Lessons from 5 Years of Space Plug & Play Avionics (SPA) Device Development with High School Students

Paul Jaffe, Sean Lynch, Jolyon Zook Naval Research Laboratory 4555 Overlook Ave SW, Washington DC, 20375; 202-767-6616

ABSTRACT

One approach to reduce spacecraft development time and cost is the use of Space Plug & Play Avionics (SPA). Initially introduced in 2004, SPA offers standardized power and data interfaces to allow for rapid design, integration, and testing of spacecraft. SPA endeavors to leverage, where possible, existing standards and tools to help maximize the potential user base without requiring specialized or new knowledge. Some examples include USB and SpaceWire for hardware interfaces, and C and FPGA constructs for software and firmware. In many high schools, emphasis on technology education has meant that students may have already been exposed to these concepts and techniques. Additionally, many motivated students have extensive backgrounds in software and hardware development outside of academic venues. The Naval Research Laboratory (NRL) is one of many organizations that participate in internship programs designed to introduce students to real science and engineering environments. We have used these opportunities for students as a pedagogical vehicle for SPA device development. From 2006 to 2010, we learned a number of lessons that may be of interest to SPA developers and technology educators.

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INTRODUCTION

Spacecraft development has historically been time consuming and expensive. Much of the time and cost is embedded in the interface development and testing that occurs between different spacecraft components. A standardized approach to interfaces has the potential to reduce spacecraft development time and the associated costs. Because the production volume of spacecraft is generally low and spacecraft missions vary widely in scope and purpose, interface standardization has been limited. Unlike the personal computer industry, where interface standardization has firmly taken hold, there are minimal financial incentives on the part of spacecraft component manufacturers to ensure interchangeability and rapid integration of spacecraft components.

While some standardization has taken place at the physical, protocol, and data interface levels, it generally has not been consistent, nor has it been implemented across the entire ensemble of network Open Systems Interconnect (OSI) layers. Efforts by a number of entities have sought to change this, or at least offer a flexible architecture that would enable standardization to those desiring it. One ongoing effort involves the Air Force Research Laboratory (AFRL), the Utah State University, and a number of other commercial and government organizations. Dubbed Space Plug & play Avionics (SPA), it entails the utilization of existing network standards such as USB and SpaceWire, as well as data constructs such as the Satellite Data Model

(SDM) and XML Transducer Electronic Data Sheets (xTEDS), to implement a system in which spacecraft may be rapidly constituted from self-describing modular hardware and software components.

Means of converting existing devices to work within this construct include the use of an Appliqué Sensor Interface Module (ASIM) which adapts an existing device interface to make it compatible with SPA.² The ASIM contains a microcontroller, a range of digital and analog inputs and outputs, and standard data and power interfaces. To empower spacecraft developers and others to avail themselves of SPA, ASIM kits were made available to allow the development or adaptation of spacecraft components to work within in a SPA system. Similar to microcontrollers. programmable gate arrays (FPGAs), or electronics development kits, they were geared towards users with only limited exposure to the hardware and software in question. This approach made them candidates for use with novice users, such as high school students, and posed an interesting test of the accessibility and clarity of the development kits.

Lacking a sponsored effort to fund full-blown research and development into the utilization of SPA, we at the Naval Research Laboratory took advantage of the confluence of contributed internship labor and a small amount of program funding to procure ASIM kits and pursue SPA device development. This effort has continued for several years and through a number of

iterations of the ASIM and SPA efforts. We have experienced varying levels of success in both producing SPA devices and enhancing students' knowledge of spacecraft, as well as science, technology, engineering, and mathematics (STEM). Some of the lessons we learned during this effort are recounted here. They have been generalized to allow for broader applicability beyond SPA and ASIM development contexts.

GENERAL LESSONS GLEANED FROM WORKING WITH HIGH-SCHOOL LEVEL ENGINEERING INTERNS

(1) Assess student knowledge and experience

Ideally, there will be an opportunity to ascertain this during an interview process, but often with student intern programs this is not possible due to time constraints. Phone interviews are recommended as a minimum to ensure you are getting someone with interest, motivation, and reasonable abilities. recommend that you ask more fundamental questions than you would for a degreed or college-level interviewee: "Do you know what a resistor is? How about a microcontroller? Have you programmed before?" Sometimes the answers will surprise you, and could lead you to discover skills a student may not have thought to put on a résumé or internship application. You are also probing to see if students are willing to admit the limits of their knowledge.

(2) Assess student interest and motivation

Interest and motivation can also be assessed during the interview process. "What have you taken apart? What happened? What do you like to build?" Many bright students will underperform if they cannot maintain interest. This unfortunate obstacle may be something a mentor has limited influence over, as some students will come in with high levels of motivation and others will not. You should not assume that high levels of motivation will be common across all students you encounter. Academic underperformers can be the most enthusiastic workers if they engage with the project. Many times, seeing the practical applications and doing hands-on activities awakens interests that have lain dormant in classroom study, and can motivate them to develop a deeper understanding of their particular topic and a broader perspective on the engineering field.

(3) Contextual awareness is paramount

Experienced engineering professionals almost invariably begin to take for granted certain aspects of their positions and their approaches to engineering tasks, often to the exclusion of new and innovative techniques. Implicit in the work environment are contexts of project lifecycles, program mandated

protocols, and administrative procedures. While these factors may be taken for granted by the professional engineer, they are likely completely alien to students. Even seemingly simple practices that are widespread in industry, such as requirements and design reviews, are almost certainly new to most students.

Mentors should keep in mind two relevant consequences of students' naiveté: Firstly, newcomers are uniquely positioned to make observations, suggestions, and contributions to improve a work environment where those who have inhabited it for a significant period of time may have become inured to shortcomings or limitations. Anyone who has been in the same role or function for an appreciable duration may cease to ask "Why are we doing it this way?" or "How could this be improved?" It must be stressed to students that they have a window in which they have a profound perspective and opportunity to find things that we, the mentors, have become blind to. Secondly, since students are likely to be ignorant of the larger significance of their work, care must be taken to ensure they are given the "big picture" or "view from 40,000 feet" to help them appreciate their role and the importance and value of their contributions to the project and to the field in general. These two areas dovetail nicely, in that they both should promote the inquisitiveness of the student, in addition to prompting their superiors to reexamine their processes and procedures, and alerting them to where they may not have provided sufficient background information to new professionals.

(4) Assemble a collection of tutorials and appropriate background material

As many students, particularly high school students, have not had exposure to some of the more specialized aspects of hardware and software development, it is often helpful to enlist the aid of tutorials and background documentation. In general, documentation must be concise to maintain the student's interest and to serve a useful purpose. Since the students discussed in this paper worked in our Spacecraft Electronics Branch, we focus on areas relevant to our activities. appendix to this paper includes a listing, by no means exhaustive, of some resources we have taken advantage of in mentoring students. Certainly, the specifics of the task at hand will dictate the appropriate background material, but students generally benefit from a rudimentary overview. If possible, provide background material in advance of the actual internship period. Not all students will take advantage of it, but those that do will likely prove more able to act independently during their internships.

(5) Emphasize note taking

For our program, students worked for eight weeks. Typically, at least a week or two was devoted to orientation. Much time in subsequent years was saved by students documenting how they solved problems, allowing future students to avoid the replication of effort to solve the same problems. Additionally, students' written communication skills were developed and honed by promoting the generation of effective documentation. Conscientiously applied feedback allowed students to improve their writing. Students may have some previous experience writing lab reports in science classes, and this is an opportunity to show documentation applied in actual practice. One should emphasize that notes should be detailed enough to allow reconstruction of their efforts by someone else with a suitable background.

(6) Give students a task that is at least somewhat new to you

As a science or engineering professional, odds are you already have a multitude of demands on your time. Somewhat counterintuitively, it is okay not to be a complete expert in what the students will be doing. It is not necessary; in fact, it is discouraged, for you to know how the project will play out and exactly what they should do. Allowing the students to make and learn from their own mistakes during the development process is a beneficial result in its own right. But it also provides a live example to the student of how engineers attack a new area of knowledge and the troubleshooting process. This format is also an excellent opportunity to employ the Socratic method. That is, asking the student questions to lead them to the solution rather than merely giving them a solution.

SPECIFIC LESSONS PERTINENT TO SPA, ASIMS, SDM, AND NANOSPA

As SPA evolved from X1 to X3, and further to NanoSPA, the student experience evolved as well. Initial focus was primarily on FPGA programming using the Xilinx ISE tools, 8051 code development using Keil μ Vision, and testing via Data Designs' ASIM utility and prototyping board.

Students refined power-up and programming sequences, largely through trial and error, and then documented what worked best. Often this documentation was invaluable to students in subsequent years, saving them the trouble of relearning lessons over again. Readily accessible technical support from the kit provider also helped immensely.

Working with the ASIM Development Kits necessitated the use of common lab equipment such as power supplies, multimeters, oscilloscopes, and logic analyzers. In most cases, students had not had previous experience with most or all of these devices, and there was a learning curve associated with building proficiency. Invariably the acquisition of the skills to use this equipment engendered confidence and a sense of accomplishment, as well as likely future utility.

Students stayed engaged and confident when they were able to get something to work initially with reasonable ease. The ASIM application test utility served this purpose well. With only minimal research, background, installation, and configuration, students were able to see the system work. This construct gave them a frame of reference within which they could fill in their understanding of all the elements in the system. For instance, the signal could be traced from the output of the PC, through the USB port, into the FPGA, and out its digital outputs to the display. Having a working demonstration gave them the insight needed to understand how the LCD display might be replaced with another output device, such as a thruster, reaction wheel, or other spacecraft actuator. Likewise, reading from a thermistor illustrated how inputs could be routed into the system. Both cases prepared them for the process of creating an electronic data sheet (the xTEDS), and lead students to contemplate all the parameters of interest associated with a given sensor or actuator.

Once students were comfortable with the prototyping hardware and had an outline of the development process, it was possible to introduce the prospect of adding an actuator or sensor to be integrated with the ASIM. In addition to technical skill development, the SPA device development format allowed us to teach elements of project planning, including scheduling and budgeting. The relevance of time and cost limitations is critical. Working within the eight-week internship window and setting a modest budget of \$50 to \$100 per student focused the development efforts and helped drive technical decisions. Hardware needed to be available, and design, test and integration time needed to be calculated to ensure the project would be completed on time. If printed circuit boards needed to be developed, rapid techniques such as using simple and effective software, such as Eagle, in conjunction with off-the-shelf board etching kits were employed. Components were often purchased from the local Radio Shack, or ordered through Digikey, Jameco, or other suppliers to minimize lead times.

A significant challenge of the first few years was getting the Satellite Data Model working properly. Many students were intimidated by the prospect of installing the Linux operating system needed to host it,

and were further stymied by the seemingly arcane Unix commands needed to install, set up, and configure SDM properly. Some students had previous exposure to Linux, but most did not. Though documentation and sometimes even instructional videos were available, much time and frustration was expended getting SDM to a point of usability in its earlier releases. Initial interfacing of the ASIMs with SDM also proved challenging. Since the ASIM Development Kits and SDM were developed by different groups, it was sometimes difficulty to discern where the problems lay and whom to consult for assistance. In addition to becoming literate in the tools needed to develop the ASIMs, students also needed to subsume what was in most cases an entirely separate domain of knowledge for getting SDM up and running.

The advent of the embedded SDM running on the CubeSat as part of the NanoSPA CubeFlow kit helped This effectively eliminated the immeasurablly. previous difficulties associated with SDM installation and configuration. Coupled with the integrated tools of the Utah State University PnP software website, students were empowered to create the xTEDs, tailor existing device code, and easily generate test application code. Previously, getting SDM installed and operating properly might have taken several weeks on its own. Students garnered greater satisfaction from getting farther through the SPA device development process. Similarly, the since the CubeFlow kit provided essentially every required development hardware and software resource except the device to be adapted for SPA, many steps in the process that had before consumed considerable time were dramatically shortened. The CubeFlow kit combined the advantages of the original ASIM kit with comprehensive resources and examples.

CONCLUSION

Plug & play devices can offer cost, schedule, and flexibility benefits for spacecraft. The development of plug & play devices and the use of their associated hardware and software prototyping aids offer an opportunity for teaching students about satellites, electronics, and programming. As the resources available through the Air Force Research Laboratory's Space Plug & play Avionics efforts have evolved, we have used them as pedagogical vehicles. The result has been student growth through hands-on experience with hardware and software, as well as a broader perspective of the engineering field. In addition, the Lab has benefited from the generation of prototype plug & play devices that could be applied to future programs.

Acknowledgments

We are profoundly grateful to Jim Lyke of the Air Force Research Laboratory for his vision and persistence, Craig Kief and Brian Zufelt of COSMIAC for their CubeFlow assistance, Mark Shaw of Data Designs for his ASIM kit support, Jacob Christensen at the Utah State University for his PnP Software site help, all of our students for their energy and efforts, and the American Society for Engineering Education's Science and Engineering Apprenticeship Program, without which this would not have been possible.

References

- T. Morphopoulos, et al, "PLUG-AND-PLAY AN ENABLING CAPABILITY FOR RESPONSIVE SPACE MISSIONS," in Proceedings of the 2nd Responsive Space Conference, Paper No. 5002, Los Angeles, CA, 2004
- 2. APPLIQUÉ SENSOR INTERFACE MODULE (ASIM) APPLICATION DEVELOPMENT KIT FOR GENERATION ONE EXPERIMENTAL MODULES Updated For ASIM Hardware Revision X3, Version 08.01.17, Data Design Corporation, 2008.

APPENDIX - STUDENT RESOURCES

Books about Space

Secret Spy Satellites: America's Eyes in Space by Timothy R. Gaffney - A children's book, but also a highly effective "Executive Summary".

Understanding Space: An Introduction to Astronautics by Jerry Jon Sellers - A readable and comprehensive textbook for the high school level.

Books about Electronics

Getting Started in Electronics by Forrest Mims III - An accessible introduction to electronics.

Basic Electronics by Gene McWhorter - A broader, slightly more technical introduction than "Getting Started".

The Art of Electronics by Paul Horowitz and Winfield Hill - A widely used and highly regarded reference that covers almost everything, despite being a little dated.

Websites

Wikipedia.org – Widely acknowledged to be decent for background information on nearly any subject, but not to be completely trusted or relied on solely.

Youtube.com – Offers short, concise tutorials on many subjects, including soldering, electronics, and a variety of space, math, and science topics.

Khanacademy.org – Clear explanations of many concepts in math, science, and other relevant areas.

Howstuffworks.com – Cogent and understandable explanations in many areas related to spacecraft and related technologies with decent references for further information.