An Approach to Promoting STEM Interest via Near-Space Ballooning

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In this paper, we articulate an approach to promote STEM interest to grades 6-12 students utilizing the state-of-the-art engineering design practices and technologies that we applied to developing a 2017 solar eclipse ballooning system. A collaborative effort for partnerships with regional school districts is essential to this approach. The core components of the state-of-the art technologies are 1) the ability to simultaneously live-stream videos via a single wireless link operating at the 5.8 GHz ISM band and 2) a robust balloon-tracking system that employs both line-of-sight and Iridium-based Internet payload position reporting. We also briefly discuss two stages of learning for grades 6-12 students, effectively integrating teacher workshops and student summer camps. Finally, an analytical method using Cohen's kappa is discussed to quantitatively interpret qualitative questionnaires.

I. Introduction

OVER the past decade, near-space ballooning has been an attractive tool to promote the skills, knowledge, and practices associated with STEM fields to young generations. Recently, the National Science Board made three recommendations on STEM education [1] which included 1) improve the access to and availability of effective K-12 formal and informal education programs and interventions to meet the needs of future STEM innovators; 2) enhance the learning infrastructure support system for students by improving educator preparation and encouraging a culture that values academic excellence and innovation in families, local communities, schools, and the Nation.

In promoting STEM learning to grades 6-12 students in particular, a near-space ballooning system for the August 21, 2017 solar eclipse can be an excellent framework for the purposes. Due to the inherent weather-dependent nature of near-space ballooning, successful ballooning systems require a proactive critical thinking process and proper incorporation of the failure mode and effect analysis (FMEA) in the payload design and the operation. These hands-on engineering design activities are well suited to address the eight practices of science and engineering identified by the Next Generation Science Standards (NGSS) Framework [2] – 1) defining problems; 2) developing and using models; 3) planning and carrying out investigations; 4) analyzing and interpreting data; 5) using mathematics and computational thinking; 6) designing solutions; 7) engaging in argument from evidence; and 8) obtaining, evaluating, and communicating information. In particular, using small, 4x3-inch, single-board computers equipped with small cameras to live-stream video via state-of-the art communication technologies over the 5.8 GHz ISM band, near-space ballooning with video streaming can effectively interest and engage students in STEM.

In the following, we describe key specifics of our solar eclipse ballooning system that can develop disciplinary knowledge, practices, and non-cognitive skills needed in STEM fields: computer operating systems (Windows and Linux), single-board computers (Raspberry-Pi) and microcontrollers (Arduino and ChipKit), information and communication technologies (GPS, RF modems, satellite, and Internet), video streaming, programming in python (for mapping software), programming in a simplified version of C (for microcontrollers), ballooning system integration and launch, and data analysis – post flight data of balloon trajectories (using Excel, etc.). We also briefly describe how to facilitate, in partnership with local school districts, and assess formal and informal learning with near-space ballooning using our 2017 solar eclipse as a baseline starting point.

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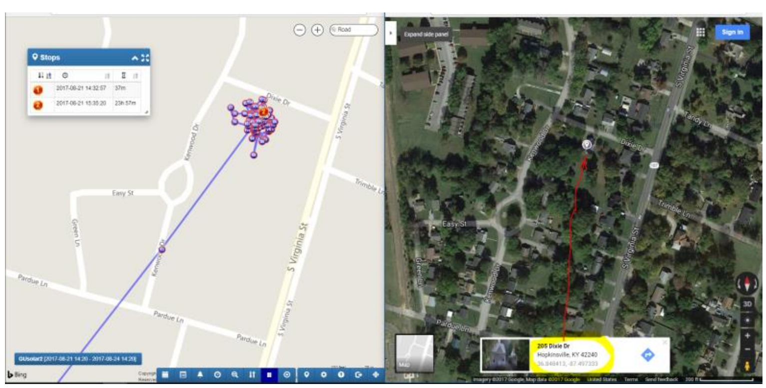
II. A Framework of the Project

There exist highly successful ballooning programs throughout the nation (for instance, see [3]-[6]). However, the solar eclipse ballooning system we developed is of distinctive nature when compared to the existing and/or past ballooning projects. In particular, we have demonstrated a system for simultaneous live-streaming of four video streams while recording additional four cameras onboard the payload, i.e., eight cameras simultaneously recording during flight. In developing our 2017 solar eclipse ballooning system with a group of undergraduate students, we have applied all facets of engineering design, adopting and utilizing emerging technologies to successfully capture images during the totality of solar eclipse (for example, see Figure 1(a)) and also to track and locate the balloon system (see Figure 1(b)). Our previous student-survey data have demonstrated improvement in participants' interest in pursuing careers in electrical and computer engineering upon graduation and also that the project carried out in an extracurricular setting complemented the learning experience within the curricular setting, i.e., course work [7]. We believe that this system can be extended to grades 6-12 students to effectively excite them through learning emerging technologies, including wireless live-video streaming and small single-board computers.

A. Project Platform: Solar Eclipse Ballooning System

Figure 2 shows the functional block diagram of the entire solar eclipse ballooning system. It consists of 1) a balloon payload subsystem, 2) a baseline ground station, and 3) a multi-band tracking system (MTS) mobile station. The balloon payload subsystem consists of five payloads which include the payloads for still image, live video-streaming, Iridium-based balloon tracking, and cut-down. The fifth payload, MTS-Tx is an additional dual-mode balloon tracking subsystem that is aimed at ensuring tracking and recovery of all payloads on board. While the balloon payloads operate on batteries, the ground station requires AC power. As such, a portable inverter generator as a part of the overall ballooning system supplies power to all components of the baseline ground station so that the ground station can be operated without access to the power grid. On the other hand, the AC power to the MTS mobile station is supplied from a standard automotive power converter that generates 120 V_{AC} output from the standard 12 V_{DC} automotive power socket.

(a) Image from near space during balloon flight on the Aug 21, 2017 eclipse day



(b) Tracking of payloads – final location for recovery

Figure 1. Images obtained during the Aug. 21, 2017 near-space ballooning and tracking

We initially started with the baseline system that was provided to all participating teams by the national project office [8], but made substantial advancements. As mentioned above, we added the capability of simultaneously live streaming from four different cameras and delivering those videos via a single 5.8 MHz wireless communication device to the ground station. Additional 4 cameras also simultaneously recorded video to the onboard storage for later retrieval, but were not streamed due to bandwidth limitations of the 5.8 GHz wireless device.

B. Description of the Ballooning System

For proper operation of the ballooning system, students have to first learn and test the functionality of each and every payload and its ground station counterpart in the lab and also outdoors. The still image payload uses a Raspberry Pi with a camera module (referred to herein as the pi-camera) to acquire pictures in flight at a predetermined rate, e.g., one per minute or more frequently. These images are then transmitted from the payload to both the patch antenna and Yagi antenna on the ground station, as depicted in Figure 2, using an RFDesign RFD900+ radio frequency (RF) modem operating at ~900 MHz. Its counterpart RFD900+ modem on the ground station is connected, via USB, to a Windows 10-based laptop running custom-built software (using Python as the programming language) to download, store, and display these images in near real time.

The video payload uses four Raspberry-Pis with two camera modules on each Pi to capture high-definition video during flight. Four of those 8 cameras are used for live video streaming to the ground station, and the other four cameras are used to store higher-resolution videos on the local memory card for later retrieval and processing. The Pi runs the Linux operating system. A 5.8 GHz Ubiquiti modem, the Rocket M5, is used on the balloon system to transmit the video to another M5 modem on the ground station, receiving the 5.8 GHz signal through a dish antenna. The M5 modem on the ground station is connected to the same laptop used for still images. Transmission of the video is initiated via remote login with the Raspberry Pi, defining the output filename (the video is also recorded to disk), and beginning streaming of the video using the Real-time Transport Protocol (RTP). The ground station uses the Open Broadcaster Software (OBS) to display the video stream and upload it to an internet video-streaming site.

Tracking of the balloon system is accomplished using the Iridium payload (depicted in Figure 2) which is built around an NAL Iridium Satellite Tracking Modem to generate packets of GPS coordinates of the balloon system. The GPS coordinates are transmitted to a server at the solar eclipse project headquarters in Montana via the Iridium satellite network, and the laptop on the ground station at the balloon launch site retrieves these GPS coordinates from the server via the Internet. This allows for accurate payload position determination even if line-of-sight communication is lost between the balloon system and the ground station. The Iridium payload is also used to send/receive the commands to cut-down the payload, and it communicates with the cut-down payload via an XBee wireless module. In the event that a malfunction prevents proper transmission of the cut down command, both the Iridium payload and cut-down payload have backup timers. These timers are reset before launch. The cut-down payload consists of a custom electronics board, developed by a team at the solar eclipse project office in Montana, that turns on a motor with a

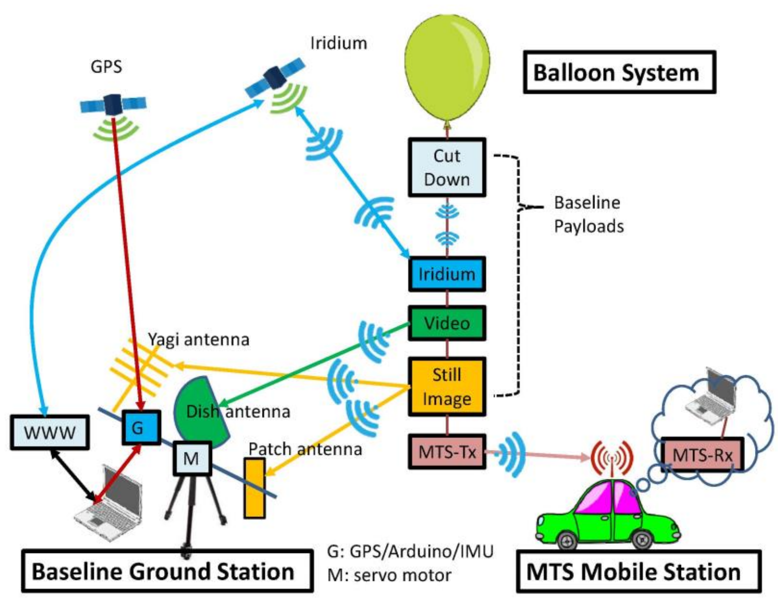


Figure 2. Functional diagram of the solar eclipse ballooning system

cutting wheel attachment. The motor turns on when it receives a command from the Iridium tracking payload via an XBee module, as described above, and cuts the line between the balloon and parachute to release the balloon and drop the payloads to the ground if/when needed in an emergency or unexpected situation during flight. In a normal flight, the balloon bursts when it reaches an intended altitude, such as ~110,000 ft, and then payloads parachute safely to the ground.

Prior to the balloon launch, all teams are required to run a flight prediction to ensure the balloon will not traverse restricted airspace. Balloon prediction can also aid in the chase and recovery process, allowing a chase vehicle to be positioned near the predicted landing location. There are a multitude of options for producing these flight predictions. An example can be found from the NOAA Ozone and Water Vapor Group [9] and our team also used the Cambridge University Spaceflight Landing Predictor (CUSF) [10].

In order to scale the project for implementation at local school districts, we will have the grade 6-12 students learn about and build individual payloads with support from our faculty and undergrads. The college team will operate its existing ground station to implement live video streaming and balloon tracking for grade students. Grade students will also learn about live streaming as they build their payloads without utilizing the entire ground station. Each school may receive lab supplies and materials from the college team, sufficient for a desired number of students to build multiple payloads in various settings, including internal competition at each school or school districts, with redundancy in lab supplies for replacement in case some parts are damaged. Payloads from different schools may be integrated into a single balloon system for a limited number of balloon launches. As such, the project is very flexible for implementation on an even larger scale. Even when scaled up, the cost is not expected to be prohibitive.

C. Key Technical Knowledge and Learning

It is anticipated that the challenge of designing a complete ballooning system is beyond the ability of most 6-12 grade students. However, learning to build and properly operate the baseline system provides significant opportunities for STEM learning. Students will learn about the Linux environment by configuring the Raspberry Pi via a remote SSH login. Working in a Linux environment is likely new to most students and requires learning the basic commands and recognizing major differences between Windows-based and Linux-based operating systems, including such fundamental aspects as clicking with a mouse to perform certain tasks on a Windows system versus precisely typing commands in a command line on the Linux system. Also, understanding the basics of computer networking is required to properly configure the GUI (e.g., communication ports) on the laptop for the modems on the ground station and also to configure the Pi remotely via a wireless connection between the laptop and the payloads.

Reviewing the datasheets and manuals of the modems used, i.e., RFD900+ at 900 MHz, M5 at 5.8 GHz and Iridium, can lead to basic knowledge of communications. Students will also gain hands-on experience working with directional antennas and beam patterns. Once again, a great deal of learning occurs on basic knowledge in radio transmission and antennas from these project activities, not just by the complex equations and theories – which are clearly beyond the ability of the average high school student – but by seeing it and operating the antenna for automatic and manual steering. These challenges, which were also faced by our own ballooning team members, actually present excellent learning opportunities to grades 6-12 students.

D. Assessment of Learning Experience by College Students

We have previously adopted ABET's student outcomes "(a) through (k)" as metrics to quantitatively assess the effectiveness of the balloon program through surveys of our undergraduate students. The survey consists of 22 questions developed in line with the 11 "(a) through (k)" student learning outcomes defined by ABET/EAC. For each student outcome, two questions may be asked: i) if the project provided opportunities for the student to improve on the learning outcome and ii) if the student actually did improve that learning outcome by participating in the project. The specific text for all survey questions and the exact methodology we have used can be found in [11]. These surveys have indicated the efficacy of this project for both providing students with opportunities to improve and helping them actually improve the ABET "(a) through (k)" outcomes. Given the overall success of this project at the undergraudate level, we feel it is reasonable to expand these learning activities to a younger group of students in hopes of improving their overall interest and proficiency in STEM fields.

E. Vertical Integration of Project-Based Learning

Various studies have been conducted in the past on the integration of different course levels in a single classroom instruction (i.e., vertical integration) to improve student learning in a curricular setting. One recent example is from an NSF-funded project performed at Arizona State University which was presented in ASEE 2017 [12]. This study was conducted by integrating an undergraduate engineering course and a graduate-level engineering course. Although various observations and conclusions were derived, it appeared that there is room to improve this "vertical integration" approach. One particular issue is that quite a bit of burden was placed on the graduate students to bring up to speed the undergraduate students while most undergraduate students got a "free ride" in carrying out the course work and project activities of the course.

One of the research questions for assessment may be whether this approach of vertical integration could be effectively applied to grades 6-12 students while undergraduate engineering students serve in the mentoring and technical support roles and/or when grade level partnership is in place (e.g., grades 6 and 9 together). Also, public school teachers and administrators perceive that as a form of vertical integration, close collaboration in project activities between college students and grades 6-12 students will be very effective in improving student learning experiences and their effectiveness in providing key aspects of STEM education.

F. Quantification of Project Effectiveness among Student Groups

To quantify the effectiveness of the project activities among students in different school districts, the Cohen's kappa could be used [13] to apply quantitative interpretations of the strength of agreement to quantitatively deducing the effectiveness of the project, based on qualitative statements. The original Cohen's kappa coefficient is a statistic which measures inter-rater agreement for qualitative (categorical) items and is intended to measure the agreement between two raters who, respectively, classify N items into C mutually exclusive categories (for example, see [14]). In our case, the Cohen's kappa can be utilized in such a way that two different groups of students rate the near-space ballooning project activities, responding to a questionnaire of qualitative statements, to quantify the degree of effectiveness of primary project activities. The value of Cohen's kappa is calculated by [14] $\kappa = (p_o - p_e)/(1 - p_e)$ where p_o is the relative number of observations in agreement and p_e is the probability of an agreement occurring by chance.

III. Partnership with School Districts

Serving as a project framework, the 2017 solar eclipse ballooning system can facilitate promoting the skills, knowledge, and practices associated with STEM professions related to grades 6-12 students in regional school districts. To ensure that the project activities will be mutually beneficial, it is necessary 1) to refine the current ballooning system to fit the needs of the regional schools for grades 6-12 STEM education; 2) to assist school districts in establishing a near-space ballooning curriculum and/or courses; and 3) to assess the effectiveness of the near space ballooning in promoting STEM interest to grades 6-12 students. Furthermore, the program needs to be adapted to meet the individual needs and resources of each school district, which may vary significantly. These activities can be carried out in both formal and informal modes of learning. Learning in formal settings may be for acquiring basic skills needed in ballooning system design in grades 9-12 classes at partner schools. Learning in informal settings may aim for the same learning objectives of acquiring basic skills but in a form rather suitable for extracurricular clubs in middle schools (grades 6-8) and high schools. These formal and informal learnings at grade schools may be considered as the first stage of learning in order to advance students' knowledge and skills to the next level. Informal learning on university campus in a form of short-duration, intensive summer camps may be considered as the 2^{nd} stage learning to acquire intermediate skills and knowledge in ballooning system design and participate in payload design, balloon launch, and tracking. Then, the next cycle of the formal and informal learning takes place with new students at the grade schools.

At grade schools, it is not uncommon that none or only a small group of students have previously tried a balloon launch and such effort is focused primarily on launching a helium-filled balloon itself with limited payload functionality and tracking capability. As such, payload recovery is anticipated to be an obstacle that hinders further effort on sustaining a ballooning program and/or curriculum. A coordinated effort between a college team with necessary tracking equipment and school districts in close partnership may be able to overcome this obstacle while providing college students with additional opportunities of developing non-technical skills critical to a successful STEM career.

IV. Conclusion

We have presented our thoughts on promoting STEM interest to grade 6-12 students utilizing a near-space ballooning system. With support from undergraduate college students and faculty, we believe that the technical scope of conducting near-space ballooning with live video-streaming is suitable for both high-school and middle-school students while presenting manageable challenges that can be overcome as part of the project activities. The design of the ballooning payloads is flexible enough that the school districts can implement the project activities to fit their specific needs in an appropriate fashion for their students.

Acknowledgments

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