EET Capstone Student Project: Chemical Mixing Plant Integrated with Programmable Logical Controller and Human Machine Interface

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Abstract

The capstone project course is an intrinsic part of the undergraduate education. The capstone projects are widely regarded as an excellent mechanism for assessing the outcomes of engineering and engineering technology programs and can serve as a direct measure of the quality of graduates. Capstone projects provide an opportunity for students to demonstrate their critical thinking skills, communication skills, as well as time and project management skills. The capstone course prepares students to better understand the professional roles in the engineering and technology community. As part of the continuous efforts in developing critical thinking skills among the graduates of Michigan Technological University, the Electrical Engineering Technology (EET) Program at the Michigan Technological University is to engage a group of EET students in solving engineering problems as part of capstone integrating experience and to fulfill the degree program requirements.

The purpose of this capstone senior design project is to integrate a programmable logic Controller (PLC) with the Human Machine Interface (HMI) to control a chemical mixing plant. The machine uses various normally open and normally closed contacts, to mix and heat/cool up to three different liquids. The PLC is used to control the various AC and DC inputs and outputs (12 volt DC inputs, 120 volt AC outputs, and 12 volt DC outputs) of the plant to achieve the desired preset conditions of the chemical process. The inputs of the plant are used to collect the data from a flow meter and temperature sensors. The HMI allows the operator to employ additional functions and the integrated PLC provides a variable control for a pressure transducer, heater, and mixer. The final product will be further used in classroom instructions providing the students with hands-on experiences programming PLC and getting familiar with HMI functions. Additionally, the project provides an excellent opportunity for EET students to apply their skills and course work and interact with faculty on a real-world design challenge. The chemical mixing plant build upon completion of this project will be further used as a stand alone training solution to teach PLC and HMI concepts in introductory and advanced PLC courses in EET program at the Michigan Technological University.

In this article, we describe an effective approach of conducting capstone senior design project, the project requirements, the significance of the project, and specific project outcomes.

Introduction

The capstone project course is an intrinsic part of the undergraduate education. The capstone projects are widely regarded as an excellent mechanism for assessing the outcomes of engineering and engineering technology programs and can serve as a direct measure of the quality of graduates. Capstone projects provide an opportunity for students to demonstrate their critical thinking skills, communication skills, as well as time and project management skills. The capstone course prepares students to better understand the professional roles in the engineering and technology community[1]. In many universities, senior-level capstone courses have been incorporated as an integral part of engineering and engineering technology education in an effort to correlate the practical side of engineering design and the engineering curriculum. Such courses provide an experiential learning activity in which the analytical knowledge gained from previous courses is joined with the practice of engineering in a final, hands-on project.[2-4] The development of capstone design courses and corresponding requirements have been influenced by various sources, including the Accreditation Board for Engineering and Technology (ABET), industrial advisory boards (IAB), faculty leading capstone projects, numerous industrial companies, and engineering research.

Earlier research[4-15] showed the importance if industrial involvement in the capstone environment, which became more than just the financial support described above. However, support in the form of equipment, materials, and technical consulting is common and in most cases necessary.[6,8,11] Most industrial sponsors have a liaison engineer who assists the students and who follows the progress of the project.[7,10] Other forms of industrial support include providing awards for meritorious designs and assisting in the evaluation of teams and projects.[4]

More recent studies provide further in depth analysis on the importance of the various benefits of capstone projects for the students' preparation for real world jobs. These include, but not limited to the importance of industry involvement, [16-18]familiarizing students with product development process and system engineering,[16,19-23] improvement in the professional skills of students,[16,21] providing multidisciplinary training,[16,22,24,25]cultivating creative problem solving skills,[16,26] and preparing students for globalization.[16,27,28]

Recently, a new trend in conducting capstone projects became noticeable. Some capstone projects are sponsored by faculty members instead of industrial partners playing an important role of supporting some larger scale externally funded faculty research projects[16]. For example, at Texas A&M University 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[16] . These types of projects may resemble projects conducted in industrial settings, where multiple divisions have to collaborate on a single, large scale project.

The intend of this article is to share developed at Michigan Technological University an effective approach of working on the sponsored SD projects. In this article authors present student's team engaged in the faculty sponsored project with the goal of the development and proof of concept demonstration of integration of a programmable logic Controller (PLC) with the Human Machine Interface (HMI) to control a chemical mixing plant. The chemical mixing plant build upon completion of this project will be further used as a stand alone training solution to teach PLC and HMI concepts in introductory and advanced PLC courses in the EET program at the Michigan Technological University. The authors describe the project requirements, the significance of the project, specific project outcomes, and assessment tools used to effectively evaluate the students' success.

EET Program at Michigan Technological University

Michigan Technological University is a public university committed to providing a quality education in engineering, science, business, technology, communication, and forestry. Michigan Technological University has a first-class reputation for excellence in science, technology, and engineering education. In fall 2013 total enrollment was 6,979 students, including 1,333 (19.1%) graduate students. Over 65% of Michigan Technological University students are enrolled in engineering and technology programs.
The EET program offers a Bachelor of Science in Electrical Engineering Technology and is designed to train the future workforce directly in response to industry needs. The EET program is application-oriented and focuses on preparing graduates for entry into the workforce upon graduation. Graduates of the program are electrical engineering technologists with career options in micro-controller applications, robotics, industrial automation, instrumentation, and control.

A major strength of the EET program in attracting and retaining interested students is the emphasis on applied laboratory experience. The program has a solid record of career placement among employers who are seeking graduates that are productive upon entering the workforce. The university as a whole has maintained a placement rate of over 95% in recent years in spite of the difficult economic times. All School of Technology faculty members have a minimum of three years of industrial experience, which enhances the ability of the School to access industry support and place engineering technology graduates. The faculty members have a strong commitment to the integration of practical laboratory experience with engineering technology fundamentals.

Capstone Course Description

In the past several years EET program in the School of Technology at Michigan Technological University was very successful in establishing collaboration with the industry. This, in turn, triggered nearly all the capstone projects conducted in the EET program to be industry sponsored. Only during the last four years, EET program has successfully completed 12 capstone projects with 10 of them being industry sponsored. The benefits of having SD projects industry sponsored are very significant for both the students and faculties. On the other hand, the faculty sponsored projects gain popularity as well. Students working on faculty sponsored projects have an opportunity to participate in externally funded research or conduct faculty defined projects resulting in the equipment that can further be used to enhance in class teaching approaches.

A capstone course in the EET program requires the application of knowledge gained in lower and upper division courses. Students participating in a capstone project demonstrate the ability to perform independent and creative work by successfully completing a major design project. Projects are normally team oriented, where the team consists of two to four members, with one member chosen as team leader. Team oriented capstone projects provide a better simulation of industrial environment, to better train today's engineers. [2] Weekly progress reports are required, and the work culminates with a final report and oral presentations, including a poster of the project. Six credits of Senior Project are required for graduation, normally satisfied in two three-credit semesters.

Upon successful completion of the capstone project course, students should fulfill the following course objectives:

- Prepare background research on applied electrical engineering technology.
- Research and organize data for synthesis.
- Prepare written reports.
- Prepare and present oral reports.
- Work in teams.
- Coordinate and work to meet scheduled deadlines and facilities, manage resources, etc.
- Consider non-engineering considerations in your work (e.g., Economic issues, marketing issues, esthetics).

At the beginning of the first semester team is required to prepare a typed project proposal in a formal memo format, including a proposed timeline. During the course of the project student's team meet with their faculty advisor weekly to discuss the progress report. The weekly formal memo is required the day prior to each weekly meeting and addresses the following three areas: current progress, problems encountered and their resolution, and plan for the following week. To stay on the top of industry requirements sponsoring the project and to receive valuable engineering feedback students conduct by-weekly web conference calls with industry liaison. The oral and written reports due near the end of each semester are to concern themselves with the progress made in each semester. The one at the end of the first semester will be a progress report, with a full final report due at the end of the second semester. To further improve the quality of capstone projects conducted in the EET program in the SoT at the Michigan Technological University and make students experience as participating in undergraduate research, in the middle of the second semester the team led by the faculty prepares the paper to be further submitted in one of the engineering journals or conference proceedings. In the author's opinion, this experience should become an integral part of any capstone project since it derives an additional benefits previously not included in the capstone environment. First, this requirement makes the students to fill them proud to be engaged in undergraduate research, which in-turn derives more responsibility and teamwork. Second, it provides the students with the opportunity to learn different styles of technical writing following required formats associated with various journals and conference proceedings. The last but not the least, it significantly improves graduates portfolio that while looking for the job can "bring to the table" more than their competitors - applicants.

Technical Content of the Project

To integrate a PLC with HMI to control a chemical mixing plant a Senior Design team of 3 students was formed in the Electrical Engineering Technology program in the School of Technology at the Michigan Technological University. The plant uses various normally open and normally closed contacts, to mix and heat/cool up to three different liquids. Figure 1 provides the closed loop chemical mixing plant overview. The machine is designed to take up to three different liquids and mix them in a beaker before sending the mixture through one of two paths. The path the mixture travels is determined by which normally open and normally closed DC valves were set. The path from the beaker to the pump is shown in Figure 2. Once the liquid mixture travels through the pump it has three different paths to take. The first is it can be pumped directly out of the system and disposed of. The other two paths keep the mixture in the system where it can either be cooled by the fans on the radiator or returned straight to the beaker. Eventually, the liquid mixture is returned to the beaker where the process can be started over again. The path after the pump can be observed in Figure 3.

Figure 1: Closed Loop Chemical Mixing Plant

Figure 2: Path Before the Pump

The CLICK PLC is used to control the various AC and DC inputs and outputs (12 volt DC inputs, 120 volt AC outputs, and 12 volt DC outputs) of the plant to achieve the desired preset conditions of the chemical process. All the valves and other components including 120V heater and mixer can be observed in Figure 4.The inputs of the plant are used to collect the data from a flow meter and temperature sensors. The CLICK PLC system shown in Figure 5 consists of a power supply module, an 8 DC output module, an 8 AC output module, and a main module containing 4 DC and 2 AC outputs.

Figure 3: Path After the Pump

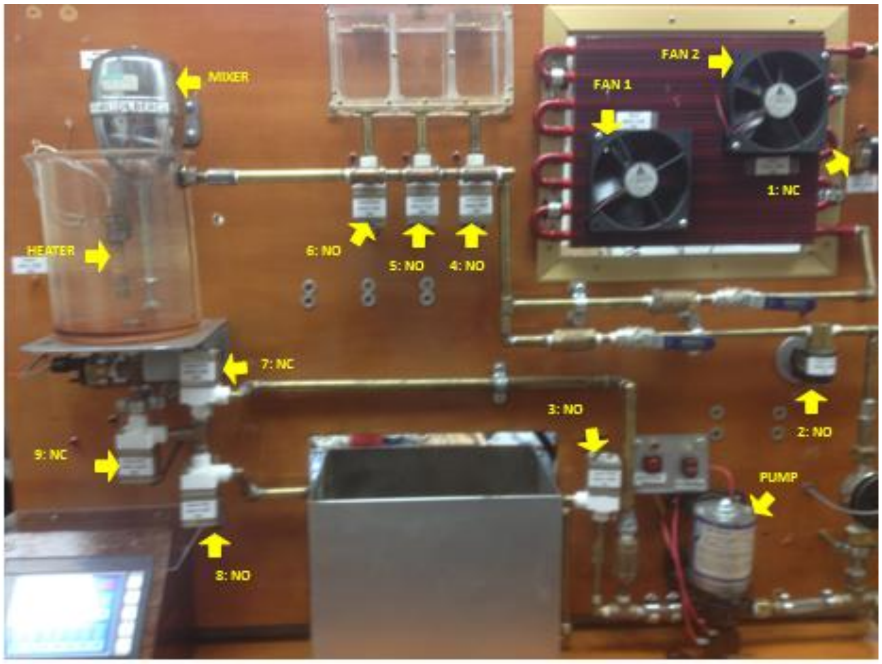

Figure 4: Closed Loop Chemical Mixing Plant Components

The HMI allows the operator to employ additional functions and the integrated PLC provides a variable control for a pressure transducer, heater, and mixer. The C-More 6-inch color HMI shown in Figure 6 is used to further add to the hands-on experience of the system. C-more software is used to configure several HMI screens including a home screen, pushbutton screen, ON/OFF switch screen, tri-state screen, meter screen (for temperature and flow percentage), and selector screen. All have the ability to be reprogrammed using and/or functions to control the control valves, fans, heater, and mixer depending on how the user programs the system. A housing was constructed for the HMI holding it at an angle for the user better interactive experience. Plexiglas was placed over top of the HMI housing in order to prevent liquid from damaging the apparatus in case of malfunction or leakage. The power supply that converts from 120V AC to 24v DC module for the HMI was placed on the back of the plant.

Figure 5: CLICK PLC

Figure 6: HMI with Housing

Laboratory Exercises Development

Upon successful assembling and testing of all hardware components, the senior design team has developed a tutorial with step-by-step instructions on how to use HMI and PLC to run the pre-programmed operational cycle of the chemical mixing plant. The tutorial also includes the detailed instructions on how to reconfigure individual control functions to modify the operating cycle of the plan. This includes all the required steps in constructing of new programs using C-More Programming Software and EA-1T6CL touchscreen HMI. The final section of the tutorial is devoted to the advanced PLC programming to providing situational condition described below:

No button will work unless the master button is pressed. In order to prime the pump, when valve 3 is closed, valves 7, 8, and 9 will be activated. When the temperature of the liquid is above 60 degrees Celsius, the heater will not run. If the heater is on, the fans will turn on after ten seconds. Fan 1 will run if the temperature of the liquid is greater than 45 and Fan 2 will run if the temperature is greater than 40 degrees Celsius. The fans will be normally off. The Mixer will run after the button is hit twice. If the heater is activated while the mixer is running, the mixer will shut off. Valves 4-6 will normally be closed. Valves 1 and 2 will activate when both their HMI button and the Master Button are ON, or 10 seconds after the temperature is greater than 45 degrees Celsius.

The situational scenario comes with the solution that provides all necessary steps for configuring HMI and programming PLC to achieve all the tasks described above. The developed tutorial along with the build closed loop chemical mixing plant will serve the purpose of providing the hands-on PLC and HMI training to the students enrolled in introductory and advanced PLC courses.

Capstone Project Assessment

To effectively assess the capstone project course outcomes the direct and indirect assessment tools have been implemented. In general, direct assessment involves looking at actual samples of student work produced in the course. These may include initial project proposal and a time line, team weekly memos, written report & project brief, team poster, and oral presentation. Indirect assessment is gathering information through means other than looking at actual samples of student work. These include student's self evaluation, faculty and IAB members' evaluations, and exit interviews. Each serves a particular purpose. Indirect measures can provide an evaluator with the information quickly, but may not provide real evidence of student learning. Students may think that they performed well or say that they did, but that does not mean that their perceptions are correct. As an indirect assessment tool the authors developed and implemented senior project peer feedback form and oral presentation scoring rubric with the last one being distributed to the faculty and IAB members during the final presentation conducted by the team at the end of the second semester.

The final grade is derived using both direct and indirect assessment tools and based on the satisfactory completion of the capstone project and the presentation of the final results in an appropriate engineering report. The final grade is based on individual and team performance throughout the semester. The points are awarded as follows:

- Initial Project Proposal and Time Line 10% Team
- Weekly Memos 20% Team
- Written Report & Project Brief 30% Team
- Poster 10% Team
- Oral Report 20% Individual
- Peer and Self Evaluation 10% Individual

To conduct peer and self evaluation, students of the team were asked to complete and submit to the faculty advisor a senior project peer feedback form shown in Figure 4. To collect the faculty and IAB members' feedback, oral presentation scoring rubric shown in Figure 5 was distributed during the final presentation conducted by the team at the end of the second semester. Students participated in the described in this paper capstone senior design project provided highly positive feedback to the team peers and scored 18.4 out 22 possible points on oral presentation scoring rubric filled by the faculty and IAB members. The following scores were given for individual assessment objectives:

- Technical Soudness 1.5/2
- Content 1.5/2
- Organization 1.8/2
- Grammar, Spelling, Vocabulary 1.6/2
- References 1.4/2
- Visual Arts 2/2

- Length 2/2
- Personal Appearance 1.7/2
- Enthusiasm 1.9/2
- Audience Rapport 1.6/2
- Poise 1.7/2

Conclusion

Academic programs in the School of Technology at Michigan Technological University are designed to prepare technical and/or management-oriented professionals for employment in industry, education, government, and business. EET program in the SoT at Michigan Technological University is constantly revamping the curriculum to meet the expectations of industry by supplying qualified technicians and technologists who have extensive hands-on experience.

As part of the continuous effort leading to priority consideration of graduates from the School of Technology an EET program at Michigan Technological University engaged a group of EET students in solving engineering problems as part of capstone integrating experience and to fulfill the degree program requirements. Working with the advisor, the team was challenged to integrate a Programmable Logic Controller (PLC) with the Human Machine Interface (HMI) to control a chemical mixing plant.
With the conclusion of this project the team was able to meet all of the requirements given by the faculty advisor and fulfill the degree program requirements at the Michigan Technological University. Successful assembly and testing of the unit was accomplished. An extensive tutorial was created which include step-by-step instructions with images and figures on how to use HMI and PLC to run the pre-programmed operational cycle of the chemical mixing plant. The tutorial also includes the detailed instructions on how to reconfigure individual control functions to modify the operating cycle of the plan. The situational scenario was also included in the tutorial and provides all necessary steps for configuring HMI and programming PLC to achieve all the tasks. The developed tutorial along with the build closed loop chemical mixing plant will serve the purpose of providing the hands-on PLC and HMI training to the students enrolled in introductory and advanced PLC courses.

Senior Project Peer Feedback Form

Assessment of (name): ______________________ ☐ *Co-worker* ☐ *Self* **Semester:** __________

Instructions: For each statement below, check one of the columns at the right to rate this individual's performance as a senior project team member.	+2 Strongly Agree	+1 Agree	0 Neutral	-1 Disagree	-2 Strongly Disagree	0 No Opportunity to Assess	**Comments** **(use back of sheet if more room is needed)**
Results Orientation							
Sets and achieves challenging goals that meet project needs.							
Takes initiative.							
Accountable for behavior and decisions.							
Persists in spite of obstacles and opposition.							
Integrity							
Behaves ethically in all situations and reports or challenges unethical behavior of others.							
Builds trust through honest interactions with others.							
Shows consistency among words, actions and values.							
Interpersonal Effectiveness							
Communicates effectively with others.							
Values individual differences and multiple viewpoints.							
Tries to foster a team environment.							
Handles conflict constructively.							
Quality Orientation							
Continually seeks to understand current and evolving project/group needs.							
Ensures that work meets the quality requirements of the course.							
Seeks to improve the project.							
Continuous Learning							
Demonstrates flexibility in adapting to change, uncertainty and shifting priorities.							
Learns from experience.							
Embraces opportunities to learn new skills and approaches.							
Innovation							
Makes creative suggestions for solving problems.							
Looks at issues in new ways and supports others when they do.							
Overall, this individual is a productive member of the team.							
Add up the number of checks in each column and enter it on the corresponding blank at right:	A ____	B ____	C ____	D ____	E ____	F ____	

Points earned = (2 × A) + B – D – (2 × E) = ________ **Points available = 40 – (2 × F) =** ________

Percentage = (Points Earned / Points Available) × 100 = ________

Figure 7: A senior project peer feedback form

Oral Presentation Scoring Rubric

Presenter ______________________________ Date ____________

Course ______________________________ Scorer *(Optional)* ____________

Part 1: Preparation				
	2	**1**	**0**	**Score & Comments**
Technical Soundness	Oral presentation and visual aids free of technical errors. *(Get a promotion!)*	Enough technical errors to erode your credibility, *(but not enough to get you fired).*	Severe technical flaws. *(Might get you fired.)*	
Content	No information is lacking. No irrelevant information is included.	May be missing some key information or a significant amount of irrelevant information is included.	Poor choices made when deciding what information to include and exclude.	
Organization	Presentation includes introduction, body and conclusion. Body information is presented in logical order. Smooth and timely transitions.	Presentation includes introduction, body and conclusion. Order in which information is presented is somewhat unclear or confusing.	Talk is very poorly organized.	
Grammar, Spelling, Vocabulary	Oral and visual presentation free of grammatical, spelling, and/or vocabulary errors.	Grammatical, spelling, and/or vocabulary errors are frequent enough to create some problems for the listener.	Grammatical, spelling, and/or vocabulary errors make the information very difficult to understand.	
References	References are clearly reliable, cited correctly and shared with audience.	Some references are unreliable or incorrectly cited.	No references cited. *(Go directly to jail for plagiarism!)*	
Visual Aids	Attractive and informative visual aids that compliment the information being presented.	Visual aids are cluttered or not informative.	No visual aids or better off not using the ones you have.	

Part 2: Delivery				
	2	1	0	Score & Comments
Length	Efficient use of time to present and handle questions from audience.	Some time management problems, either too short or too long.	Significant mismanagement of time.	
Personal Appearance	Professional, effort made to look sharp, right level of formality.	Neat but inappropriate (too casual or too formal).	Sloppy.	
Enthusiasm	Voice and body language reveal enthusiasm and interest in topic.	Neutral. Doesn't appear disinterested but not obviously enthusiastic.	Voice and body language seem unenthusiastic, bored with own presentation.	
Audience Rapport	Frequently checks for audience understanding; keeps audience engaged by maintaining eye contact and modifying delivery style if needed; attentive to questions and answers questions thoroughly.	Occasionally focuses on audience for reaction; responses to questions are generally relevant but little elaboration may be offered.	Oblivious to audience reaction; very abrupt when answering questions.	
Poise	Good posture and pacing; speaks clearly with sufficient volume; limited use of filler words; minimal reliance on notes; called on visual aids at appropriate times.	Not bad but could appear more confident.	Very stressed; reads visual aids to audience; composure is lost if distracted; significant use of filler words; speaking too fast or too softly.	

Total Score: _________ out of a possible 22

Figure 8: A senior project oral presentation scoring rubric

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