

# Using NFPA-Funded Capstone Project to Teach Fluid Power and Mechanical Design

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## Abstract

The A. Leon Linton Department of Mechanical Engineering at Lawrence Technological University offered a new senior capstone project to a small group of students, which is funded by a teaching grant from the National Fluid Power Association. All of the students major in mechanical engineering with various concentrations, including an international visiting student from Brazil. Three faculty in Mechanical Engineering, each with different area of expertise, mentored and worked closely with the students in every step of this project. The objective of this project is to design and fabricate a classroom-scale gantry crane for material handling. In this self-guided, real-world design problem, the undergraduate students directly involved in the design and benefited from an increased understanding of fluid power. In addition, the students worked on advanced modeling of mechanical components and systems, and mechanical design.

## 1. Introduction

The A. Leon Linton Department of Mechanical Engineering at Lawrence Technological University requires all students to complete a capstone project in their senior year in order to graduate. The senior capstone projects could involve product design, manufacturing, ergonomics, structures, materials research, mechatronics computer systems and control systems. The department offers two tracks for senior capstone projects: competition projects and industry-sponsored projects (ISPs). Competition projects include Baja SAE, Formula SAE, Formula Hybrid, and SAE Aero Design. These represent known quantities for students with strict timelines. Industry-sponsored projects are more varied, representing real-world problems posed by industry partners. Over the course of two semesters, the students complete 5 credit hours by attending lectures on the design process, working on the design as a team, testing the design, and evaluating their progress. Each student submits monthly progress reports and the team prepares a comprehensive report each semester. The comprehensive report is presented through with a poster and oral presentation to ME faculty and Industry Advisory Board (IAB).

Capstone Project course has been a great success in producing students with skills and experience in project management, oral and written presentation, and the designing and building of a new design to solve a real-world problem. The studies<sup>1</sup> indicate students finish the senior design courses well-equipped for their role in the rapidly changing world of engineering.

Students involved in capstone projects with support from industry gain a better understanding of the design process, have access to more resources, are more engaged, and ultimately produce a

better product<sup>2</sup>. Practical projects, like ISPs, provide the potential of being useful even in graduate level education<sup>3</sup>, where students study more than just the characteristic learning objectives of common classroom assignments. Working on real-life design problems has a great impact on students; helping them understand the decision making process, assess impact of design on cost and schedules, giving them a view of real-world engineering<sup>4</sup>.

Funded by a teaching grant from the National Fluid Power Association, a new senior capstone project was offered during Fall 2013 and Spring 2014 semesters. Students enrolled in the ISP track were offered the opportunity to join a team designing and building a gantry crane that uses fluid power for material handling.

## 2. Project Description

### 2.1 Project objectives

The objective of this project is to design and fabricate a classroom-scale gantry crane for material handling. The crane is fluid powered and capable of supporting at least a 50 lb. load while moving across a 10 ft. work space. The crane is able to lift to a height of at least 2 ft. and move horizontally in a single axis. The support structure will be capable of being disassembled for storage. Operation of the crane is controlled by a human interface system.

The motivation for this work was twofold: to facilitate deep learning about fluid power in a design sequence for the enrolled students and to develop a platform for future classroom and laboratory sessions on fluid power and associated topics. Upon completion of the project, the gantry crane will provide a test bed for future educational activities at both the undergraduate level and the graduate level.

### 2.2 Group work – faculty and students

Three full-time faculty in Mechanical Engineering (shown in Table 1), each with different area of expertise, mentored and worked closely with the students in every step of this project. The undergraduate project team was supported during the design process by integrating the expertise from all three faculty members. This is expected to continue during the fabrication and validation phase.

Table 1 - Participating faculty

<b>Faculty</b>	<b>Expertise</b>
Dr. Mynderse	feedback control theory and mechatronic design
Dr. Liu	fluid mechanics and thermal sciences
Dr. Arslan	power generation and thermal sciences

Students in the ISP track at Lawrence Tech were presented with available projects for each semester. Students then expressed preferences for desired projects. Working from student preferences, as well as the needs of the project as determined by the faculty advisors, the course coordinator assigned students to project teams. Student skills are informally evaluated from faculty advisor experience, student transcripts, and selection of technical elective courses. For this work, the project needs, as determined by the faculty advisors, were students with skills in design, fluids, and mechatronics. Mechatronics was viewed as valuable for this project for

integration of the fluid power, mechanical structure, and electronic control; dynamic modeling of the cart motion; and prototyping of the user interface. Many students in the BSME program at Lawrence Tech wait until their last semester to take the only required course in mechatronics. Thus, skill in mechatronics is rare during the senior capstone project.

During the Fall 2013 semester, three students were involved in the gantry crane design. During the Spring 2014 semester, four students are in the process of fabricating, assembling, and testing the gantry crane. Two students carried over from Fall 2013 to Spring 2014. The students and their assessed skills are shown in Table 2.

Table 2 - Participating students

Student	Fall 2013	Spring 2014	Skills
A	X		Fluids, Mechatronics
B	X	X	Design, Fabrication
C	X	X	Fabrication
D		X	Limited Mechatronics
E		X	Solid Mechanics

### 2.3 Project management

The students meet in and out of their ISP classes to collaboratively work on the project. All three faculty members meet with the team weekly to track progress and offer suggestions. Interim progress reports are prepared by the team to elaborate all the design details and to report to NFPA Education and Technology Foundation. The project is planned to be accomplished in two consecutive semesters, Fall 2013 and Spring 2014. The team focused on and has completed designing the gantry crane in the first semester. Currently the students are acquiring all required parts and materials and will be dedicated to building and testing of the system.

### 3. Student Design Description

Gantry cranes are used to move large loads horizontally and vertically. In industrial applications gantry cranes (an example shown in [Figure 1](#)) are an important part of the fabrication and production process as they aid in the transportation of materials to and from work cells. The use of overhead gantry cranes can reduce labor costs and can improve working conditions and safety.



Figure 1 - An industrial gantry crane<sup>5</sup>

The objective of the senior capstone project is to design and fabricate a classroom-scaled gantry crane for material handling. The crane must be fluid powered and be capable of supporting at least a 50 lb. load while moving across a 10 ft. work space. The crane will be able to lift to a height of at least 2 ft. and move horizontally in a single axis. The structure will be disassembled for storage. Operation of the crane will be controlled by a human interface system.

### **3.1 Mechanical Design**

The structure design of this project consists of two T-frame sides with a beam connecting them together at the topmost point (Figure 2a). This frame structure has locking swivel caster rollers at the base that will allow for easy movement and positioning of the crane. The frame structure will be fabricated from 2×4 rectangular aluminum tube. The top beam will be attached with four bolts and will be removeable from the sides for easy storage. The columns will be 2 in wide by 6 ft. tall and will support the top beam which measures 9 ft. by 4 in. A shelf will be attached to one of the T-frames to support the air compressor.

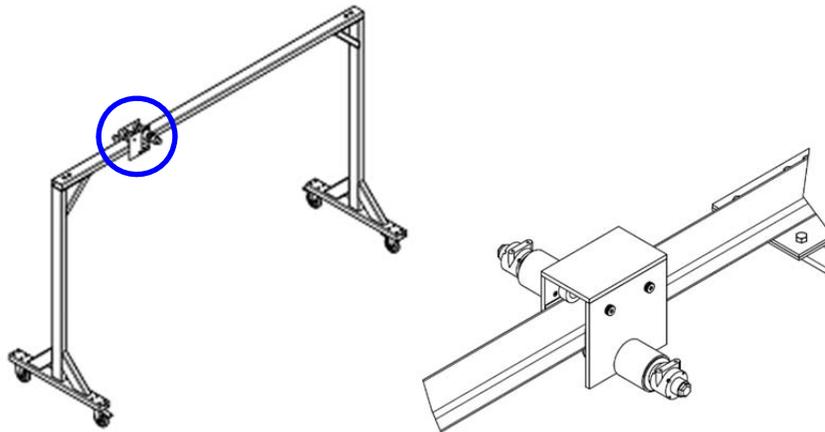


Figure 2 - (a) Gantry crane structure; (b) Magnified trolley section

A trolley (Figure 2b) will be located on the top beam and will house two low speed pneumatic motors (Figure 3). One motor will be attached to a pulley responsible for the vertical movement of the load. The second motor will be responsible for the horizontal movement and will be attached to two 3-in wheels, which will drive the trolley horizontally.

### **3.2 Pneumatic Motor Control**

Pneumatic H-bridges (Figure 4) will provide both speed and directional control of the trolley and crane hook via a tethered remote and Arduino Uno microcontroller. The pneumatic H-bridge was prototyped on a Festo pneumatic testbed in Lawrence Tech's Mechatronics Lab. The microcontroller and accompanying electrical circuit were used to control the Festo solenoid valves. The pneumatic H-bridge system was demonstrated to provide bi-directional motor control.



Figure 3 - Low speed pneumatic motor<sup>6</sup>

The operator will control the direction of the crane hook with five pushbuttons on the tethered remote. The first button will function as a safety enable button that must be pressed at all times in order to allow for any motion. The other four buttons will be directional control for the trolley: up, down, left, and right motion. The overall speed of the system will be controlled with a proportional regulator located on the main pneumatic line just after the air compressor. This will allow the operator to control the speed of the crane hook by controlling the pressure being supplied to the motors. This adjustment can be made by the operator using the potentiometer located on the tethered remote.

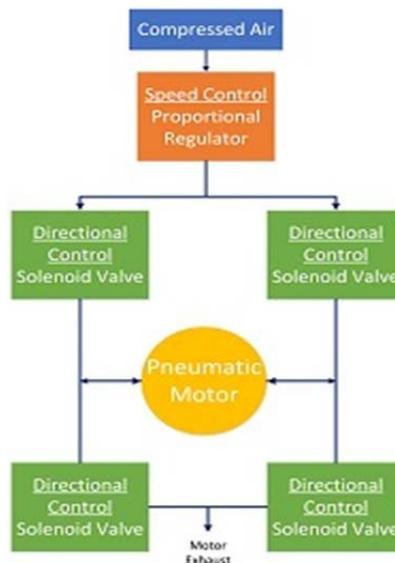


Figure 4 - Pneumatic H-bridge

#### 4. Assessment

Student progress was assessed during the semester using a series of four individual progress reports. Progress report followed a strict template with the following fields to be completed by the student:

1. What's the overall purpose of the project?
2. Summarize your own accomplishments since the last progress report.

3. What expenditures did you have since the last progress report? Were these within the budget?
4. What work do you expect to do during the next month? Are you on schedule?
5. Are there any issues, problems or budget concerns? What tasks are behind schedule?
6. How many hours have you worked on this project since the last report? What is the average hours/week worked on this project?

Each field was assigned a weighting in the template. All progress reports submitted for a single deadline were evaluated by one faculty advisor. Each faculty advisor evaluated at least one set of progress reports.

At the conclusion of the Fall 2013 semester, the students presented four items for evaluation: individual logbooks, a group written report, a group poster, and a group oral presentation. Individual logbooks and the group poster were evaluated by the course coordinator and not the faculty advisors. A rubric was used for each of these items. Students received individual scores for their logbooks and group scores for their poster.

The group presentation was made to the faculty advisors and members of the department Industrial Advisory Board (IAB). The students presented their problem, design, analysis, and continuing work. Following the presentation, audience members were invited to ask questions of the group. Faculty members as well as IAB members evaluated each student in the team using designed rubrics. The course coordinator compiled faculty and IAB evaluation into presentation scores for each student in the group. Figure 5 shows the students and faculty advisors with their posters immediately following the presentation.

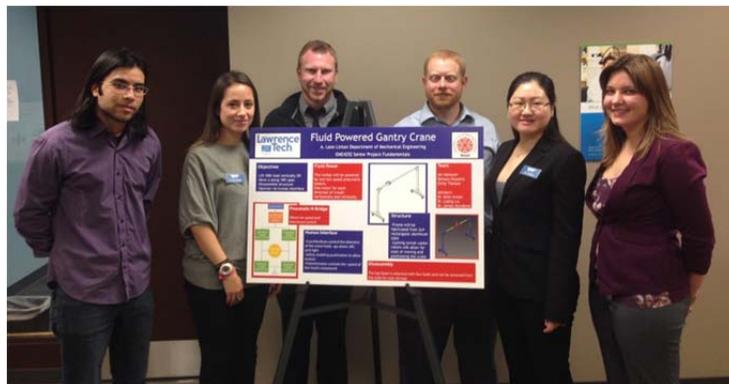


Figure 5 - Team group picture on IAB meeting, December 2013

## 5. Summary and Future Work

Sponsored by the National Fluid Power Association Teaching Grant, students in Mechanical Engineering at Lawrence Tech are involved in a collaborative capstone design project. Three faculty and five students participated the team work of designing and fabricating a classroom-scale gantry crane for material handling. The students not only gained hands on experience on building a mechanical system, but also acquired deeper understanding on fluid power and advanced modeling of mechanical components.

To date the design has been completed and during the Spring 2014 semester, students will purchase materials and fabricate the designed gantry crane. After the operation of the crane is validated and all performance specifications are met, the crane will be presented to the department. Upon completion of the project, the gantry crane will provide a test bed for future educational activities at both the undergraduate level and the graduate level. Future undergraduate students will benefit from a laboratory showing a practical application of fluid power combined with instrumentation and classical control theory. The project has applications to the study of statics (the structure), dynamics (motion of the cart), modeling of dynamic systems (motion of the cart and load), and fluid flow (from the fluid power). Graduate students in the Mechatronic Systems Engineering program will benefit from a test bed for implementation of more advanced feedback control designs incorporating nonlinearities due to the use of fluid power. Students will learn about fluid power in lecture and immediately practice modeling and control of a fluid power actuation system in the lab. The application of a gantry crane is well suited to robust control problems and modern control techniques.

## Acknowledgement

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