

## **AC 2010-847: ELEVATOR CONTROL SYSTEM PROJECT**

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# Elevator Control System Project

## Abstract

As part of the requirements in a junior-level measurements & instrumentation course (for an Electrical and Computer Engineering Technology program), students are required to design and implement an elevator control system project. The elevator simulator is pre-built and equipped with a car that travels through three floors, a car hoist system that uses a 12-volt DC motor, floor sensors to detect the position of the car, and an elevator call pushbutton on each floor. Terminal strips are provided for I/O connections. Students are required to use a National Instruments data acquisition system with analog I/O and digital I/O capability. The objective of the project is for students to design the software (using LabVIEW) and hardware interfacing electronics for the simulated elevator control system such that it mimics the operation of a typical elevator. This paper provides a detailed listing of the engineering requirements for the system and the functional test procedure for verifying proper operation of the system. Examples of student work are provided, along with a project assessment. This project is also linked to several ABET criteria and can be used for assessment of the same. Recommendations are provided to help ensure student success on the project. This project has been found to effectively integrate both hardware and software design, while utilizing information covered from many prerequisite courses. Due to the slow response characteristics of this system, this PC-based control project lends itself well to this application.

## Introduction to the Measurements and Instrumentation Course

This is a required first semester junior-level course for Electrical and Computer Engineering Technology students. The course description covers measurement concepts, transducers, electronic-aided measurement, and mechanical and electrical measurements. A LabVIEW textbook is required for the students<sup>1</sup>. Prerequisite knowledge includes circuit analysis and design, analog and digital electronics, microprocessor applications, and PLC applications. The students' software background includes high-level programming, assembly language programming, and ladder-logic programming.

The course is 3 credits and consists of 2 hours of lecture and 2 hours of lab per week. The lecture content of the course is divided into three sections: Programming applications using LabVIEW (5 weeks), data acquisition and signal conditioning (4 weeks), and measurement applications (7 weeks).

The lab content of the course is designed to reinforce concepts discussed during lecture. Each lab is considered a project since it lists a series of engineering requirements and requires either 2 or 3 weeks to complete, depending upon the scope of the project. Each project is completed by a student team that consists of no more than 2 students (some students prefer to work by themselves). Students pick their team members at the beginning of the semester.

For nearly all of the projects, students are expected to work outside of the scheduled lab time in order to complete the objectives. Grading for the project consists of 60% based on meeting all of the engineering requirements (no partial credit is given), 30% based on the content of the report, and

10% based on spelling, grammar, and writing style. There is a 10% reduction for late submittals. A listing of the projects for the course is shown below.

- Lab 1: Software-defined Calculator Project (2 weeks)
- Lab 2: Thermocouple Project (2 weeks)
- Lab 3: Waveform Generator Project (2 weeks)
- Lab 4: Digital Multimeter Project (3 weeks)
- Lab 5: Elevator Control System Project (3 weeks)
- Lab 6: Temperature Control System Project (2 weeks)

Also, an individual final project (rather than a final exam) is required for the course. Two weeks of scheduled lab time are provided at the end of the semester for students to work on their project, and students present their work during finals week. The purpose of the final project is to demonstrate and document a working prototype for the design of an automated test & measurement system. A detailed listing of engineering requirements for the project is provided to the students. In general, the students design and implement a power supply and control board that requires 2 regulated DC output voltages (9 & 3.3V), an AC output waveform (sinusoidal, triangular, or square waveform) with peak-to-peak, offset, and frequency adjustments, 4 TTL outputs with separate adjustment for each logic level, and 4 TTL inputs with visual indicators showing the logic level for each input. Then, the students are required to design the software, using LabVIEW and a data acquisition (DAQ) card, to automatically test each function of the board and record the results from each test to a file on disk.

### **Elevator Control System Project**

The elevator control system project is given during the 10<sup>th</sup> week of the semester, and it is scheduled for 3 weeks. Students are provided with a prebuilt elevator simulator and a PC-based DAQ system containing an analog I/O card and a digital I/O card. The objective is to design a control system for the elevator such that it mimics the operation of a typical elevator.

This project is appropriate for a measurements and instrumentation course since it requires both hardware and software design for interfacing the elevator to a PC-based DAQ system for a measurement and control application. Floor sensors on the elevator are used for controlling the position of the car. The response characteristics for this system are sufficiently slow such that control theory for dynamic control applications is not needed.

### **Elevator Simulator**

A pre-built elevator simulator is available for each student team. The simulator contains 3 floors and a 12-volt DC hoist motor for the car. There is an IR transmitter/receiver at each floor to detect the position of the car. The receiver output is connected to the base of a BJT and the emitter functions as the detector output. The IR detection system is designed for 24 volts, but it will function properly at lower voltages. Three hardware pushbuttons are used as the floor call pushbuttons. Some of the elevators are equipped with the pushbuttons, while others require students to connect them externally. Terminal strips are provided for I/O connections. The picture of the elevator simulator is shown below in Figure 1.

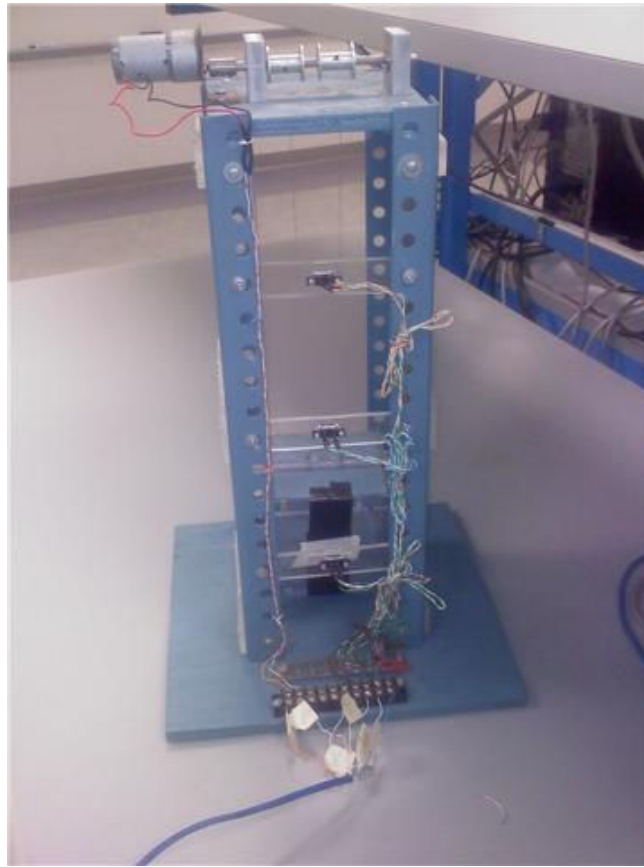


Figure 1. Elevator simulator.

## **Engineering Requirements for project**

### Special features:

- Program designed using LabVIEW
- Pre-built elevator simulator will be used for the control system
- Elevator simulator will be interfaced to the NI PCI-6040E and/or PCI-6503 DAQ card(s)
- 7-segment display readout indicating the position of the car (showing the floor that the car is on)

### Functional Requirements:

- Ability to call the car to each floor using hardware pushbuttons (one for each floor) and the hoist motor. External pushbuttons may be needed, depending upon the configuration for the pre-built elevator.
- The same call pushbuttons can be used for advancing the car to another floor, or 3 software pushbuttons can be used on the front panel.
- A method of simulating the opening and closing of the car door will be designed. An audible feedback or visual feedback (on the front panel) can be used, or another DC motor can be used.

- Ability of detecting the position of the car using floor sensors will be utilized in the design.

#### Operating Sequence:

- When the program is started, the car automatically moves to the first floor.
- When the call pushbutton is depressed, the car automatically moves to the appropriate floor.
- When the car is at the appropriate floor, the car door opens and remains open for 10 seconds, the door closes, and then the car automatically advances to the selected floor based upon the call pushbutton.

#### Documentation:

- VI online description
- Title information is presented on front panel
- Appropriate comments are provided on block diagram

#### Deliverables:

- Soft copy of the lab report will be provided
- Soft copies of VI and all SubVIs will be provided

### **Student Background Information for Project**

During the 10<sup>th</sup> week of the semester, students will have a sufficient software background in LabVIEW from learning LabVIEW programming basics, implementing equations using LabVIEW functions and MathScript, editing and debugging, creating subVIs, and implementing structures (For loops, While loops, Case structures, Sequence structures) using both LabVIEW and MathScript. Students will have also been introduced to the analog input operation of a PCI-6040E NI DAQ card (using both DAQmx subVIs and MathScript) and a brief introduction to the PCI-6503 NI DAQ card (for digital I/O operations).

From a PLC course taken during their second semester sophomore year, students interfaced the same elevator simulator to a PLC. They had a similar set of engineering requirements, but they used an Allen Bradley MicroLogix 1000 PLC with ladder-logic programming.

### **Hardware and Software Designs for Project**

For the hoist motor control system, students were provided a list of available parts. They were given the option of designing an H-bridge configuration using relays or transistors. They could also use a driver IC that is pre-configured to implement the H-bridge (quad half-H driver IC). Power op-amps with sufficient drive capability for the DC motor were also provided. Students chose the control method and selected the appropriate parts. This enabled students to exhibit uniqueness and creativity in their designs.

Students were given the flexibility of using the PCI-6040E NI DAQ card (analog I/O card with 1 digital port) and/or the PCI-6503 NI DAQ card (digital I/O card). This provided an opportunity for

students to consider the tradeoffs between analog and digital signals used for input and output operations. They needed to reference the DAQ cards user manuals for pin out information and signal characteristics. For digital I/O connections, students were instructed to include TTL inverters in order to help protect the ports on the DAQ card.

For the software design, a state machine design was suggested. Since this was not discussed during the course, appropriate reference material for a state machine was provided to the students<sup>2</sup>. Also, an example for the design of a simple traffic light using a state machine was covered at the beginning of the lab project. First, a template for a state machine was provided to the students and the engineering requirements for the traffic light were reviewed. Then, students implemented the simple traffic light using a state machine (with Go, Prepare to Stop, and Stop states). For this design, students used a wait function to halt the program for a specified amount of time in each state. The program was then modified. Rather than halting the program for specific periods of time in each state, the traffic light state machine was changed to include a loop iteration time of 100mS. This enabled the program to read inputs and write outputs for periods of time by using the iteration count. Finally, the traffic light state machine was modified again to include a pedestrian pushbutton.

This example was utilized to introduce the students to a state machine and to show the advantages of using a state machine as compared to a sequence structure. Then, the students were presented with a list of suggested steps for designing a state machine.

- Define the states.
- Determine what needs to happen in each state.
- Determine the conditions that need to occur to enter each state.

### Functional Tests for Project

Several tests were performed by the students to demonstrate successful operation of the elevator control system, as shown below in Table 1. Each test is numbered with a description and a pass/fail indication.

Table 1. Functional test procedure.

Test number	Function	Description	Pass/Fail
1	1 <sup>st</sup> floor call button	When the car is on the 1 <sup>st</sup> floor, open/close the door	
2	2 <sup>nd</sup> floor call button	Call car to the 2 <sup>nd</sup> floor from 1 <sup>st</sup> floor, and open/close door	
3	2 <sup>nd</sup> floor call button	When the car is on the 2 <sup>nd</sup> floor, open/close the door	
4	3 <sup>rd</sup> floor call button	Call car to the 3 <sup>rd</sup> floor from 2 <sup>nd</sup> floor, and open/close door	
5	3 <sup>rd</sup> floor call button	When the car is on the 3 <sup>rd</sup> floor, open/close the door	

6	2 <sup>nd</sup> floor call button	Call car to the 2 <sup>nd</sup> floor from 3 <sup>rd</sup> floor, and open/close door	
7	1 <sup>st</sup> floor call button	Call car to the 1 <sup>st</sup> floor from 2 <sup>nd</sup> floor, and open/close door	
8	3 <sup>rd</sup> floor call button	Call car to 3 <sup>rd</sup> floor from 1 <sup>st</sup> floor, and open/close door	
9	1 <sup>st</sup> floor call button	Call car to 1 <sup>st</sup> floor from 3 <sup>rd</sup> floor, and open/close door	

## Student Results

Out of 11 student teams, 9 completed all of the engineering requirements with 4 submitting all of their work on time. One team utilized a state machine for their software design. The other teams used Sequence Structures. All student teams either designed their own H-bridge configurations using relays and various other components or utilized the quad half-H driver IC. There were no teams that used the power op-amp to directly drive the hoist motor.

Examples of student work from 2 different teams are shown below in Figures 2 and 3. In Figure 2, this student team used a state machine for their design. The available states included Initiate, Wait, Motorstop, Open, Close, Up, and Down, with the Up state shown in Figure 2b. They also used a horizontal progress bar indicator for simulating the opening and closing of the car door, as shown in Figure 2a. An emergency stop button, which was in addition to the specified engineering requirements, was utilized.

The schematic in Figure 3 illustrates that this student team used a quad half-H driver IC to control the hoist motor. They used the PCI-6040E NI DAQ card for their design. The digital port was used for reading the call pushbuttons and the floor sensors. The 2 analog output channels were used for writing the appropriate signals to the driver IC.

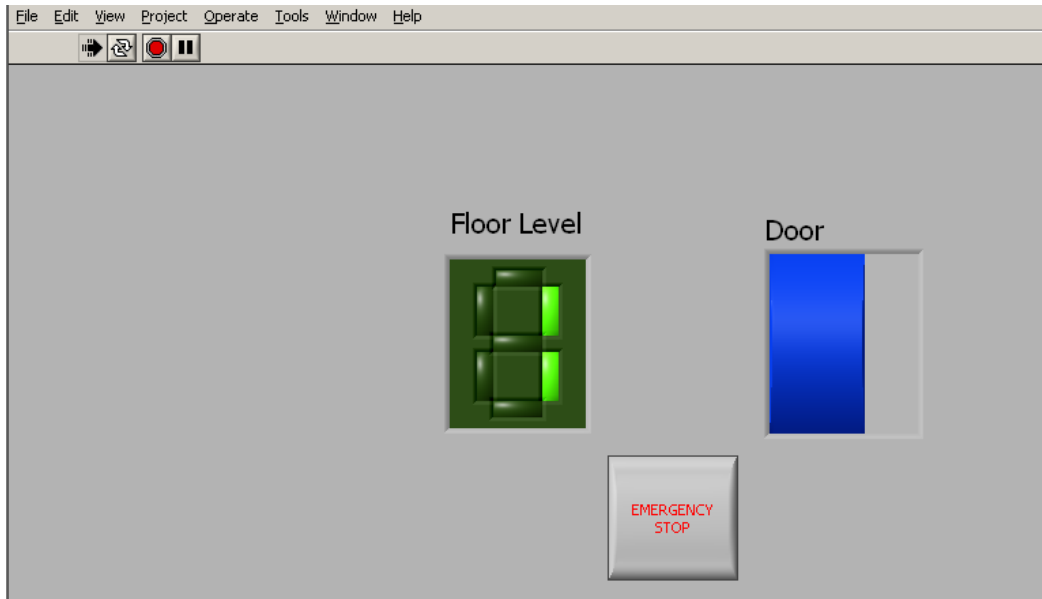


Figure 2a. Example of a student team's LabVIEW front panel.

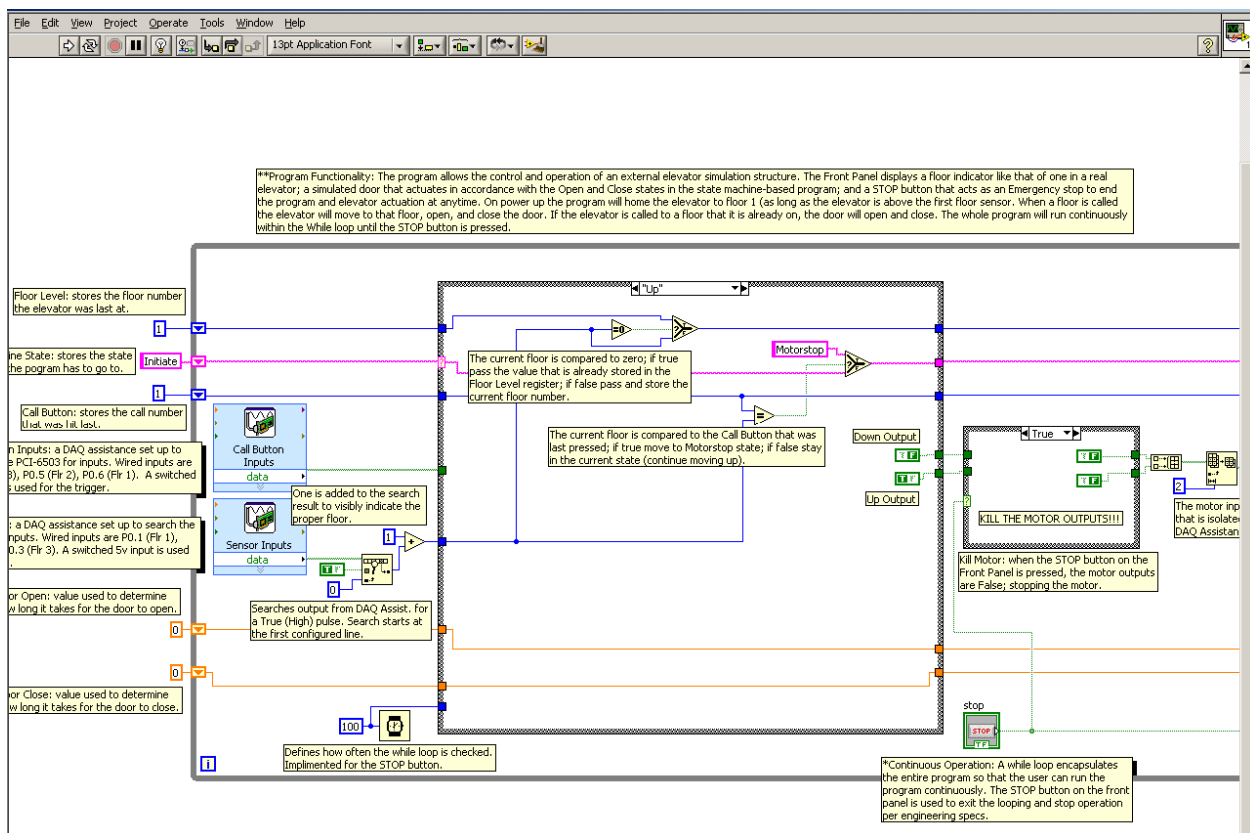


Figure 2b. Example of a student team's LabVIEW block diagram.



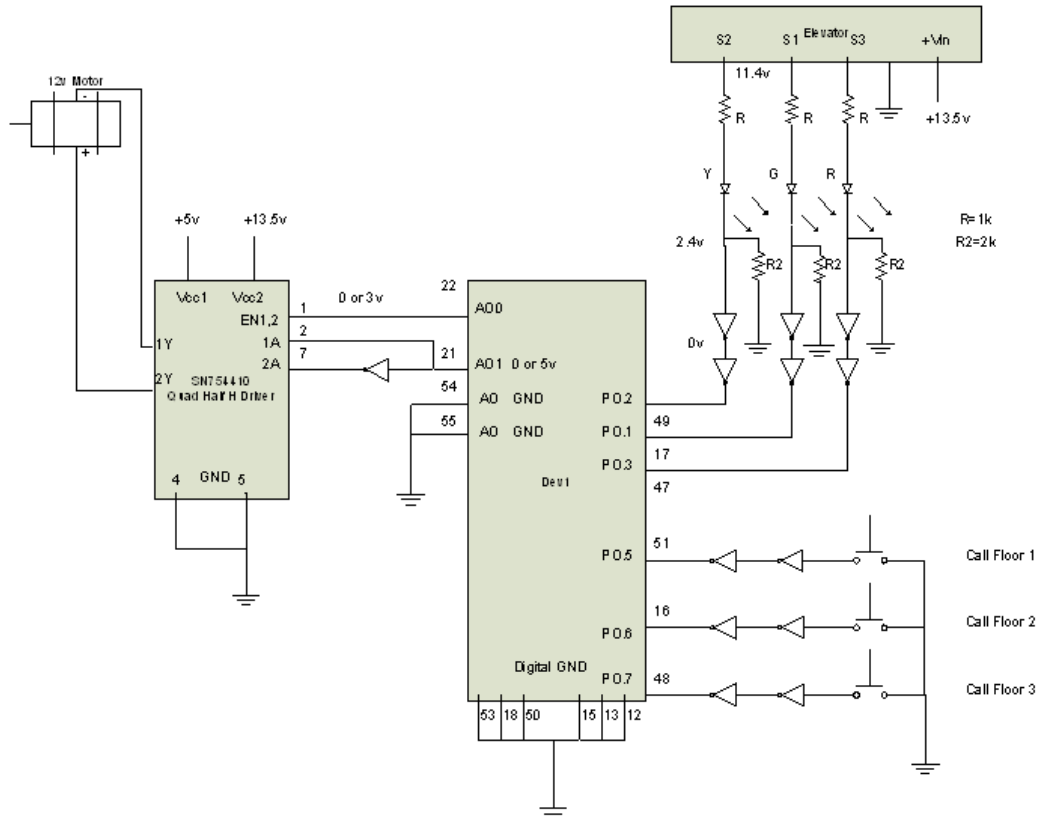


Figure 3. Example of a student team's schematic.

## Project Assessment

Student comments about the project were mixed. Some students commented, “The idea of being able to create something that works, that people use every day is a great feeling”, and “The information gained when interfacing hardware to software was vital to learn and will be helpful later on not only in this course, but also in the workforce.” Other comments indicated that students were uncertain about how to begin and that the lab was very difficult with students putting in hours of time.

At the end of the semester, course objective surveys were completed by the students. One objective was that students can design and implement an elevator control system, and they were asked to rate their level of agreement with this statement (5-point scale from strongly disagree to strongly agree). The results indicated that 100% of the students either agreed or strongly agreed with this objective.

## ABET Criteria Assessment

This project can be used for the assessment of ABET criteria<sup>3</sup>. Based upon criterion 3 of the general criteria, this project can be used to demonstrate that students have an ability to apply creativity in the design of systems, components, or processes (part d). At a secondary level, this project can also be used to assess the following criteria.

- An ability to conduct, analyze, and interpret experiments, and apply experimental results to improve processes. (part c)
- An ability to function effectively on teams. (part e)
- An ability to identify, analyze and solve technical problems. (part f)
- An ability to communicate effectively. (part g)
- A commitment to quality, timeliness, and continuous improvement. (part k)

Based upon program specific criteria for ECET programs, this project can also be used to assess the following outcomes:

- Demonstrate knowledge and hands-on competence in the application of computer programming and analog and digital electronics to the building, testing, operation, and maintenance of computer systems.
- Demonstrate an ability to analyze, design, and implement hardware and software computer systems and instrumentation systems.

## **Conclusions**

For applications with slow response characteristics, such as this elevator control system project, utilization of a PC-based data acquisition system with LabVIEW provided an effective alternative to a PLC-based control system. Most of the student teams were able to complete all of the engineering requirements. However, less than ½ of the teams submitted all of their work on time. Student comments about the project were mixed, but 100% of the students either agreed or strongly agreed with being able to design and implement an elevator control system. Since this is the first time the project was used in the course, additional student feedback will need to be assessed to determine the overall effectiveness of the project, while considering the overall scope of the project and the project completion length.

Additionally, this project effectively integrates both hardware and software design concepts covered from many prerequisite courses. The project can be used to assess both ABET general criteria and program-specific ECET outcomes.

## **Recommendations**

Based upon the student comments, it is recommended that more time be placed on covering state machines during lecture. Students need to be given homework problems where they design state machines for simple applications. This needs to be completed prior to the start of the lab project.

Since the scope of this project was sufficient to require 3 weeks to complete, it is recommended that students demonstrate sufficient progress on a portion of their work before the deadline. For this lab, students were required to demonstrate successful control of the elevator using software pushbuttons (UP, DOWN) after 2 weeks. This helped the students to properly manage their time.

It is recommended that students purchase their own DAQ card. National Instruments provides a student data acquisition kit that contains a USB DAQ card along with the student version of

LabVIEW<sup>4</sup>. There are only 2 kits offered, and they differ in the specifications for analog input operations. The kit that contains the USB-6008 is recommended, since it is very cost-effective and provides sufficient resolution and sample rate. It is also important for students to take proper precaution to not damage the ports on the DAQ cards. It is recommended that they should use TTL inverters on digital I/O ports.

Although not needed for this design, students should be aware that there are real-time data acquisition cards available for time-critical control applications. National Instruments has also developed programmable automation controllers which are similar to PLCs with PC functionality<sup>5</sup>.

## **Acknowledgment**

I would like to thank Roger Kuntz, an instructor in our Electrical and Computer Engineering Technology program, for providing information regarding the requirements for the PLC-based elevator simulator lab completed by sophomore students.

## **Bibliography**

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