AC 2012-3139: INTEGRATION OF CAPSTONE EXPERIENCE AND EXTERNALLY FUNDED FACULTY RESEARCH

Dr. Wei Zhan, Texas A&M University

Wei Zhan is an Assistant Professor of electronics engineering technology at Texas A&M University. Zhan earned his D.Sc. in systems science from Washington University in St. Louis in 1991. From 1991 to 1995, he worked at the University of California, San Diego, and Wayne State University. From 1995 to 2006, he worked in the automotive industry as a System Engineer. In 2006, he joined the electronics engineering technology faculty at Texas A&M. His research activities include control system theory and applications to industry, system engineering, robust design, modeling, simulation, quality control, and optimization.

Dr. Ana Elisa P. Goulart, Texas A&M University
Dr. Joseph A. Morgan, Texas A&M University

Joseph A. Morgan has more than 20 years of military and industry experience in electronics and telecommunications systems engineering. He joined the Engineering Technology and Industrial Distribution Department in 1989 and has served as the Program Director of the Electronics and Telecommunications programs and as the Associate Department Head for Operations. He received his B.S. degree in electrical engineering (1975) from California State University, Sacramento, and his M.S. (1980) and D.E. (1983) degrees in industrial engineering from Texas A&M University. His education and research interests include project management, innovation and entrepreneurship, and embedded product/system development.

Mr. Matt Allen Bird, Maxim Integrated Products
Stephen Peck

Integration of Capstone Experience and Externally Funded Faculty Research

Abstract

Capstone projects are important components in undergraduate educational experience. At Texas A&M University, students are required to go through a two-semester design process to develop new products. The capstone projects are typically sponsored by industrial partners. The industry-sponsored projects allow students to work on real-world projects with inputs from engineers and customers and have brought critically important benefits to the Electronics Engineering Technology and Telecommunication Engineering Technology (EET/TET) programs at Texas A&M University.

Recently, several capstone projects were sponsored by faculty members instead of industrial partners. These projects played an important role of supporting some larger scale externally funded faculty research projects. Undergraduate students involved in these projects as a capstone team had to work with graduate students, faculty members, and potential customers. Software, hardware, interface, system integration, and testing all involved other researchers instead of just the capstone team. In some sense, these kinds of projects resemble larger scale projects in industry. In addition to the student learning during their capstone experience, the faculty members were more motivated and more actively involved. In this article, a capstone project sponsored by faculty members is discussed.

Introduction

Capstone projects are important components in undergraduate educational experience. They have existed in engineering schools for many years. The benefits of capstone projects have been extensively studied in the literature. Surveys on this subject were provided by Todd *et al*.[28] and Howe[10]. The majority of the capstone projects involved industrial partners as sponsors and stakeholders[3,11]. Familiarizing students with product development process and system engineering is one of the approaches to better prepare students for real-world engineering tasks[4,5,7,12,26]. Improving the professional skills of students[7], using capstone project as a part of curriculum vertical integration effort[8], service learning and community outreach[2,27], providing multidisciplinary training[12,22,23], cultivating creative problem solving skills[17], and preparing students for globalization[14,15] are just some of the practices and potential benefits for capstone projects.

At Texas A&M University, students are required to go through a two-semester design process to develop new products. The capstone projects are typically sponsored by industrial partners. The industry-sponsored projects allow students to work on real-world projects with inputs from engineers and customers and have brought critically important benefits to the Electronics Engineering Technology and Telecommunication Engineering Technology (EET/TET) programs at Texas A&M University.

Recently, several capstone projects were sponsored by faculty members instead of industrial partners. These projects played an important role of supporting some larger scale externally funded faculty research projects. Undergraduate students involved in these projects as a capstone team had to work with graduate students, faculty members, and potential customers to meet their deadline for capstone projects and deadline for the externally funded research. Software, hardware, interface, system integration, and testing all involved other researchers instead of just the capstone team. This created new challenges in terms of team work, communication, documentation, scheduling, and many other aspects of project management. In a sense, these kinds of projects resemble larger scale projects in industry.

The importance of undergraduate research has been studied by many scholars over the past two decades[6,9,13,16,18,25,29,30,32]. The benefits of undergraduate research include its impact on a students' decision to pursue a graduate degree and a career in the science, technology, engineering, and mathematics (STEM) workforce, research skills learned by students, and learning other skills such as teamwork, communication, and presentation. While there is overwhelming evidence provided in literature for the value of undergraduate research and capstone projects, more research is needed in analyzing the benefits and drawbacks of making undergraduate student capstone stone projects as a part of a faculty led externally funded research projects.

In addition to the student learning during their capstone experience, the faculty members were more motivated and more actively involved in the capstone projects if they are parts of funded research projects.

In this article, a capstone project sponsored by faculty members will be discussed. Two faculty members in EET/TET program received external funding from American Public Power Association to develop a low cost intelligent transformer monitoring device. The externally funded research was divided into two smaller projects, one of which was a capstone design projects conducted by two students.

The rest of the paper is organized as follows: Section 2 contains the details of the research and capstone projects; the details of the capstone design are discussed in Section 3; Section 4 contains the results. Section 5 contains the conclusions.

1. Research project and capstone project

The power distribution industry is responsible for delivering power to millions of homes and offices. An important stage in the delivery process is stepping down voltage from the high transmission voltages, up to 100kV, to the lower 120V that one uses every day through wall sockets. The process of stepping down voltages is performed by transformers.

A major problem with current transformers is that there is no effective, inexpensive way for power distribution companies to gather the necessary performance statistics of a transformer while it is deployed and in use within the power grid. Current solutions on the market are priced outside of range for small utility companies. This results in too many unexpected transformer failures which dramatically increase the cost of replacement units and, ultimately, the cost of power to the end users. These factors give rise to the need for a low-cost solution that will provide a means for reduced preventative maintenance as well as increased warning before a failure.

Two faculty members from EET/TET program at Texas A&M University received funding from American Public Power Association to develop a remote monitoring device for transformers that can predict the remaining life of the transformers. It is expected that the information will be wirelessly transmitted to a desktop computer or a cellular phone. The device would also have data logging capability and be configurable by a technician using a laptop and direct serial communication.

The research project was divided into two smaller projects. One led by the faculty members with the support of two graduate students focusing on theoretical analysis and feasibility study of the estimation algorithm. The second one was a capstone project carried out by two undergraduate students. The undergraduate capstone team was tasked to design a prototype that has the capabilities of collecting sensor data, processing the raw data including conversions and filtering, sending alarms and text message to control center and designated users via cellular communication, and saving data to a USB device. The capstone team was also required to implement the algorithm, which was developed and validated in MATLAB[21] by the graduate students and faculty members, in a microcontroller. One of the faculty members served as the sponsor and the other served as the advisor for the capstone team.

As a potential customer, a local utility company provided user requirements to the faculty team and the capstone team. The requirements were first studied by the faculty and graduate students team and the capstone team. The requirements were then divided between the research team and capstone team.

2. Capstone design

The capstone team, working as a start-up company named “Outlier Engineering”, did extensive work to understand the exact requirements for their product named “TransAlert”[1]. This was the first step of their product development process. The major requirements are listed below:

- Low cost (<$500);
- Small form factor (8’’x8’’x5’’);
- Wireless capability for sending alarms, data, and text messages;
- Modbus TCP/IP communication with a host SCADA system;
- Wired communication with laptop for configuration;
- Monitor the load, ambient temperature, humidity, and vibration;
- Five additional I/O channel for future use;
- Data logging to USB for up to a year;
- Implementing MATLAB code for remaining life prediction and place holder for further algorithm development;
- Self diagnostic capability;
- Nonintrusive to the transformer;
- AC voltage power source with battery backup;
- Two operational modes: research and production;
- Environment requirements: temperature (-40C to 80C operational, -40C-100C storage), humidity (0-100%), EMC noise (in substations);
- User manual;
- Training for graduate students;
- Project documentation.

After some research, a conceptual diagram, as illustrated in Fig. 1, was created as a potential product that meets the design requirements. A test matrix and a test plan were created, a part of which is shown in Fig. 2. The tests are specified in the rows and the requirements are in the columns. An “x” in a cell implies that the test in the row will be used to validate the requirement in the column. The test plan provides specific information about how the tests are set up and conducted; what equipments are to be used; and the pass and fail criteria.

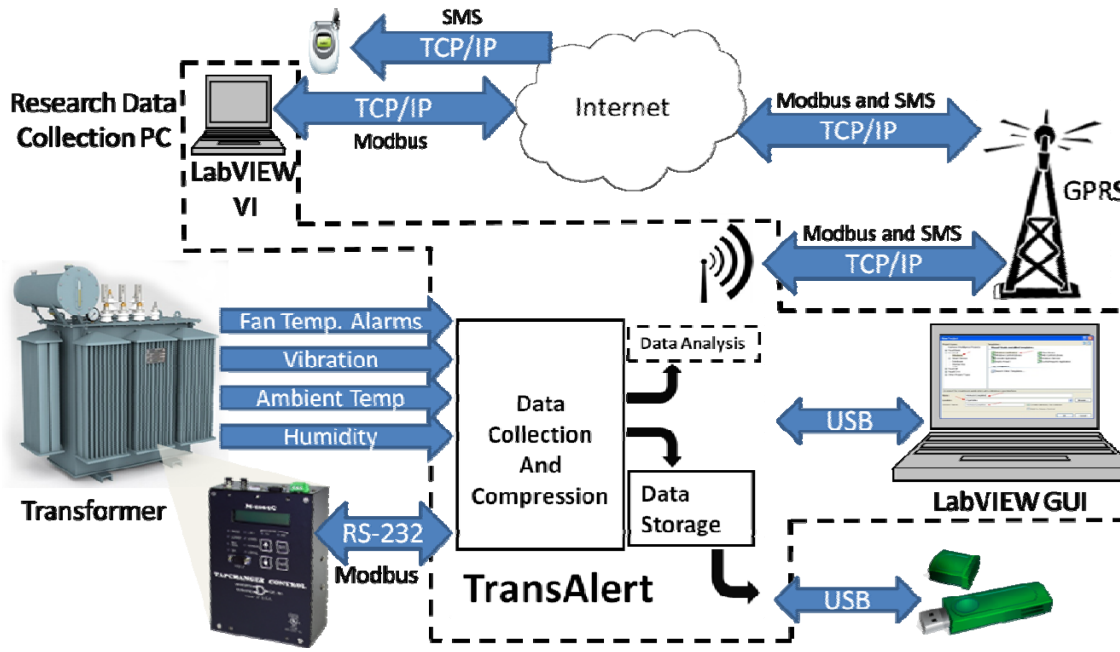

Figure 1: TransAlert Conceptual Diagram

Test \ Function	Powered from 120VAC	1 Hour Battery Backup	Local Data Storage	Analog Sensor Readings	Event Driven Data Collection	Research Data Production Mode	GPRS Web Pages Communications
Alarm Trigger					X		
USB Mass Storage Write							
Flash Memory Read/Write			X				
Status LEDs							
Real Time Clock Accuracy				X	X		
Mode Selection						X	

Figure 2: A subset of the test matrix

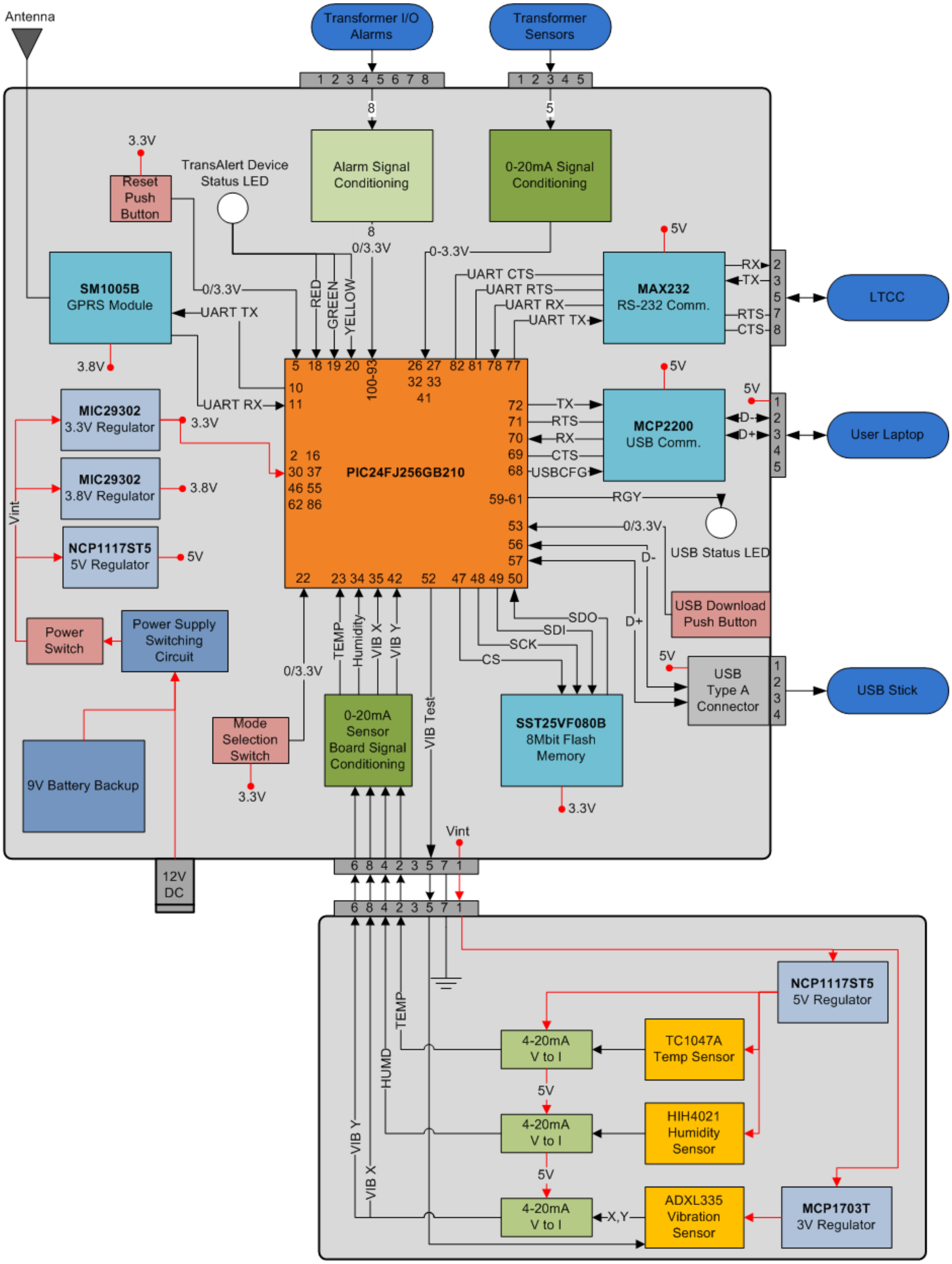

Figure 3: TransAlert Functional Block Diagram

The capstone design team used Multisim and Ultiboard[20] to design the electronic circuit for TransAlert. A part of the sensor board circuitry is shown in Fig. 4. The design was simulated extensively in Multisim first followed by breadboard implementation for certain parts of the design before the PCB layout was finalized. The copper top of the PCB is shown in Fig. 5.

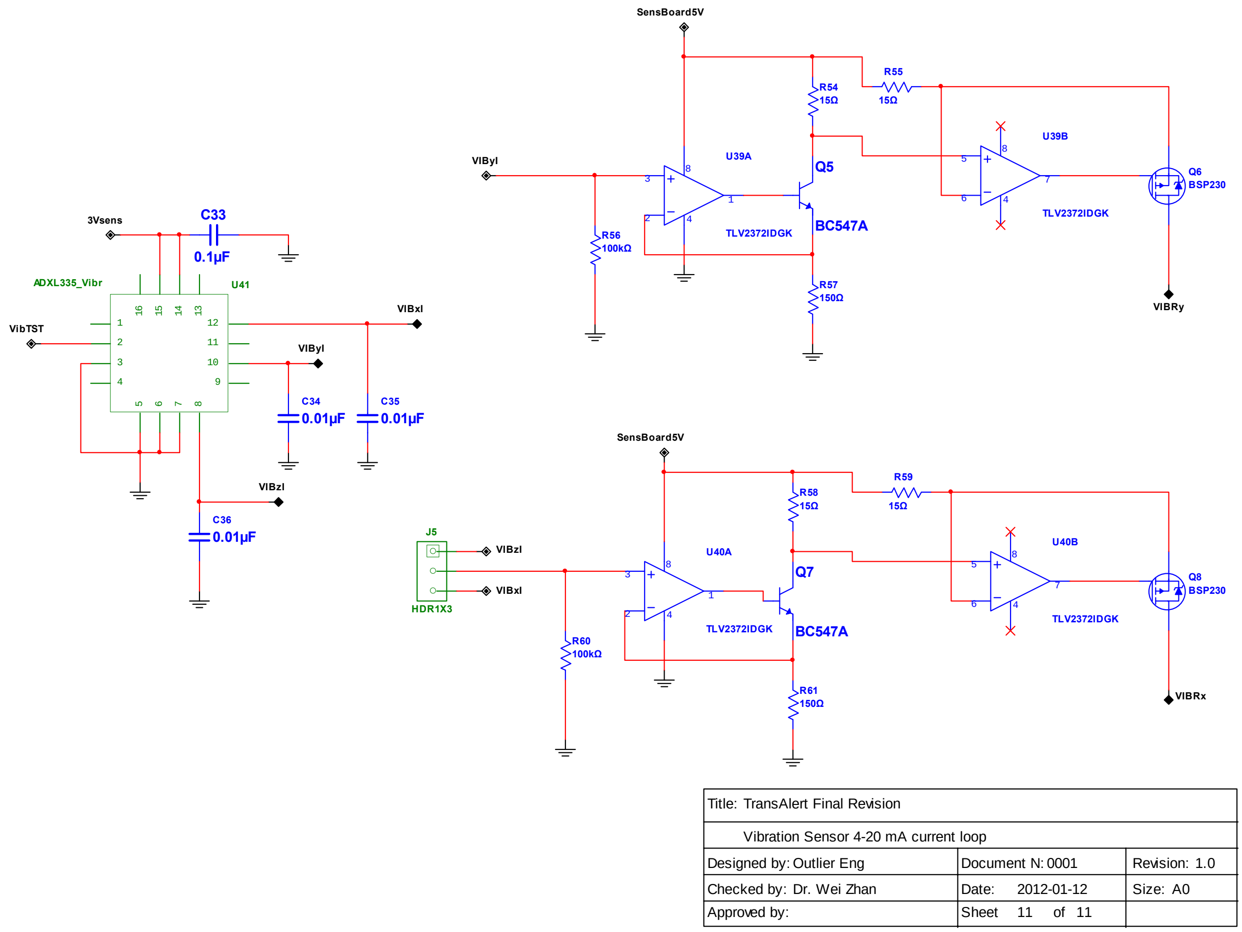

Figure 4: TransAlert sensor board circuitry

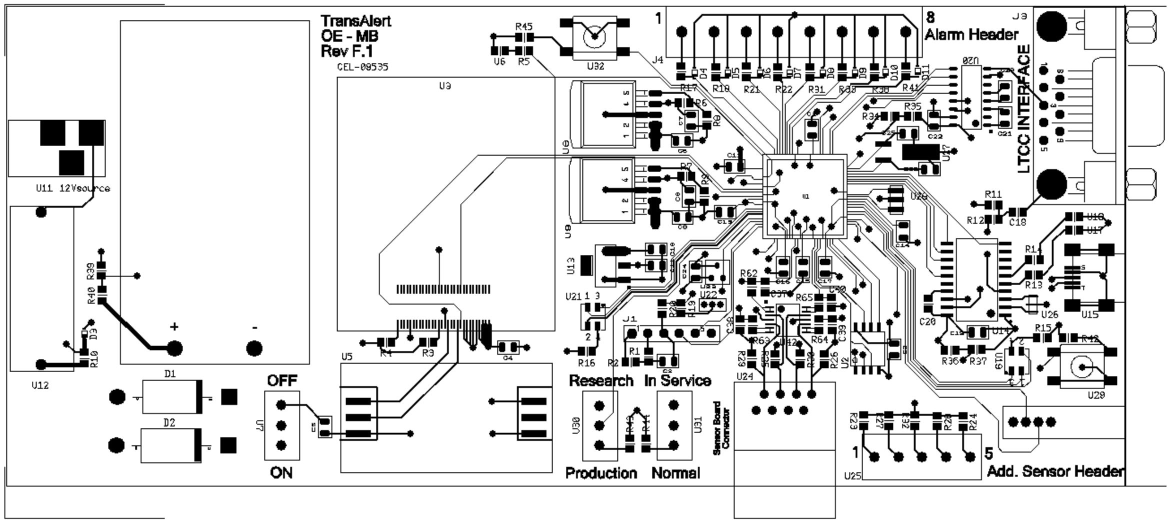

Figure 5: TransAlert PCB Copper Top

A PIC24FJ256GB210 made by Microchip was selected as the microcontroller for TransAlert. The firmware was designed by the capstone team. The top level state machine is shown in Fig. 6.

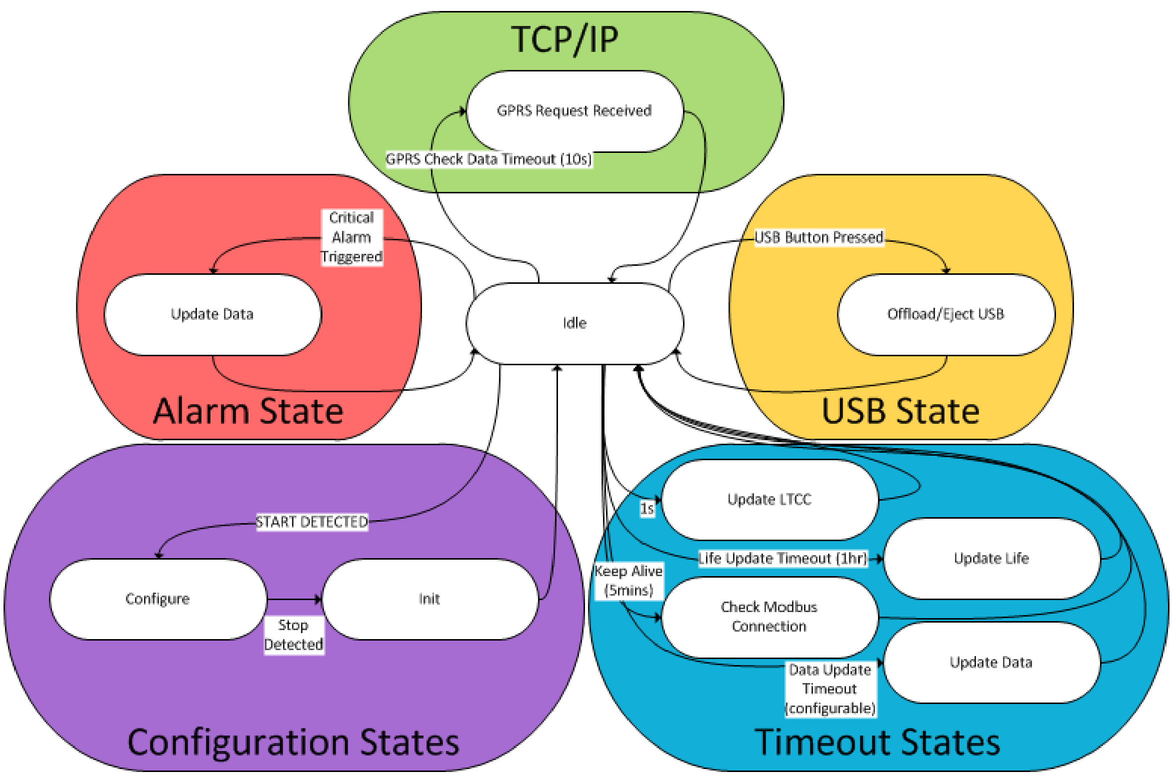

Figure 6: TransAlert firmware state machine

Two LabVIEW[19] VIs were created, one for configuration and the other for wireless data collection. Fig. 7 illustrates the state machine for the LabVIEW VI for wireless data collection. A part of the block diagram for the LabVIEW VI is shown in Fig. 8. Fig. 9 shows a GUI for configuration of the TransAlert device.

The graphical user interface provided by the LabVIEW VIs greatly simplifies the configuration and operation process of TransAlert. The capstone team also took pains to carefully document their design. Details of hardware design were captured. Firmware and LabVIEW VIs were modularized so that it is easy for further expansion of their functionalities. This is important because after the capstone project was finished, the faculty led research project will go through many revisions before the final delivery of their project. The transition from the capstone team to the faculty and graduate students team provides a unique opportunity for the two teams to work together, which is a real-world scenario for large scale engineering projects.

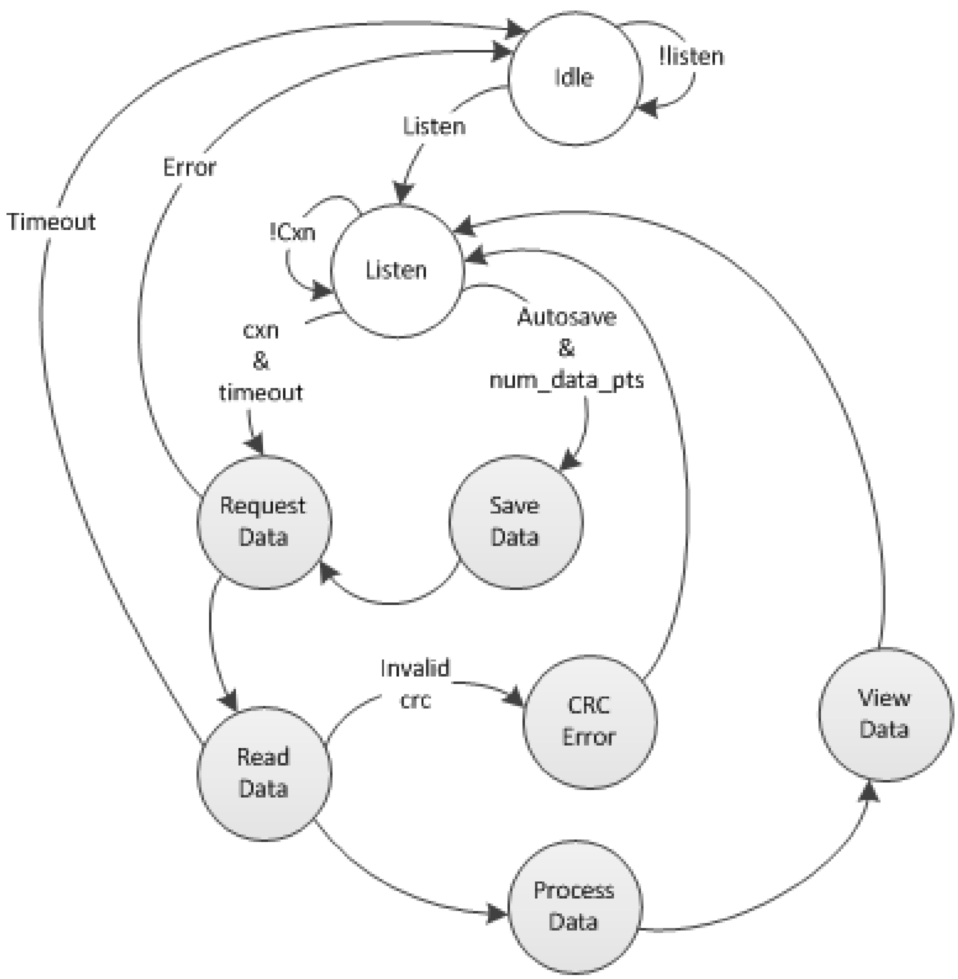

Figure 7: Researcher Application (LabVIEW VI) State Diagram

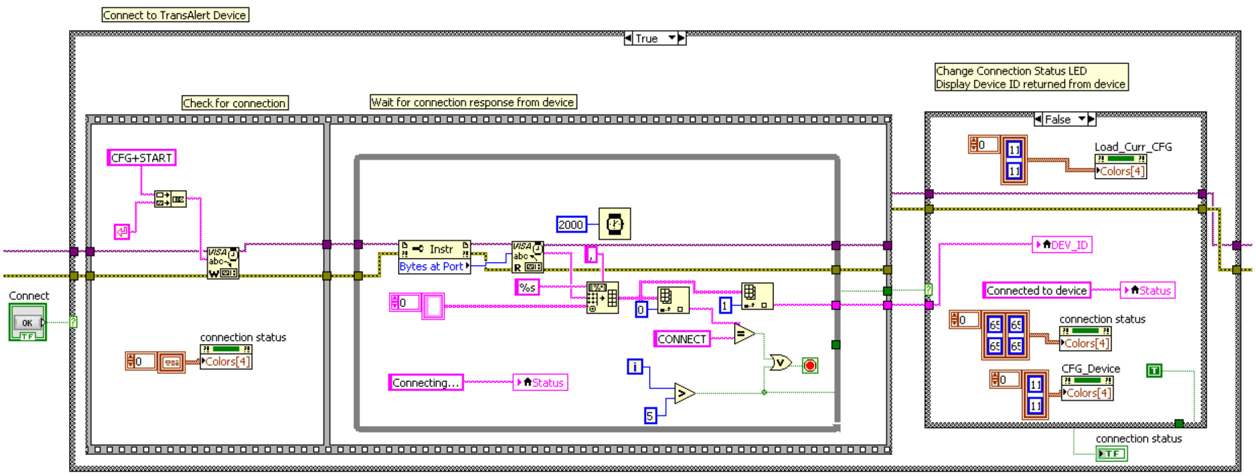

Figure 8: Connecting to device (Block diagram for data collection LabVIEW VI)

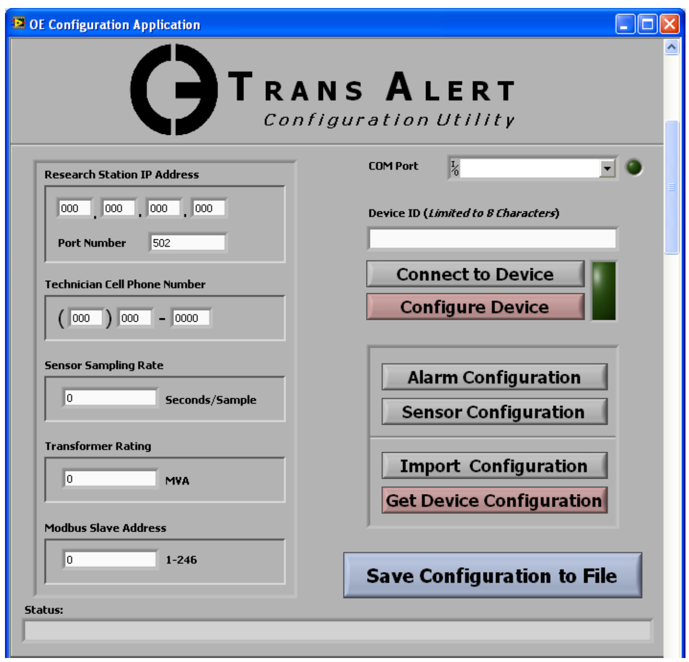

Figure 9: Configuration Application GUI

During the entire capstone project, the students used project management tools[31] to make sure they could deliver the prototype and all the supporting documents in time and under budget. Cost Performance Indicator (CPI) and Schedule Performance Indicator (SPI) were used by the students. The CPI value indicates the efficiency in utilizing the resources allocated to the project. The SPI value indicates the project team's efficiency in utilizing the time allocated to the project. More detailed discussion on CIP and SPI can be found in reference[31]. Fig. 10 shows that they were over the budget and behind schedule in the 5th week. One of the challenges for this capstone project was to meet the larger research project timeline requirement while constrained by the two semester capstone project timeline. This is one of the reasons that not all the faculty research projects can be used for a capstone project.

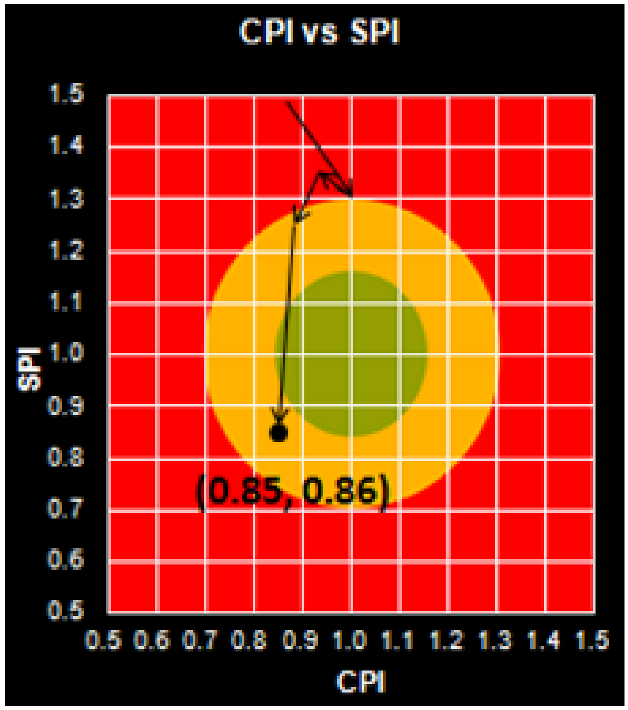

Figure 10: Project status in 5th week

3. Results

The faculty and graduate students team developed an innovative algorithm, which is submitted for publication[24]. The alorithm was implemented in one of the place holders in the TransAlert firmware. The TransAlert design was finalized, fully tested according to the test plan, and deployed to a transformer in a substation. Fig. 11 shows the TransAlert device in operation. Fig. 12 shows the test result for battery backup requirement.

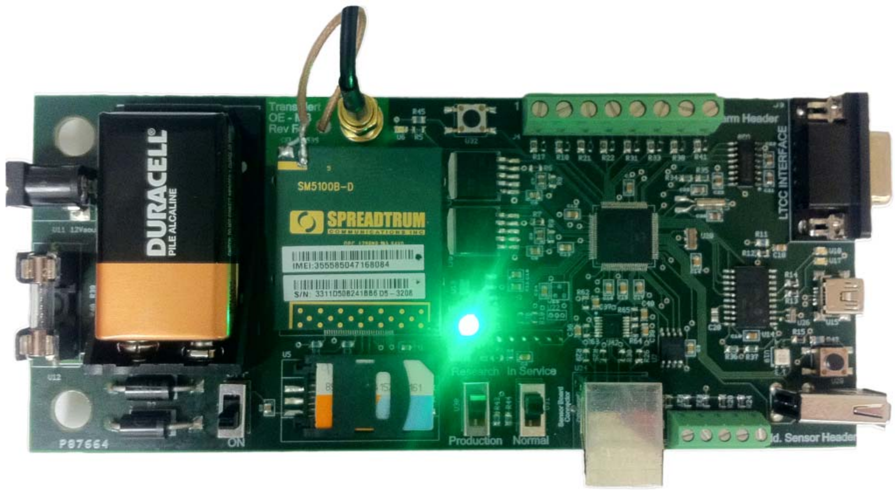

Figure 11: An TransAlert device in operation

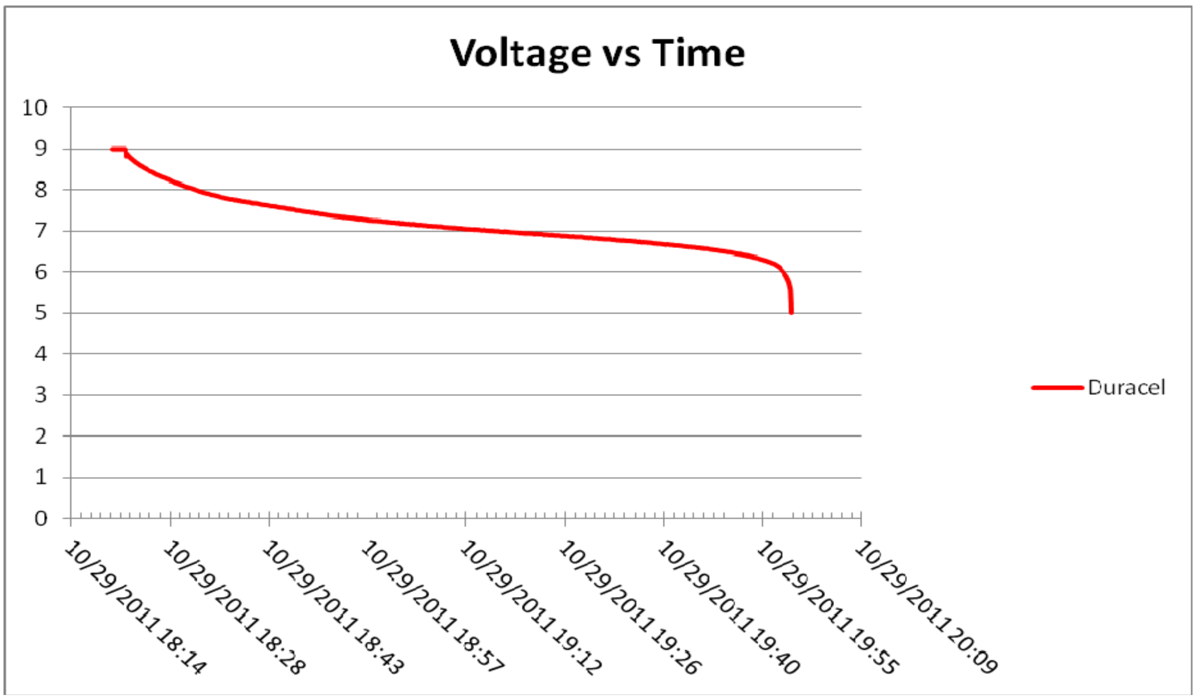

Figure 12: Test result for battery backup time

Fig. 13 shows a deployed TransAlert device in a substation. Fig. 14 shows the real time wireless data collection using a LabVIEW GUI.

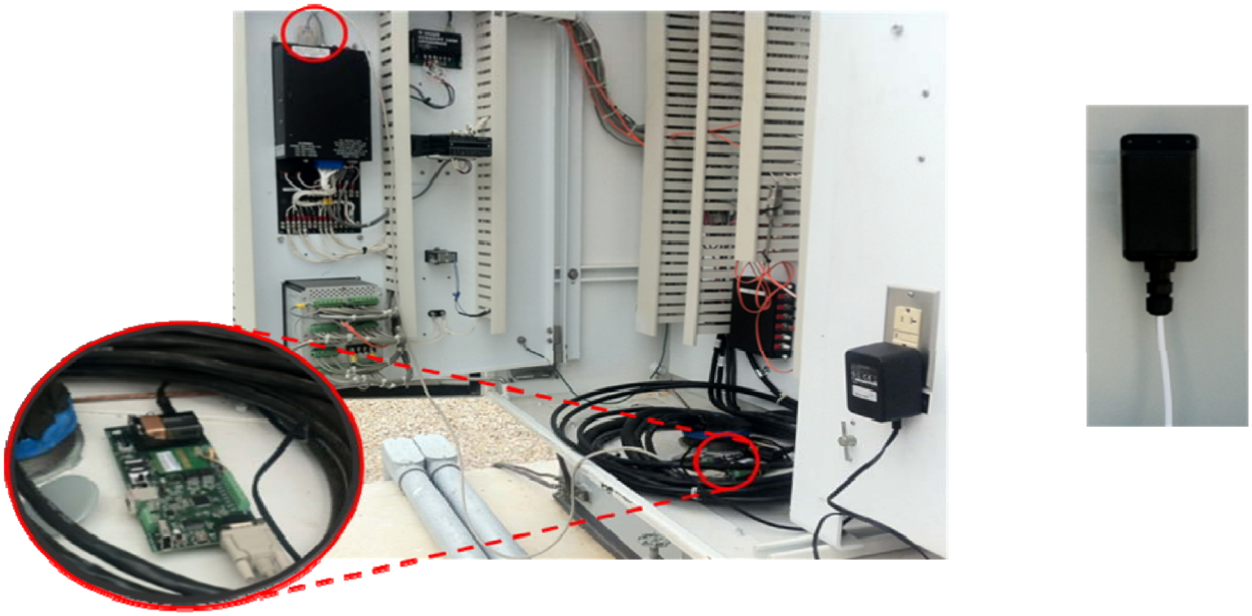

Figure 13: TransAlert deployed in a substation

Figure 14: Real time wireless data collection

Within two semesters, the undergraduate capstone team finished their project a head of the deadline. All design requirements were met. The device has been tested in the laboratory and in the field. The device deployed in a substation is has been monitoring a transformer since November 2011.

4. Conclusions

Combining a capstone project and externally funded research probably will not become a majority in capstone design. However, if done properly as shown in this paper, it can provide unique benefits to the undergraduate students, the graduate students, and the faculty members involved in the projects. Compared to the industry sponsored capstone project teams, the Outlier Engineering team had to work with the graduate students and faculty members during the entire project in addition to the normal interaction with potential customers. The interactions between the two teams and effects on each other's timeline requirement provided the students with additional opportunities in developing their project management skill and other soft skills. It has been a great learning experience for all parties. In some sense, these kinds of projects resemble larger scale projects in industry. In addition to the student learning during their capstone experience, the faculty members were more motivated and more actively involved. Due to limited number of such capstone design project, not sufficient data are available to conduct a comparative analysis between this kind of faculty sponsored projects and the industry sponsored projects. Educational research in this subject is worth further investigation.

References

1. Bird, M. and Peck, S., "Outlier Engineering Final Documentation," Capstone Project Report, Department of Engineering Technology & Industrial Distribution, Texas A&M University, November 14, 2011.
2. Brackin, M. P. and Gibson, J. D., "Service-Learning in Capstone Design Projects: Emphasizing Reflection," Proceedings of the American Society for Engineering Education Annual Conference, 2004.
3. Brackin, M. P. and Gibson, J. D., "Capstone Design Projects with Industry: Emphasizing Teaming and Management Tools," Proceedings of the American Society for Engineering Education Annual Conference, 2005.
4. Corns, S., Dagli, C. H., and Guardiola, I. G., "SE Capstone: Integrating Systems Engineering Fundamentals to Engineering Capstone Projects: Experiential and Active," Proceedings of the American Society for Engineering Education Annual Conference, 2011.
5. Crain, G. E. and Tull, M. P., "A Capstone Course Targeting Industry Transition," Proceedings of the American Society for Engineering Education Annual Conference, 2004.
6. Fitzsimmons, S. J., Carlson, K., Kerpelman, L.C., and Stoner, D., "A Preliminary Evaluation of the Research Experiences for Undergraduates (REU) Program of the National Science Foundation," Washington, D.C.: National Science Foundation, 1990.
7. Gerbus, D., Cordon, D., Walker, M., Drew, R., Odom, E., Beyerlein, S., and Rink, K., "Improving the Professional Skills of Engineering Graduate Students through Capstone Project Mentoring in IEWorks," Proceedings of the American Society for Engineering Education Annual Conference, 2002.

8. Hardin, J. M. and Sullivan, G., "Vertical-Integration Framework for Capstone Design Projects," Proceedings of the American Society for Engineering Education Annual Conference, 2006.

9. Hathaway, R.S., Nagda, B.A., and Gregerman, S.R., "The relationship of undergraduate research participation to graduate and professional education pursuit: an empirical study," J. Coll. Stud. Dev. *43*, 2002, pp. 614 -631.

10. Howe, S., "Focused Follow-Up to 2005 National Capstone Survey," Proceedings of the American Society for Engineering Education Annual Conference, 2008.

11. Karimi, A., Eftekhar, J., Manteufel, R., and Singh, Y., "Industrially Supported Projects in a Capstone Design Sequence," Proceedings of the American Society for Engineering Education Annual Conference, 2003.

12. King, L., El-Sayed, M., Sanders, M. S., and El-Sayed, J., "Job Readiness through Multidisciplinary Integrated Systems Capstone Courses," Proceedings of the American Society for Engineering Education Annual Conference, 2005.

13. Kremer, J.F. and Bringle, R.G., "The effects of an intensive research experience on the careers of talented undergraduates," J. Res. Dev. Educ. *24*, 1990, pp.1-5.

14. Lin, Y. and Harby, D., "Teaching Capstone Design in Globalization Environment," Proceedings of the American Society for Engineering Education Annual Conference, 2004.

15. Lin, Y., Harby, D., Jang, D., and Ye, Z., "Problems and Solutions in Internationalizing Capstone Design," Proceedings of the American Society for Engineering Education Annual Conference, 2005.

16. Lopatto, D., "Undergraduate Research Experiences Support Science Career Decisions and Active Learning," Cell Biology Education, 6, 2007, pp. 297-306.

17. Lumsdaine, E., "Creative Problem Solving in Capstone Design," Proceedings of the American Society for Engineering Education Annual Conference, 2007.

18. Mogk, D.W., "Undergraduate research experiences as preparation for graduate study in geology," *J. Geol. Educ. 41*, 1993, pp. 126-128.

19. National Instruments, LabVIEW User Manual, April 2003.

20. National Instruments, NI Circuit Design Suite, January 2007.

21. Pratap, R., "Getting Started with MATLAB 7: A Quick Introduction for Scientists and Engineers," Oxford University Press, 2006.

22. Redekopp, M., Raghavendra, C., Weber, A., Ragusa, G., and Wilbur, T., "A Fully Interdisciplinary Approach to Capstone Design Courses," Proceedings of the American Society for Engineering Education Annual Conference, 2009.

23. Seaward, G. H., "Converting Single Disciplinary Capstone Projects to Interdisciplinary Experiences," Proceedings of the American Society for Engineering Education Annual Conference, 2001.

24. Rondla, P., Falahi, M., Zhan, W., and Goulart, A., "A Regression Algorithm for Transformer Fault Detection," submitted to the 2012 IEEE Power & Energy Society General Meeting, November, 2011.

25. Russell, S. H., Hancock, M. P., and McCullough, J., “Benefits of undergraduate research experiences,” Science, 316, 2007, pp. 548-549.

26. Sheppard, K. G., Nastasi, J., Hole, E., and Russell, P. L., “SE Capstone: Implementing a Systems Engineering Framework for Multidisciplinary Capstone Design,” Proceedings of the American Society for Engineering Education Annual Conference, 2011.

27. Somerton C. W. and Thompson, B. S., “Community Outreach for Capstone Design: The Cycle Projects,” Proceedings of the American Society for Engineering Education Annual Conference, 2002.

28. Todd, R. H., Magleby, S. P., Sorenson, C. D., Swan, B. R., and Anthony. D. K., "A Survey of Capstone Engineering Courses in North America." Journal of Engineering Education,” 84(2), 1995, pp. 165-174.

29. Tomovic, M. M., “Undergraduate research—prerequisite for successful lifelong learning,” ASEE Annu. Conf. Proc. 1, 1994, pp. 1469 -1470.

30. Zhan, W., “Research Experience for Undergraduate Students and its Impact on STEM Education,” submitted to Journal of STEM Education, Dec., 2011.

31. Zhan, W. and Morgan, J. A., “Use of visual project management tools,” Journal of Management and Engineering Integration, Vol. 4, No. 1, 2011, pp. 137-144.

32. Zydney, A., Bennett, J. S., Shahid, A., and Bauer, K. W., “Impact of Undergraduate Research Experience in Engineering,” J. Eng. Educ., 19, 2002, pp. 151-157.