An Approach to Promoting STEM Occupations via Near-Space Ballooning

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In this paper, we describe an approach to promote STEM occupations 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 (SDs) is described. 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 present two stages of learning for grades 6-12 students, effectively integrating teacher workshops and student summer camps, while also benefitting college students who will be trained as technical support personnel. 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 occupations to young generations. Recently, the National Science Board made three recommendations on STEM education [1] which include 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 young generations, particularly, grades 6-12 students, a near-space ballooning system for the August 21, 2017 solar eclipse can be an excellent framework for the purposes. Near-space ballooning

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systems require, due to the inherent weather-dependent nature of near-space ballooning, a proactive critical thinking process and proper incorporation of the failure mode and effect analysis (FMEA) in the payload design and the operation. They are well suited, through hands-on engineering design activities, for addressing the needs for improvement in the eight practices of science and engineering identified by the Next Generation Science Standards (NGSS) Framework [2], which are essential for all students to learn – 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, the tangible nature of conducting live streaming through utilization of 4x3-inch single-board computers equipped with small cameras and integration of the state-of-the art communication technologies over the 5.8 GHz ISM band can be fascinating and very attractive to students, and effective in engaging them in the project activities.

In the following, we describe more 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 and microcontrollers (Raspberry Pi, Arduino, and ChipKit),, information and communication technologies (GPS, RF modems, satellite, 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.).

II. Partnership with School Districts

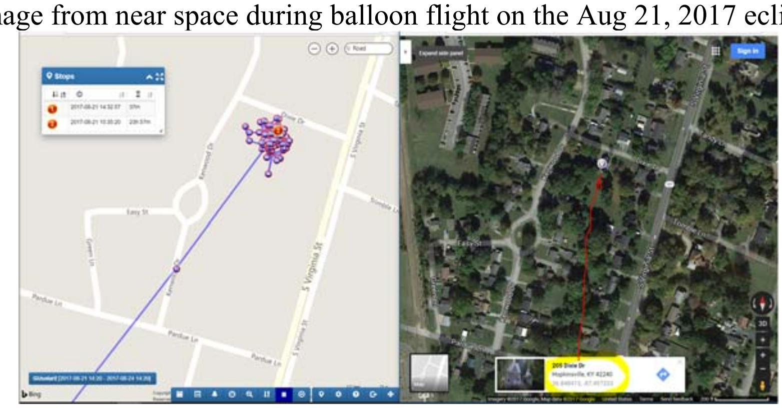
Utilizing the high-altitude ballooning system for live video streaming and balloon tracking as a framework, we have partnered with four school districts (SDs) in the northwest Pennsylvania region to promote the skills, knowledge, and practices associated with STEM occupations to grades 6-12 students - Erie SD, Fairview SD, Wattsburg Area SD, and Union City Area SD. The project activities that will be mutually beneficial are 1) to refine the existing near-space ballooning system for real-time video streaming to fit the needs of the partner schools for grades 6-12 STEM education; 2) to establish a near-space ballooning curriculum and/or courses at each of the partner schools; and 3) to assess the effectiveness of the near space ballooning in promoting STEM occupations to grades 6-12 students. These activities can be carried out in two modes of learning - formal and informal: 1) Learning in formal settings – Grades 9-12 classes in partner schools (1st stage learning: acquiring basic skills needed in ballooning system design); 2)

Learning in informal settings – extracurricular clubs in middle school (grades 6-7) and high school (1st stage learning: acquiring basic skills needed in ballooning system design) and also summer camp on university campus (2nd stage learning: acquiring intermediate skills in ballooning system design and participation in ballooning system design, launch, and tracking). In these partner schools, only a small group of students have tried a balloon launch and such effort was focused primarily on launching a helium-filled balloon itself with limited payload functionality and tracking capability. As such, payload recovery turned out to be a huge burden for them to continue the effort.

III. 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 has some distinctive nature when compared to the existing and/or past ballooning projects. 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 (see Figure 1). Our previous student-survey data have demonstrated improvement in participants' interest in pursuing careers in electrical and computer engineering upon graduation and

(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

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 for the excitement and effectiveness of learning emerging technologies, including wireless live-video streaming and small single-board computers, via hands-on engineering design.

A. Project Platform: Solar Eclipse Ballooning System

Figure 2 shows the functional block diagram of the entire solar eclipse ballooning system that we have developed and used for the August 21, 2017 solar eclipse. 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 for balloon tracking, and cut-down. The fifth payload, MTS-Tx is a dual-mode tracking subsystem that is aimed at ensuring balloon 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 if the ground station is placed far from any source of AC power. 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.

We initially started with the baseline system that was provided to all participating teams by the national project office [8], but made substantial advancements to add the capability of simultaneously live streaming from four

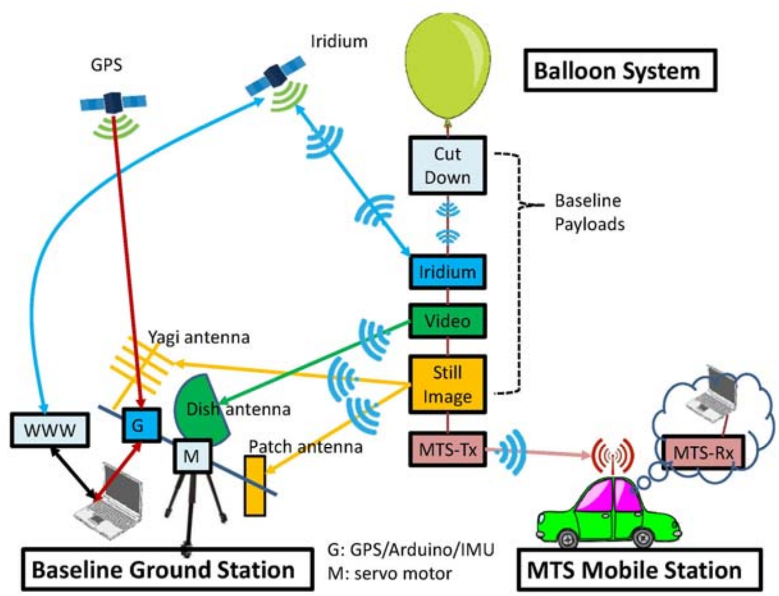


Figure 2. Functional diagram of the solar eclipse ballooning system

different cameras and delivering those videos via a single 5.8 MHz wireless communication device to the ground station. An additional 4 cameras also simultaneously recorded video to the onboard storage for later retrieval, but were not streamed due to bandwidth limitations.

B. STEM Learning Aspects 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 Pi's 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 on 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 GPS 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 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 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].

Scalability of the proposed project: The students at the school districts will participate in learning about and building payloads and the Gannon team will operate their existing ground station for demonstration of live streaming to the students and balloon tracking for them. Students will also learn live streaming as part of the work to build their payloads, without utilizing the entire ground station. Each school will receive lab supplies and materials sufficient for 25 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. As such, the project is very flexible for scalability to a larger scale, especially in future endeavors, and its cost, when scaled up, is not prohibitive.

C. Key Technical Knowledge and Learning

Although not as challenging as designing a complete ballooning system of a complexity similar to the baseline system described above, quite a bit of effort and understanding is required for typical ECE undergraduate students to properly operate the baseline system. For most college students in the ECE department on the electrical engineering track as opposed to computer engineering track, configuring the Raspberry Pi via a remote SSH login to the Linux environment requires a significant amount of learning. Working in a Linux environment is fairly new to them 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, learning 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, lead to basic knowledge of communications. ECE students in most colleges do not get into communications subjects until taking a technical elective in introduction to communications either in their junior or senior year. A great deal of learning occurs on basic knowledge in communications from the project activities. Students are required to develop a basic understanding of directional antennas and beam patterns, relevant to the dish, Yagi, and patch antennas used. In a typical college-level curriculum for electrical engineering, learning about antennas occurs later in the semester of the junior year as part of an electrical engineering core course, Electromagnetic Fields. Once again, a great deal of learning occurs on basic knowledge in radio transmission and antennas from the project activities, not just by the complex equations and theories, but by seeing it and operating the antenna for automatic and also manual steering. The challenges faced by the Gannon ballooning team members actually present a great deal of learning opportunities to grades 6-12 students.

D. Assessment of Learning Experience by College Students

To justify the effectiveness in enhancing the learning experience in STEM and collecting assessment data from the project, we had adopted ABET's student outcomes "(a) through (k)" as metrics to quantitatively assess the effectiveness of the balloon program through student surveys. 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, we asked two questions: 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. For instance, for the student outcome (a): an ability to apply knowledge of mathematics, science, and engineering, the survey questions for Q-a(i) and Q-a(ii) are, respectively, Q-a(i): "The project activities provided me with an opportunity to improve my ability to apply knowledge of mathematics, science, and engineering;" and Q-a(ii): "Participating in the project activities, I have improved my ability to apply knowledge of mathematics, science, and engineering." More details and specific texts for all survey questions can be found in Table 2 in [11].

E. Vertical Integration of Project-Based Learning

There are various studies conducted in the past on integration of different level of courses in one classroom instruction (i.e., vertical integration) to improve student's performance in learning courses 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 is 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 as Wattsburg school district intends to implement for the proposed project). 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

Quantitative Measures -- To quantify the effectiveness of the project activities among students in different school districts, we adopt the Cohen's kappa [13] and apply quantitative interpretations of the strength of agreement to quantitatively deduce 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 project, we will utilize the Cohen's kappa 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.

IV. Conclusion

We have briefly presented our plans to outreach and promote STEM occupations to grade 6-12 students utilizing our near-space ballooning system used for live-streaming of the 2017 solar eclipse. The technical scope of our project is suitable for both high-school and middle school students while presenting manageable challenges that should/can be overcome as part of the project activities. 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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References

[1] National Science Board, *Preparing the next generation of STEM innovators: Identifying and developing our nation's human capital*, May 5, 2010.

[2] NGSS Release, *The Next Generation Science Standards*, June 2013, [on line] available at http://www.nextgenscience.org/sites/default/files/Final Release NGSS Front Matter - 6.17.13 Update_0.pdf.

[3] C. Kansaku, L. Kehr, and C. Lanier, "STEM-related K-12 outreach through high-altitude balloon program collaborations," in Proc. ASEE 2007.

[4] D. Takehara et al., "High altitude ballooning into undergraduate STEM curriculum: Preparing for widespread implementation," on line, last accessed on Oct. 13, 2017, available at http://nebula.wsimg.com/f6aa3a8e42908399efc6c02b47acc62c?AccessKeyId=2150098A98A3948388C8&disposition=0&alloworigin=1.

[5] High Altitude Student Platform, Call for Payloads 2016, issued by Department of Physics & Astronomy, Louisiana State University and Balloon Program Office, NASA Wallops Flight Facility, Wallops Island, VA, Oct. 7, 2015.

[6] J. Straub, G. Ingwalson, and R. Fevig, *A Design for Inspiring Students with Near-Space Exploration*, Journal of Aviation/Aerospace Education & Research, vol. 23, no. 1, pp. 35-48, JAAER Fall 2013.

[7] W. Lee and N. Conklin, "Assessment of Student Learning Experience in Two Exemplary Engineering Projects," in Proc. ASEE Annual Conference and Exposition, June 25 - 28, 2017, Columbus, Ohio.

[8] Eclipse Ballooning Project: About the Eclipse Ballooning Project Systems, available at http://eclipse.montana.edu/about-the-systems/.

[9] NOAA Ozone and Water Vapor Group, Balloon Prediction Software, available at https://www.esrl.noaa.gov/gmd/ozwv/wvap/sw.html.

[10] Cambridge University Spaceflight Landing Predictor (CUSF), available at http://predict.habhub.org/.

[11] W. Lee and N. Conklin, "High-altitude radiation detector (HARD): An exemplary means to stimulate electrical and computer engineering undergraduate research," in Proc. ASEE Annual Conference and Exposition, June 14-18, 2014, Indianapolis, IN.

[12] M. ElZomor et al. "Leveraging Vertically-Integrated Courses and Problem Based Learning to Improve Students' Performance and Skills," manuscript submitted to ASCE Journal of Professional Issues in Engineering Education and Practice, June 12, 2107.

[13] J. Cohen, "A coefficient of agreement for nominal scales," Educational and Psychological Measurement, no. 20, pp. 37-46, 1960.

[14] S.J. Dickerson, S.P. Jacobs, A.M. Garcia and D.V.P. Sanchez, "Joint assessment and evaluation of senior design projects by faculty and industry, FIE 2016, Erie, PA, pp. 1-7.