Sensors for a Weather Balloon - a Classroom Design Experience

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Introduction

Undergraduate engineering students need meaningful design experiences in their course work. These experiences are necessary to allow them to see the practical implications of their courses, to consider the interplay between system components, and to also view external forces, economics, safety, environmental impact, and cost in away that is not outside their own background. Accreditation organizations, ABET is particular, now require a "design continuum" in engineering programs. The continuum will take students through simple design exercises in lower-level courses and bring them through successively more challenging experiences to a "capstone" design shortly before graduation. We believe that this is a very good and necessary path that all engineering students should take to reach competence in their trade.

We have also found that it is very difficult to find realistic, simple, unconstrained design exercises for lower-level engineering courses. In this paper we outline a project that was used in a junior-level sensors course for systems engineering majors. The project required each student to design a portion of the systems needed to successfully complete a balloon-borne environment sensing mission. In this mission a weather balloon is to carry a student designed instrument package to its maximum altitude, where the balloon will burst and the package will return to earth safely. Data gathered during the mission may be recorded in the instrumentation package for later play-back, or it may be telemetered back to earth receiving stations. We have found this type of exercise to be an excellent vehicle for discussing project management and the tradeoffs that are often necessary between cost, weight and complexity. In execution the students find that a relatively simple concept can be very complex, and enjoy the freedom to express themselves through original, and in some cases novel, designs. The paper design may lead to actual construction of the vehicle and launch in later course work, or a student or student team will adopt the project for their own capstone design experience.

The course that this design exercise was used in is a course in the Systems Engineering department of the United States Naval Academy that provides students with theoretical and practical aspects of closed-loop control. Fundamentals of statistical measurements, sensors, motors, motor drivers, and closed-loop control are all subjects that are introduced in the classroom and reinforced in the laboratory through several practical experiments. Thus, the subject matter of the course provides a near perfect environment for an applied design project. Furthermore, all of our system engineering majors know that they must successfully complete a design project of their own during their senior year. They are often uncertain of the steps they need to take for this major design effort, so the project provides a welcome early practice session.

Weather Balloon Project Objectives

To begin the assignment, the students were told that they will be designing an environmental sensing package that will be sent aloft with a meteorological balloon and that the information that is gathered will be radioed by a telemetry system to receiving stations for further processing. They were to design a sensor (later broadened to a sensor or other flight system) that will meet a broad set of preliminary specifications that were given to them at that time. They were informed that they could use their classroom knowledge and experience to choose the types of sensors, structure and other system details that were necessary to fulfill the mission requirements . They are also told that their final design (in the form of a report) would be judged upon its adherence to specifications, build-ability and reliability. Other factors like realistic cost and system safety were also considered. During the course of the semester, the students were provided with other supplemental information ons ystem design steps, areas to research, catalogs and sensor trade publications, and a set of "lessons learned" notes that came from other amateur weather balloon groups. One of the more well know groups, Edge of Space Sciences (EOSS), based in Colorado, has much useful information available on the internet [1], which was distributed to the students.

Guided Design

Our experience in capstone designs shows that when students are faced with a design project for the first time they commonly encounter the following pitfalls:

- The "open-field syndrome" The vast possibilities that a student is faced with when confronted with an open-ended problem is sometimes overwhelming. They don't know in which direction they should proceed since there are generally many solutions to the problem.

- They do not thoroughly think through their project from beginning to end. The student will come up with a design without investigating all the issues involved. They will then proceed with their design only to discover a major flaw when they are well into the project. They need to investigate how their solution impacts other aspects of the project, does their solution work for all contingencies, and what are all the other contingencies.

- The scope of their project is too large or unrealistic. Enthusiastic students often come up with large ill-defined projects. Enthusiasm and motivation are desirable qualities and should be encouraged. However, without focusing their objectives, the project maybe unattainable within the framework of the course thus resulting with the student coming up empty handed at the end of the course.

Allowing students to struggle with these pitfalls can lead to them learning valuable lessons. Yet, providing a structured design procedure with guidance and constant feedback will produce better results.

The weather balloon project was intended to introduce the students to a structured design process that helps them avoid the common pitfalls associated with open-ended problems. Classroom discussions and assignments focused on developing well defined objectives, flushing out unforeseen issues, gathering information, and making tradeoffs. The design process that was used paralleled the steps recommended by Wales and Nardi [2].

Each student started the task by performing a mission analysis and submitting a complete outline of the balloon's anticipated flight profile. This activity got the students thinking about launch location, launch preparation, ascent, descent, operating environment, and recovery of the balloon. In addition to the outline, each student was asked to come up with ten questions about the balloon's mission. The questions motivated the students to think about what kind of information they needed and helped them identify issues. The student's questions were compiled into a list that was distributed to the class for discussion. The students were amazed at the various issues that arose from these questions. They ranged from the balloon's limitations to legal restraints on the mission.

For the next phase of the project, each student was required to define a sensor experiment. They selected an environmental property to measure, such as temperature or pressure, then proposed away to measure it. Their -r experiment had to comply with the weather balloon's payload that was specified by the course instructors. The payload specifications were originally intended to provide guide lines for the student's sensor experiments. However as the project proceeded, a number of students expressed interest in other facets of the project such as the telemetry and the recovery systems. The project's scope was then expanded so that the students were responsible for all facets of the project. They established their own requirements and design constraints based on tradeoffs they performed. The students submitted their proposal to their instructor for approval. Their proposal was to define their experiment or subsystem and specify any requirements needed for their design. The instructors reviewed the proposals for problem definition, feasibility, and relevant content. They then provided feedback and guidance to the student indicting weak points in their proposal.

Once the students proposal was approved they proceeded to develop a detailed design. The students were encouraged to keep an engineering notebook to record their calculations, assumptions made, resources used, etc. Some of the instructors collected the notebooks to track the students progress. At the end of the semester the students submitted a final design document providing sufficient information and drawings to facilitate the construction of their sensor experiment or subsystem. The design documents were to contain the following information as a minimum:

A. DESIGN GOALS A discussion of the principal goals their design is trying to achieve. What is their subsystem suppose to accomplish?

B. SYSTEM DESCRIPTION A description of their system concept in simple easy to understand language. The description should include sketches, diagrams, and schematics that illustrate the device and identify relationships between their subsystem and the overall system. Relevant equations and algorithms should be presented.

C. SCHEDULE A description of all tasks required to accomplish the design. A timeline that shows the chronological order and the amount of time required for each the task.

D. PARTS LIST A complete list of equipment, hardware, software, and parts that are needed to accomplish the design. The list must include where the part can be acquired, its availability, and cost. Items that may take considerable amount of time to make or acquire must be annotated so builders can order these parts, or determine an alternate part or source.

E. RISK ASSESSMENT Identify tasks thatmust to be performed in a specified sequence. If any task in this sequence is not completed, the remaining task can not proceed. This type of sequence is often referred to as a "critical path". Identify elements of the design that are critical to its success. If any of these elements fail, the design will fail.

F. TEST PLAN A test procedure assuring that the system will meet its objectives.

The Student Experience - Results

A panel of instructors selected four final design documents to incorporate into a weather balloon that was going to be flown the following term. The selected design documents were based on completeness of design, feasibility, reliability, and originality. This gave the project a competitive flare that motivated some very interesting designs. Below is a brief summary of two of the selected designs.

Project 1. Altimeter Using a Pressure Sensor

The design will consist of three main components: a voltage regulator, the pressure sensor, and an instrumentation amplifier. The first component, the voltage regulator, is essential for clean operation of the sensor. The payload section of the balloon will be powered by five high-energy lithium batteries in series, providing 15 v. supply. This will be regulated to +5v. and +12v. for use by the components. . . . The voltage regulator to be used for this circuit is shown in Figure 1. The second component of the altimeter is the pressure sensor. The sensor chosen is the SenSym SCX15ANC absolute pressure sensor. This sensor was chosen for its low cost and reliability over a broad range of temperatures. The SCX15ANC is internally calibrated with built in temperature compensation for accurate and stable output form O"C to 70ºC, and is capable of operation from -40ºC to 85ºC. In the compensated range of temperatures, the device is accurate to +/-1%. Outside this range, the error of the sensor increases non-linearly and will produce a maximum error of +/-3 .9°/0.

Project 2. Temperature Sensor

The main components of the temperature sensor area thermistor, transistors, and a 555 timer. This sensor's output (a square wave) will vary in frequency with varying temperature. The 555 timer is an oscillator that varies according to the capacitor and resistance values at pins 6 and 7. The formula by which the frequency varies is:

$$f = \frac{0.722}{(R_{th} + R)\,C}$$

where R_{th} is the resistance of the themistor which decreases as the temperature increases. This thermistor is chosen so that it is linear from -50ºC to 100ºC, which is the anticipated range of temperature seen by the weather balloon in going from sea-level to the burst altitude of 75000 feet. Fig. 2 shows the 555 timer hookup for the termistor.

Conclusions

The students in some sections of the course presented their designs to the rest of the class at the end of the semester. They prepared 10-15 min presentation discussing their experience with the project. Most of the reactions were very positive: they stated that they learned a lot about "real" components in manufacturers catalogs and in their applications. The serious challenge for them was interfacing the various types of devices needed for the whole system to work.

The students were encouraged to network and seek information from various sources instead of directing all of their concerns to one professor. The networking included communication between the students, which was promoted in class by publishing student responses to early assignments. Most of the students found interacting with other instructors and departments very interesting and they were pleased with the engineering society professionalism; some students preferred just talking to professors. Most students took pride in their designs and after performing some testing and iteratively changing the details of their project they became quite confident and could discuss the advantages and disadvantages of different solutions.

The weather balloon project was an equally pleasant experience for the faculty. Our students were enthusiastic about the project and clearly enjoyed finding appropriate solutions engineering problems. The major lessons we learned were to schedule the project so that an actual launch could be achieved towards the end of the semester (this time we were notable to successfully launch the experiment), and to make the exercise a formal part of the course, rather than an additional classroom exercise. Finally, each instructor felt that this was an excellent vehicle for teaching undergraduate students about the craft of applied engineering design.

References

[1] Mullenix, Dave, Balloon FAQ (frequently asked questions). Available on Internet (http://www.usa. net/~rickvg/eoss.htm).

[2] Wales, C. E., and Nardi, A., "Teaching decision-making with guided design," Idea Paper No. 9, Center for faculty Evaluation and Development, Kansas State University, Manhattan, KS, Nov. 1982.

Biographical Information

Carl Wick received the D. SC. in Computer Science from the George Washington University in 1993. He is an Assistant Professor with the Weapons and Systems Engineering department at the United States Naval Academy since 1990, when he retired from naval service as an aerospace engineering duty officer. His research interests are in image processing, fuzzy logic control, digital communications systems and embedded computer systems.

George Piper recieved the Ph.D. in Mechanical Engineering from Drexel University in 1990. Since 1994 he has been an Assistant Professor with the Weapons and Systems Engineering department at the United States Naval Academy. Proir to joining the Naval Academy, Dr. Piper was a senior member of the technical staff at Martin Marietta's Astro Space Division. At Martin Marietta he was involved in the design of many successful satellite programs such as NASA's Advanced Communications Technology Satellite (ACTS), U.S. Air Force's DMSP meteorological satellites, and AT&T's Telstar IV satellites. His research interest include spacecraft attitude dynamics & control, and noise& vibration control.

Jerry Watts received college training in Oregon, Louisiana, Utah, and California, receiving the Ph.D. degree in Systems Engineering from the University of California--Irvine in 1975. He has since taught in the Weapons and Systems Engineering Department at the U. S. Naval Academy. His research specialty is the modeling and control of gas turbine engines.

Svetlana Avramov-Zamurovic received the Ph.D. in Electrical Engineering from the University of Maryland in 1994. At present she is an Assistant Professor with the Weapons and Systems Engineering department at the United States Naval Academy. From 1990 to 1994, Dr. Avramov-Zamurovic was involved in developing a measurement bridge for voltage ratio calibration for NASA space experiment Zeno. She was Guest Researcher at the National Institute of Standards and Technology (NIST) from 1990 to 1994. During the summer of 1995 she was involved in development of capacitance ratio bridges to support the Single Electron Tunneling Experiment at NIST. Her research interests include precision measurements of electrical units, in particular the development of bridges to measure impedance and voltage ratios.

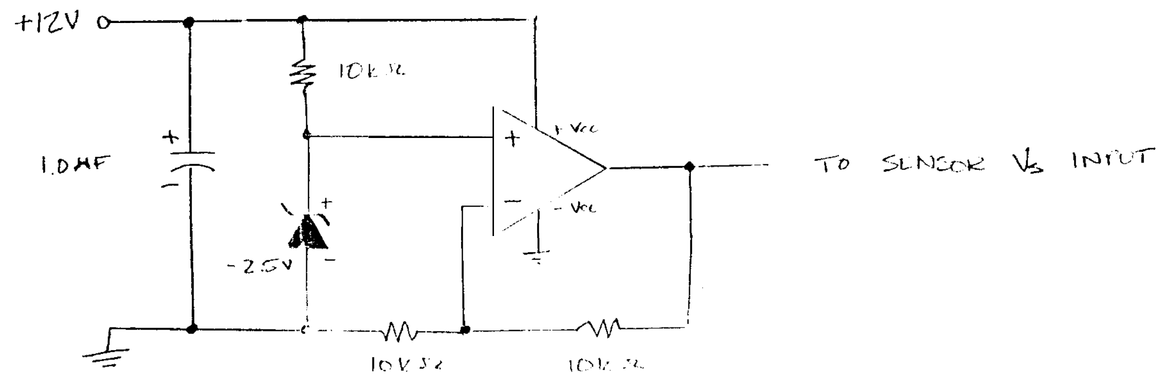

Fig. 1 Voltage regulator (5 v.) from a 12 volt supply.

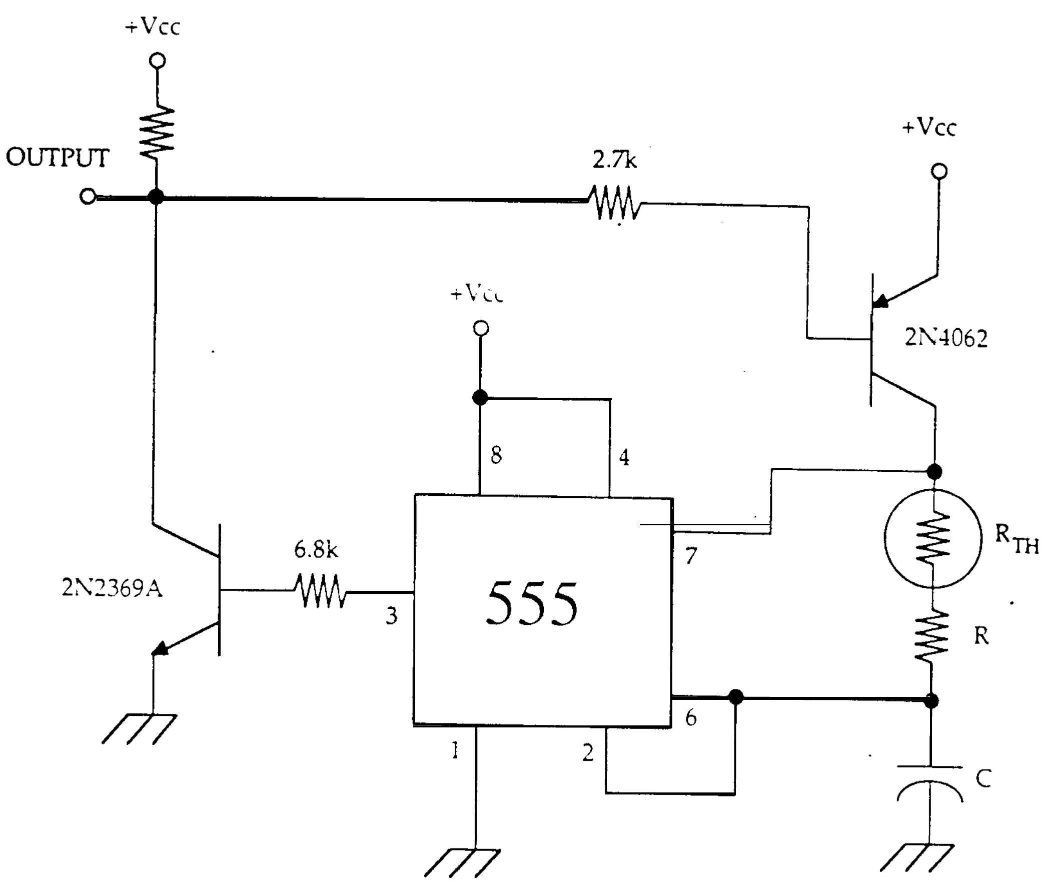

Fig. 2 Using a thermistor to control the pulses of a 555 timer.