unless the payload has actually landed. Not shown in the flow chart, a testing routine is also implemented in the microcontroller such that a sequence of linearly varying, pseudo random altitudes are internally generated for the purpose of testing the payload without an actual flight. An external mechanical switch is also installed to close/open the circuit between the batteries and the hardware components in the payload and it is flipped only right before the lift-off, in order to prevent the routine functioning prematurely with GPS coordinates remaining the same while the balloon system is on the ground for preparation of a balloon launch.

C. Mobile Station and Position Mapping

In the MTS mobile station, the formatted data string from the tracking payload is received by the XTend RF radio for data processing. The RF radio is connected via a USB port to a laptop in the MTS mobile station and the laptop runs custom C# code to read the position string from the COM port for the USB port and write 3 values of the position coordinates (i.e., latitude, longitude, and altitude) each time into a CSV file. Once it is created by the custom C# code the first time, the CSV file keeps accumulating position coordinates during a balloon flight such that an entire trajectory of the balloon flight can be displayed when the file is read into the mapping software. In our implementation, these position coordinates can be displayed by either a) a mapping software application built in house using Google Earth or b) Microsoft MapPoint. To display a position location, Google Earth reads in location coordinates from a Keyhole Markup Language (KML) file which is an output file from our custom C# code converting the CSV file. Google Earth may require an Internet connection even though it has already been installed locally on the laptop. On the other hand, Microsoft MapPoint reads in the CSV file itself to display positions on the map, and does not require an Internet connection once installed locally on the laptop.

D. Experimental Observations

Fig. 5 shows the payload positions reported to the AccuTracking server after landing on top of a tree in a neighborhood in Hopkinsville, KY, on the August 21, 2017 eclipse day. Although the payload itself didn't move, the positions are somewhat scattered in a small area. We assume that this is due to the accuracy resolution of the GPS receiver in the cellphone we chose to use.

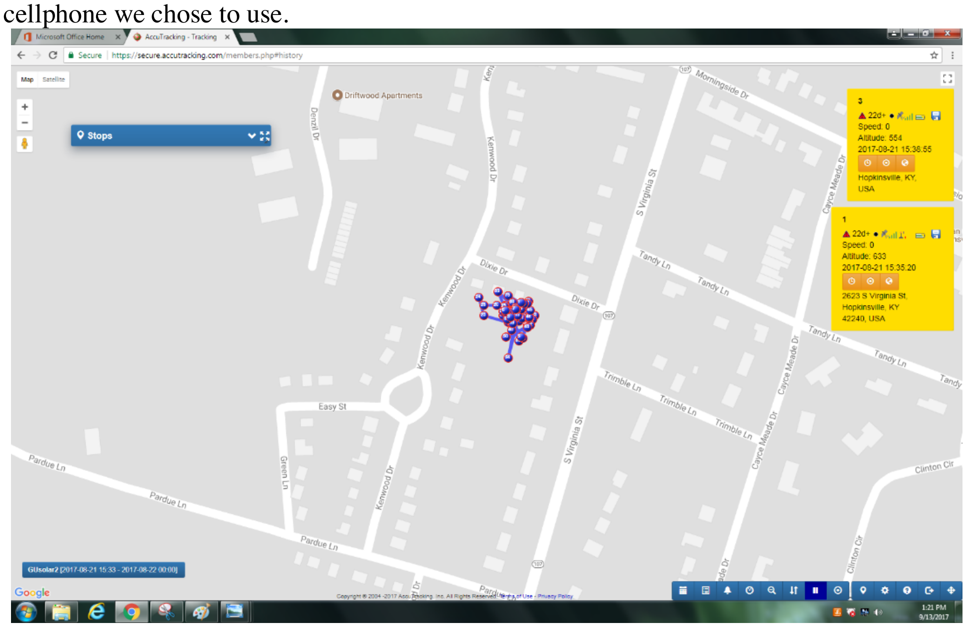

Fig. 5 Mapping on AccuTracking of the landing location of the tracking payload.

IV. Conclusions

We have briefly described the implementation aspects of our dual-modal tracking payload that integrates an RF radio and a cellphone. Both tracking methods are successfully tested before or during the solar eclipse ballooning. Although some small details of the implementation are omitted, we hope that it presents some guidance to others who may wish to take a similar approach to establishing a more robust tracking capability for high-altitude ballooning.

Acknowledgments

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