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Teaching students science and engineering with high altitude balloons and ChipKits

Mr. Matthew Nelson, Iowa State University

My background and interests are in embedded systems and radio communications. I have a BS in Electrical Engineering and will be completing my MS in Computer Engineering in 2014. My research is focused on software defined radios and in applications for remote sensing.

Currently, I serve as the Program Coordinator for the Make to Innovate program at Iowa State University in the Aerospace Engineering Department. This program provides our students with an opportunity for hands on projects and includes projects from underwater to space and everything in between. One of those projects is our high altitude balloon program which I have been working with the students with for for the last 8 years. We have been using high altitude Balloons as a low cost vehicle for our students to learn more about science and engineering and to give them real world problems to solve.

In addition to my duties at Iowa State University I also serve as the President of the Stratospheric Ballooning Association. This organization aims to promote, educate and encourage collaboration for high altitude balloon projects.

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Abstract

A low cost method for introducing students to science and engineering is in the use of high altitude balloons. These balloons are capable of reaching near space altitudes and in many cases above 30 km above sea level. The use of high altitude balloons introduce students to science through a variety of experiments that can be carried out on these missions. Engineering is taught through the design, build and fly concept where students design critical components of the system, build them and then test the concept through flights. Students also learn the operations side of successfully launching, tracking and recovering a high altitude balloon. Because the flight costs of high altitude balloons are low, usually between $400-$600 USD, multiple flights can be carried out throughout a school year. This low cost allows us to give students access to near space conditions at a fraction of the cost for a normal space flight such as a cubesat mission.

Introduction

At Iowa State University, our program is called the High Altitude Balloon Experiments in Technology (HABET) and is part of our Make to Innovate (M:2:I) program. This program is under the Aerospace Engineering Department, but the program is open to all students on campus. Our goal with M:2:I is give students hands on learning through interactive learning. The HABET team is a perfect example of M:2:I's goals by allowing students to participate in a design, build, fly type of environment.

One of the key components on a high altitude balloon flight is to be able to be able to record flight data, communicate with the ground station and control key systems on the spacecraft. One option is the Arduino, which is recognizable by many students and is easy to learn. The ChipKit however was chosen as it offers a more powerful 32-bit processor and additional I/Os while keeping the same Arduino form factor and programming language. This allowed the students to use this for more complicated missions and to standardize on a common hardware platform. By maintaining the same Arduino form factor, we are also able to take advantage of a number of existing shields that allow us to carry out a variety of missions.

High altitude balloons have been used in several educational institutions for teaching students in the area of STEM (Science Technology Engineering and Math) and Iowa State University (ISU) is no different. High altitude balloon flights allow our aerospace engineering students to design, build and fly spacecrafts that will experience near space conditions at a fraction of the cost of a full space based mission. We are able to use this to educate students by using hands on learning within our program. This allows us to test and experiment with hardware and software with less risk and lower costs than by flying them in actual space missions. A typical flight costs ISU between $400 to $600 depending on Helium costs and transportation costs for recovery. We can also use these flights to teach students the operation side of conducting these flights by teaching them the value of having a well thought out plan in executing these flights. Finally we also work with other departments in our University to bring science based payloads to these missions and to allow other students from other disciplines to be involved with these flights.

Methods

The high altitude balloon program at Iowa State University has two main teams, the Engineering team and the Operations team. The Engineering team handles all engineering aspects of a high altitude balloon flight and the development and building of the spacecraft. The Operations team is further divided into 3 smaller teams, Launch team, Mission Control team and the Recovery team. These teams handle the execution of launching the high altitude balloon, handling flight prediction, flight tracking and data management from the spacecraft and finally the recovery of the spacecraft upon returning to Earth. All teams in this program are comprised of students and are also lead by student team leaders.

Teams usually consist of two to five students per team. Size of the team depends on the mission at hand and if there are special requirements called for the mission. When possible, we try to engage the students by giving them as much ownership in their team and responsibilities. One method for giving students ownership is to create leadership roles within these teams. This allows the students to not only learn the engineering that goes into this project but also learn project management, leadership and financial responsibilities as they must manage a budget as well.

The Engineering team has the responsibility of designing and building the spacecraft used to bring payloads to altitudes in excess of 30 km ASL. This exposes the spacecraft to temperatures from -60 C to 40 C and pressures as low as .12 Pa. The spacecraft must also be designed to withstand landings when the spacecraft returns to Earth. The Engineering team also works on integrating the payload into the spacecraft. This may mean working with other groups on campus that are flying a scientific mission and integrating their science payload and sensors. In fact it is encouraged and we often bring students and faculty from plant pathology, meteorology, agronomy, and biology. This often results in designing a spacecraft that is flexible enough to accommodate a wide variety of sensors and payload options.

An area in high altitude ballooning that needs to be flexible and offer enough resources for conducting a variety of experiments is with the on board computer. The on board computer needs to manage several subsystems on the spacecraft including power systems, reading sensor data, storing sensor data and communication with the ground support teams. This means that it must have several input/outputs, be able to communicate with several data buses such as I^2C and SPI and be able to process the data. An additional requirement however was ease of use for the students. Since the students would be working and programming these units, they wanted something that would be easy to learn and use. Several types of systems were looked and could have served these roles. However, the students decided, with some input from myself, to standardize on the ChipKit platform to serve as the on board computer for their high altitude balloon flights.

Results

As mentioned earlier, there are several options out there. The Arduino platform is one such option that many students are already familiar with. There is very good reason for this, the Arduino is a low cost embedded system, usually less than $30 USD. It has a fairly easy to use Integrated Development Environment or IDE that is based on C/C++. It also has a strong community that has developed additional libraries to enhance the functionality of the Arduino and offer support to those wanting to learn to use the Arduino. Finally this community has also helped to develop several “shields” which expand on the hardware that the Arduino has access to. This common shield architecture also allows for anyone to develop their own shields that can be plugged into the Arduino.

While the Arduino does provide a number of advantages, there were a few short comings of the Arduino, especially the more popular Arduino Uno. The Arduino Uno is an Atmel 8-bit processor that operates at 16 MHz and has 32 kB of program space. It has 14 digital Input/Output pins and 6 analog input pins that are exposed through the Arduino’s headers. While this does allow for quite a bit that can be done with this system, for some experimentation and payloads may be too limited for what is needed.

The ChipKit uC32 has the same form factor as the Arduino Uno however has a completely different processor running under the hood. The uC32 uses a Microchip 32-bit processor which has 512 kB of program memory. In addition this board has more Input/Outputs, a total of 42 inputs and outputs. The processor also runs at a much faster speed, up to 80 MHz instead of the 16 MHz that runs on the Arduino Uno. Since the uC32 has the same form factor as the Arduino Uno, it is compatible with most Arduino Shields that are currently in existence. However, since the uC32 has 42 inputs and outputs, it has also added some additional rows to the headers. This allows it to be compatible with existing Arduino Shields but allows others to build shield for the uC32 that can take advantage of these extra I/Os.

While this means that hardware wise, the ChipKit is compatible with most Arduino shields designed for the Arduino Uno, what about the IDE or software used to program these? Fortunately there is a similar IDE called MPIDE that is built off the Arduino IDE. The ChipKit uC32 also uses the same type of bootloader so the process for uploading your code is the same as with the Arduino. Since the IDE is a fork of the Arduino IDE, the programming language is also the same as with programming the Arduino. This means that many of the Arduino libraries can also be used with the ChipKit uC32. However, there are times where some modifications need to be made. This is especially true of the Arduino libraries makes references or calls to specific Atmel instructions. In most cases though, only minor edits are needed to make the libraries work with the ChipKit.

The ChipKit uC32 now gives us a embedded system that uses hardware and software that many students may be already familiar with. In addition, because the Arduino was designed to be easy to use, so is the ChipKit uC32 and allows for many students to pick up using and programming the ChipKit easier than some more traditional embedded systems. This allows us to have the students do the integration of both hardware and software into the high altitude balloon system even if they do not have a strong background in electrical and computer engineering or have little experience in this area. With the ChipKit uC32, we also now have more programming space, processing power and additional inputs and outputs that allow us to support a wider variety of payloads and experiments on board.

Discussion

High altitude ballooning is one way of engaging our students in hands on and real world engineering problems and to give them the opportunity to design, build and fly systems that will fly to the edge of our atmosphere. It also allows us to do this with a much lower cost and risk than with traditional space based projects. In addition, using the ChipKit uC32 board allows us to introduce electrical and computer engineering concepts to students that may not otherwise be exposed to these and to give a more rounded experience in their engineering education at Iowa State University.