Center for Technology and Innovation Spindle Drill Controller

Final Design Report

Watson Capstone Project No. WCP04

Sponsor: IEEE, Binghamton Section

Alex Marcus, ME
Ian Doughty, ISE
Jared Snapp, EE
Lu Yang, CoE
Wyatt Lendle, CoE

Faculty Advisor: Jack Maynard
External Advisor: Art Law, CT&I.

April 29, 2016
Revision: 1

Submitted in partial fulfillment of the requirements of ME 493/EECE 487
in the Spring Semester of 2016.
Thomas J. Watson School of Engineering and Applied Science
State University of New York at Binghamton

Executive Summary

The Center for Technology and Innovation (CT&I) in Binghamton NY, came into possession of a spindle drill, which when operational, was used to fabricate printed circuit boards by the hundreds. These PCB's were very complex, and the drill worked with extreme precision. This drill, which was manufactured in 1999, has been out of use for at least 6 years and was obtained from an auction of obsolete equipment. This drill is now considered vintage due to the newer drilling technologies that have been developed in the past 10 years. CT&I has given full use of their facilities, staff, and equipment to this WCP team so we can begin to research this drill and assess its functionality. This is a 2 year project, and this year our success will be measured on creating both a Theory of Operations manual and a Proof of Concept Controller for the drill provided. The operations manual and the controller will be used by next year's team to aid them in their goal of creating a user friendly game that will be on exhibit at CT&I. The main component that this team has designed is the controller for the drill motors. The controller moves the drill in the X and Y directions and also has the ability to change the drill's speed from slow to fast. Our team will be reimbursed for all costs spent on the drill by the Binghamton section of IEEE, up to a total of $500. Next year will see another WCP team further our controller and turn it into an interactive exhibit.

Table of Contents

List of Tables and Figures

1. Problem Definition

It is important for children to learn about technology at a young age to facilitate technological advances in the future. The Center for Technology and Innovation (CT&I) in Binghamton plans to promote this by preparing a museum in which all of the local technology of the area can be showcased. The exhibits will be interactive so visitors will be able to see this technology in action. One of the planned exhibits involves the use of a high precision Spindle Drill to make interactive games and demonstrations.

1.1 Scope

CT&I has recently acquired two vintage Spindle Drills manufactured by Electro Scientific Industries, Incorporated, and originally used by I3. The Spindle Drills were used to drill very small holes with extreme precision in Printed Circuit Boards (PCBs). The drills can move in the X-Y directions as well as the Z direction and can change drill bits. The drills were stored in poor conditions and have not been calibrated or undergone the suggested weekly and monthly maintenance. Also, in the original salvaging of the drill, all of the tubing and wiring had been cut, separating the pressure gauges and controller chassis from the Spindle Drill. The Spindle Drill parts and manuals are described in Table 1.

The goal of CT&I is to use these drills to create a museum exhibit that will teach children about technology in the Southern Tier. To achieve this goal our WCP group must design a Spindle Drill Controller to control a critical subset of the Spindle Drill functions. Then next year another group will use the Controller to develop demonstrational games suitable for a museum setting.

Figure 1: One of the Spindle Drills acquired by CT&I

Table 1: Provided Spindle Drill parts and manuals

Part	Description
2 Spindle Drills	The body of the drill including all motors and the surface upon which the circuit boards are mounted
2 Spindle Drill Stands	Large, heavy granite stands upon which the Spindle Drills sit
Controller Chassis	Chassis that house the Spindle Drill controllers for the X-Y motors as well as a power source for the Drills
Pressure Regulator	5 pressure gauges along with many valves that control the pneumatics of the Spindle Drill
Dynamotion and ESI 100MD Maintenance Manuals	Two manuals which illustrate the monthly and weekly maintenance that the Spindle Drills should undergo

1.2 Technical Review

The Spindle Drills acquired by CT&I were used to manufacture extremely complex Printed Circuit Boards. The Spindle Drill drills holes are drilled in the PCB so copper leads can be inserted, which create electrical connections between the various layers of the board. The Spindle Drill can drill 40,000 holes in a single circuit board that can have up to 40 layers. Each hole requires 4 "hits" from the Spindle Drill, which leads to over 100,000 hits in some PCBs. Some of the holes have to be as small as half the length of the thickness of a human hair. It is extremely important for the holes to be accurate, especially in large-scale manufacturing. If one hole is drilled in the wrong position during manufacturing, it could lead to a large amount of non-functioning PCBs, and ultimately a significant loss of time and profits.

Due to the density of electrical components on each board and the exactness of those components, the Spindle Drill must be able to drill with incredible precision. The accuracy required by the Spindle Drill is far beyond the capabilities of a human, so a computer operates the drill. For each type of PCB a different program is loaded to tell the drill where to drill the holes. The Spindle Drill also has various components that all have to work together in order for the Drill to function correctly.

Perhaps the most important are the X-Y motors, which control the majority of the motion of the drill. The Drill moves on a rail that tracks how far in the X direction it has moved, while the base moves in the Y direction. Because of these 2 separate motors, the drill can operate in the X and Y plane simultaneously, which decreases PCB production time significantly. The Drill can also move in the Z direction and is controlled by a linear motor. Air is fed, at regulated pressures, through various tubes to control other functions of the Drill. These pneumatics are used to keep the PCBs in place while the drilling occurs. The Drill also has a cooling system to counter the heat generation caused by the rapid rotation of the drill axis. The cooling system uses a mixture of glycol and water as the coolant. Figure 2 illustrates how each system in the Drill interact with each other.

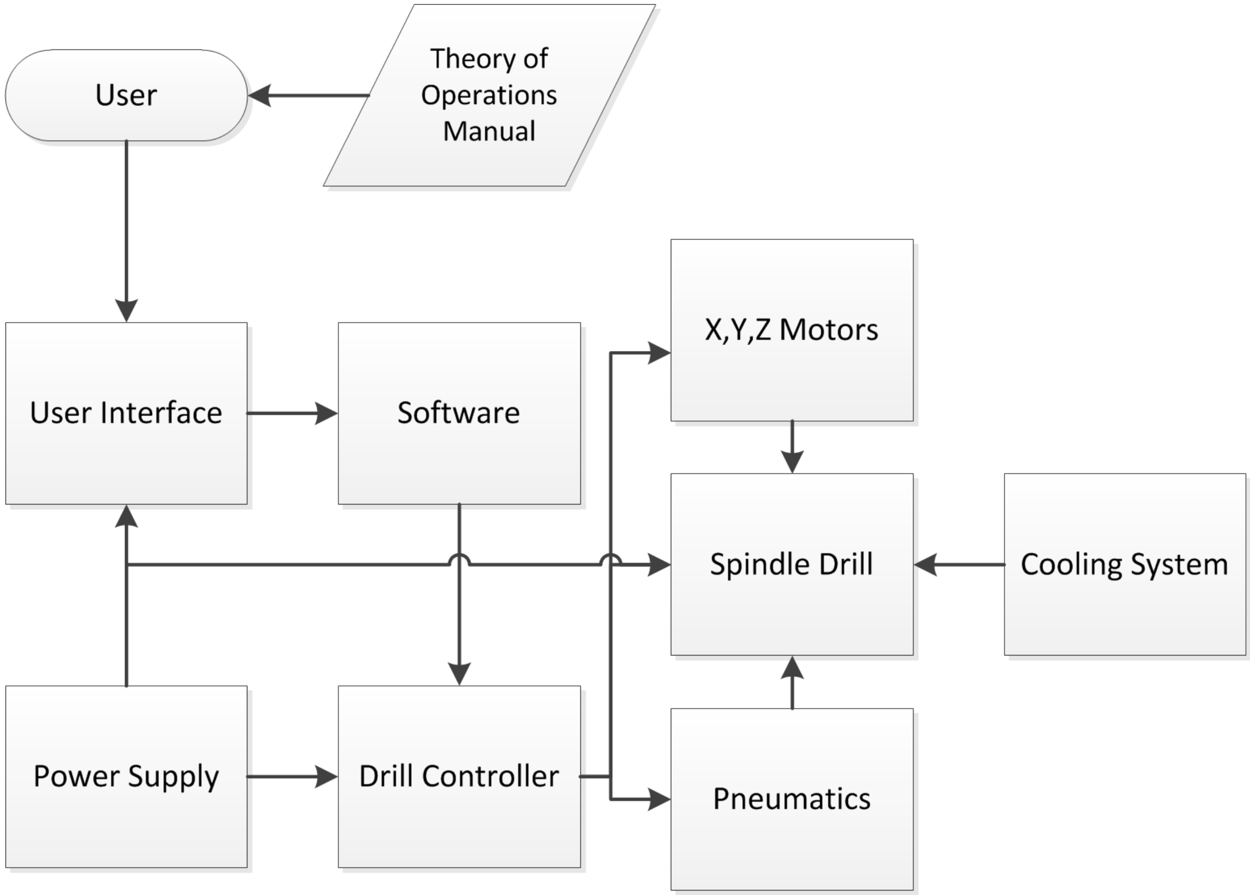


Figure 2: Spindle Drill System diagram

1.3 Design Requirements

There are various requirements that have an influence on the success of the rehabilitation of the Spindle Drill. It is important to keep in mind that another WCP team is going to continue working on the Drill next year to create interactive demonstrations and games, so a majority of the requirements have to do with gaining a firm understanding of the Drill and creating in depth documentation on it. See Appendix B: Project Requirements for a complete list of requirements.

One of the most important requirements (WCP04-R-01) given by the client, CT&I, states that all of the Spindle Drill capabilities and interfaces shall be documented in a Theory of Operations manual. This manual shall include a detailed description of all of the Spindle Drill functions so the the next WCP team will be able to understand all they need to know to develop the demonstrations. The next requirement (WCP04-R-02), also given by CT&I, states that to test the correctness of the Theory of Operations manual, a Proof of Concept Controller shall be developed. This Controller shall demonstrate that the essential Spindle Drill capabilities function as described in the Theory of Operations manual.

Another major requirement provided by CT&I (WCP04-R-04) describes the software that shall be developed in order to facilitate user-drill interactions. A simple software package shall be designed so that the Spindle Drill functions can be tested and the Theory of Operations manual can be verified.

The next important requirement was provided by our WCP team. Requirement WCP04-R-05 states that our team shall fully research and understand the Spindle Drill power, controller and pneumatics. These the attributes that are essential to the functioning of the Drill. It is also important to gain an understanding of these aspects of the Spindle Drill in order to create the Theory of Operations manual. Another requirement created by our team (WCP04-R-08) explains the controller that has to be designed. The controller must be able to move the Spindle Drill in the X-Y directions. The X-Y movement of the Spindle Drill is essential for the completion of this project next year.

One more requirement that is important for the completion of this project is WCP04-R-09 which describes the evaluation of the provided controller chassis. When CT&I acquired the Spindle Drills they also received the controller chassis that originally controlled the drill. Our WCP team shall evaluate this controller chassis to see if it is still capable of controlling the Spindle Drill and if a new controller needs to be designed.

2. Design Description

2.1 Overview

The spindle drills mechanical or moving parts have already been built and assembled. Our main purpose is to create a control system to send and receive signals to the X-Y motors, allowing user control of the drill's direction and speed. We used an Arduino platform to achieve this. The Arduino receives input from a 5 button controller and based on the signal received, it outputs a 3.3V signal to our H-Bridge that then moves the drill in the specified direction. Figure 3 shows an overview of how the entire system worked when fully functional.

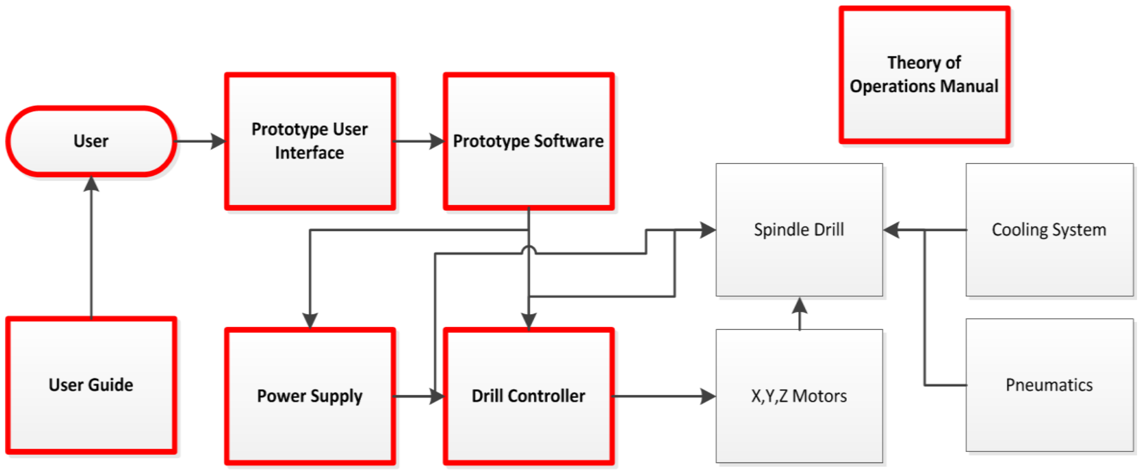


Figure 3: System Diagram

2.2 Detailed Design Description

The controller is broken into four main components. The first being the Arduino micro controller which is the brain of the device. The Arduino sends the motor control signal to the H-bridge. The H-bridge allows the Arduino to control the high power coming from the power supply as the Arduino cannot interface with such high voltages and currents directly. An external power supply provides power for the motors which run at 12 volts and 6 amps. Figure 4 displays how our controller interacts with the different drill systems.

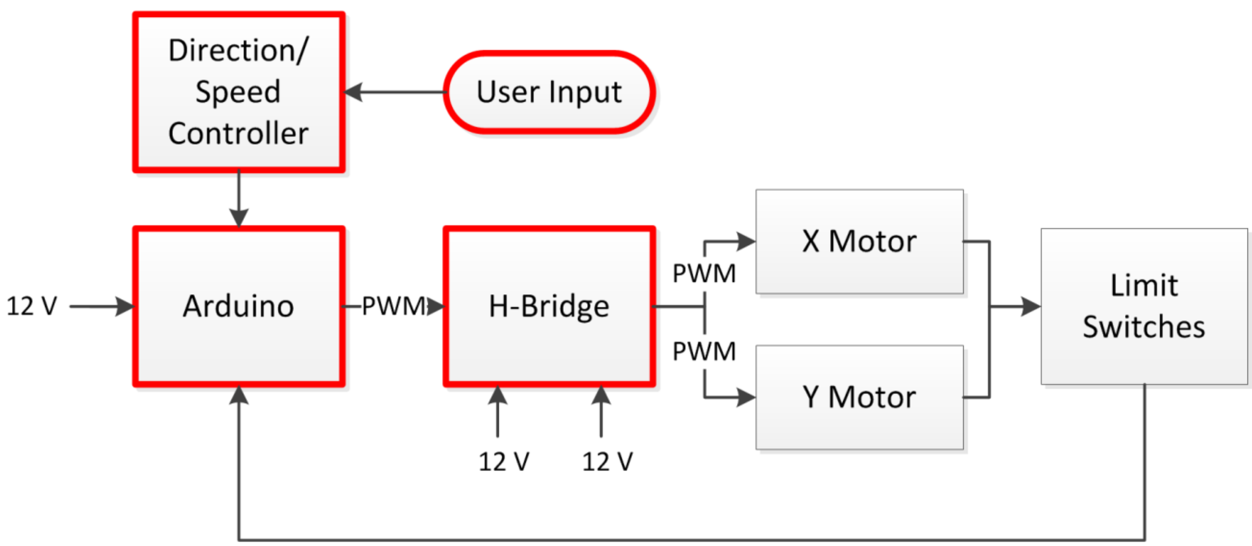


Figure 4: Controller Layout

The brain of the drill controller is an Arduino Uno board. The Arduino is powered by an ATMega328p chip made by Atmel. An advantage to using an Arduino over a microcontroller itself is that the Arduino has a lot of support and software libraries which will help with programming and debugging the chip. The Arduino also has a built in power supply regulator along with other useful features that we would otherwise have to design ourselves. The motors will not be operated very fast for safety reasons, this makes the 16Mhz clock speed on the Arduino more than adequate to control the motors. Figure 5 illustrates the layout of the Arduino connections.

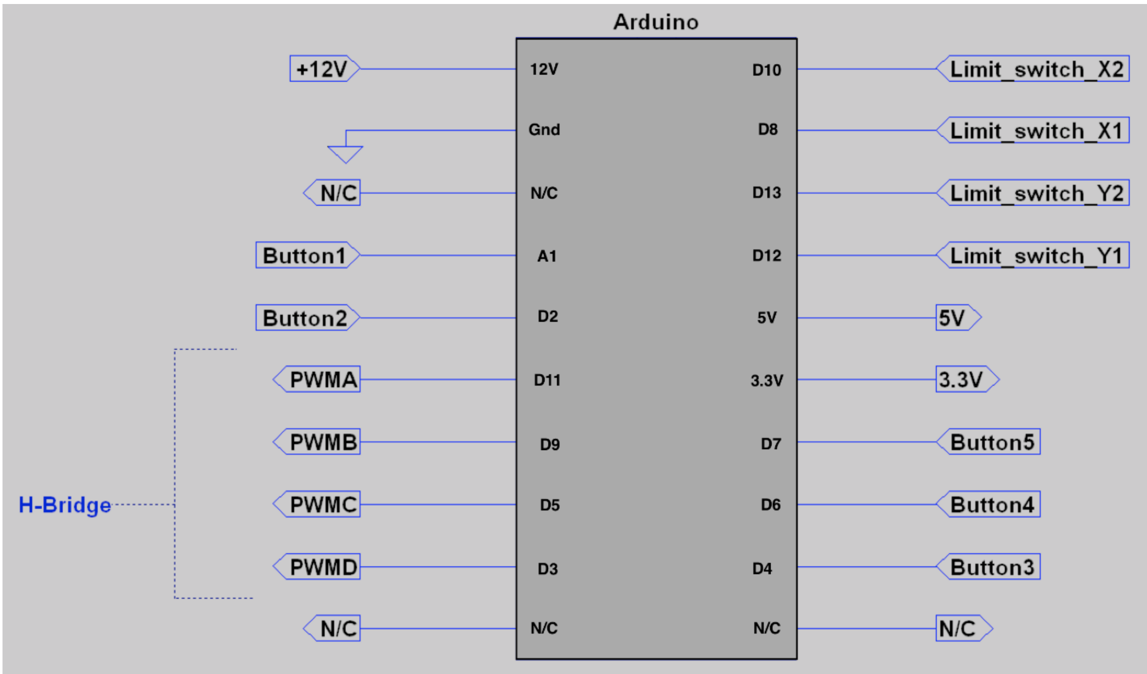


Figure 5: Arduino Connections Layout

All of the pins will be used as digital pins. Pins D11, D9, D5, and D3 are for controlling the h-bridges. D5 and D11 will be the actual pulse modulated signal that will control the speed and direction of the motors. The four buttons (A1, D2, D4, D6) will be part of the user interface, and will allow the user to control the direction in which the motor moves. D7 will allow the user to alternate between 2 duty cycles, one that makes the drill go near top speed and the other that will make the drill go at half speed. Figure 6 shows the schematic for the user interface circuit. The circuit consists of five buttons connected to pull-down resistors that are then read by the Arduino. The 5 volts will be supplied from the Arduino.

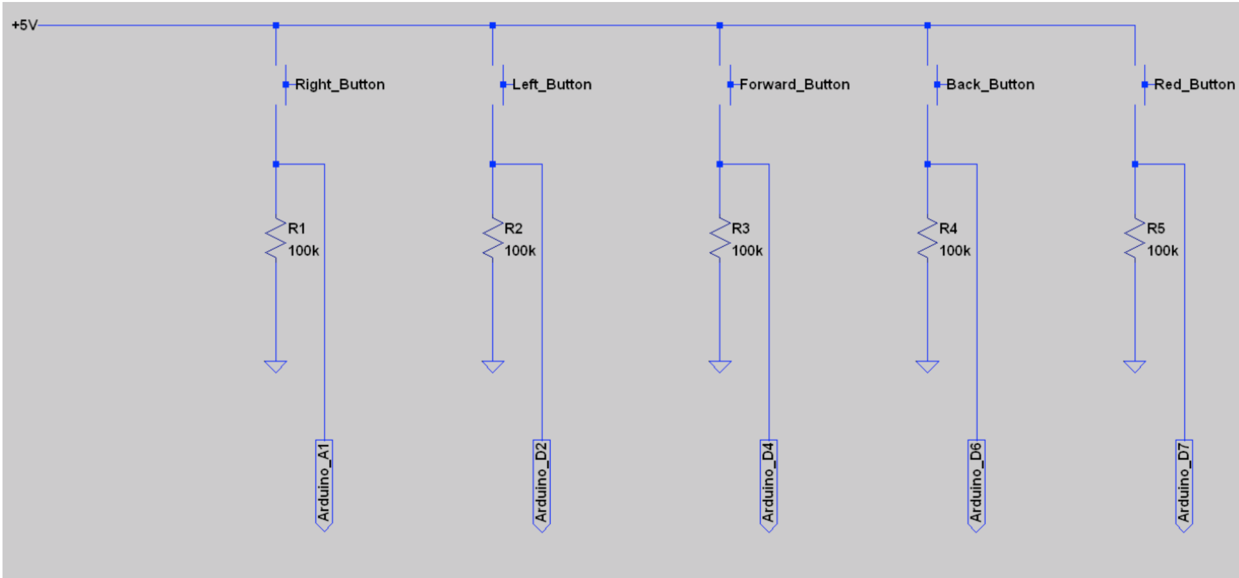


Figure 6: User Interface Layout

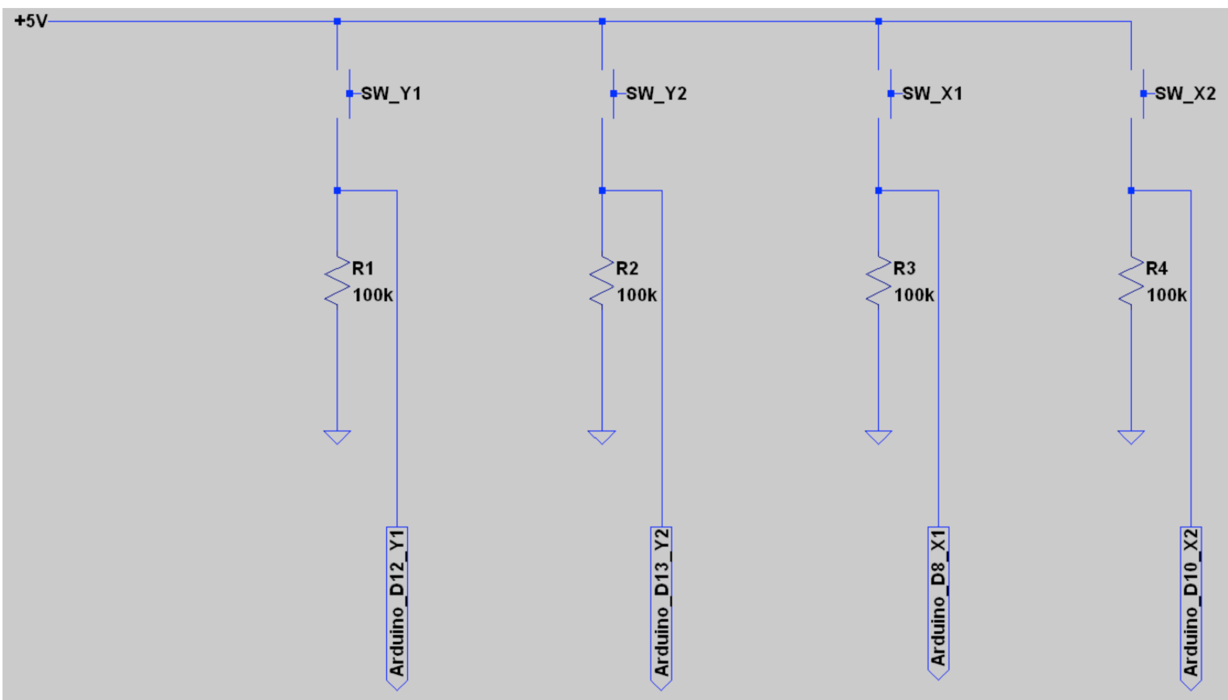


Figure 7: Limit Switches Schematic

The Arduino will receive feedback from the sensors on the drill on pins D12, D13, D8, and D10. Figure 7 shows the circuit for limit switches that signal when the drill is at its farthest limit on the X or Y axis. The drill will depress one of the switches whenever it moves all the way over to one side on either the X or Y axis. Upon being pressed, the limit switch will cease user input and send the drill in the opposite direction to the middle of its track. The Arduino will continuously monitor these sensors to make sure the drill operates safely.

The Arduino will first wait for an input from our button controller. This controller has 5 buttons that are each connected directly to an Arduino pin. 4 of them will serve as directional keys for the drill (2 for each motor), and the 5th will cause the drill to alternate from a 50% to a 98% duty cycle. This change in duty cycles will cause the drill to be able to alternate from a low to a high speed. Due to current/ software limits, the drill can't move the X & Y motors simultaneously. However, given that the purpose of this controller is to demonstrate the functionality of the drill this is not a problem at all. Once the desired motor is selected, the Arduino will power the motor through an H-bridge.

An H-bridge is a chip comprised of switches used to control motors. The H-bridge we will be using will take a 3.3-volt signal from the Arduino to switch on the 12 volts, from the power supply, to the motors. This signal can then be pulse modulated at up to 500 Hz to adjust the speed at which the motors move. The H-bridge itself requires 12 volts to power the various controls and features, which will come from the same power supply.

8.2.1 Full Bridge Mode Operation

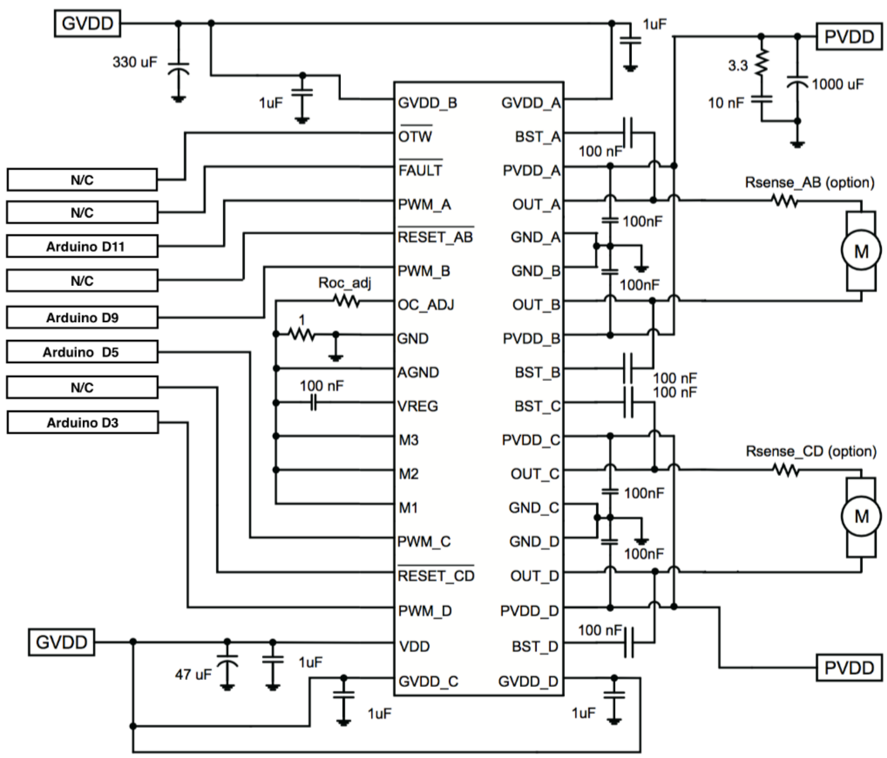


Figure 8. Application Diagram Example for Full Bridge Mode Operation Schematic

Figure 8: DRV8432 H-Bridge Schematic

The H-bridge circuit is from its datasheet for the full bridge mode configuration. The chip (a Texas Instruments DRV8432) itself consists of two H-bridges, both being able to operate at a maximum constant current of 7 amps. Since for our design the drill will only be operating at 12 volts, the current will never exceed 4 amps. Also by only moving 1 motor at a time via the full bridge mode configuration, we are never in danger of exceeding the 7-amp threshold.

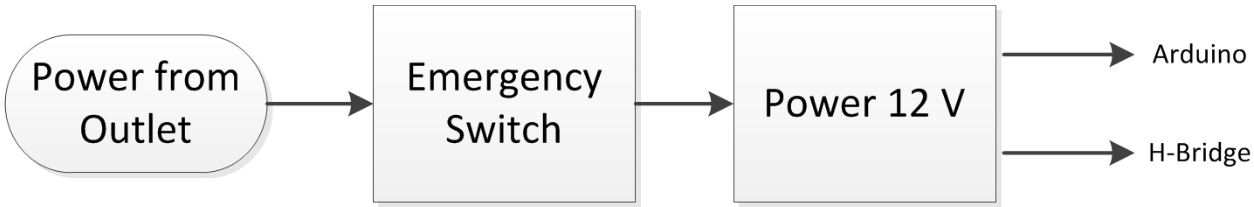


Figure 9: Emergency Switch Schematic

An external power supply was provided to supply power to the motors. The motors in our system will only require 12 volts at 3.5 amps of typical current. The maximum for the motors is 90 volts and 28 amps of current. Above is shown a diagram of the power supply connections. The mains power will first run through an emergency shutoff switch. This enables the power to be shut off entirely in case of equipment failure or danger to people. Next it will run to the power supply which will convert the AC power from the wall to DC power. A 12-volt power supply will be all that is needed to power the low power components of the controller as well as supply voltage to the motors. The Arduino, H-bridge, and motors will all be powered by this power supply.

2.3 Use

Our proof of concept controller will be used to demonstrate the movement of the drill in the X and Y directions. This will show that the X and Y drill motors are still operable and that the documentation on the drills functionality is correct. This design will also be able to be expanded upon by future senior design students to create games or demonstrations. Please refer to Appendix C for diagrams on how our controller will function in the context of the entire drill.

3. Implementation

3.1

3.1.1 Theory of Operations Manual

Our Theory of Operations manual is being designed to illustrate all the different functions within the drill. It will also explain in detail how to operate the drill using our created Proof of Concept Controller. This document will be shown to both members of CT&I and industry drill experts at CT&I. By showing this to them, we shall receive feedback on the correctness and accuracy of our manual, and fulfill several requirements in the process.

3.1.2 Proof of Concept Controller

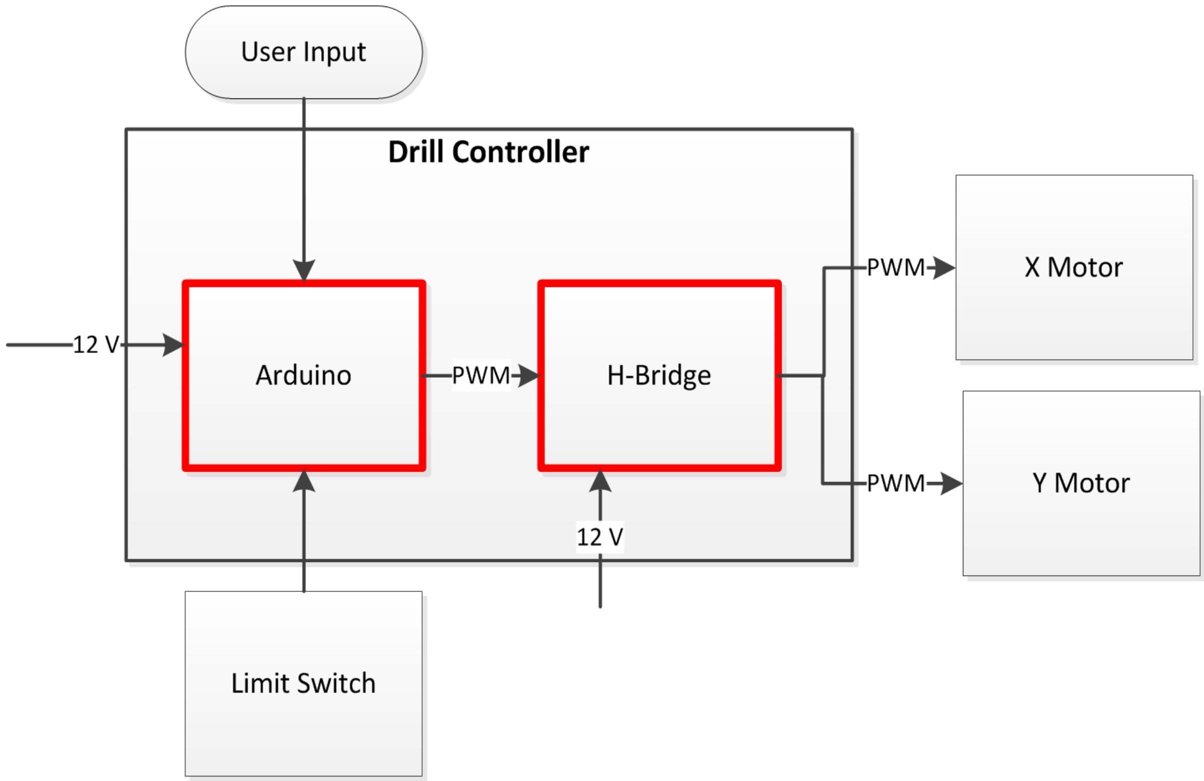


Figure 10: Proof of Concept Controller Schematic

Our Proof of Concept Controller is being designed to demonstrate both our knowledge of the drill and effectiveness of our Theory of Operations Manual as a viable resource. The Controller will be tested through several tests at CT&I, and will be demonstrated to the members of CT&I. The above diagram shows where it will be implemented within the Drill's system.

The purpose of the prototype was to verify that the research we did on the drill was accurate and provide CT&I with a controller for the drill. The prototype controls the movement of the spindle in the X direction, and the movement of the base in the Y direction. The prototype also allows the operator to adjust the speed of the drill's movement between fast and slow.

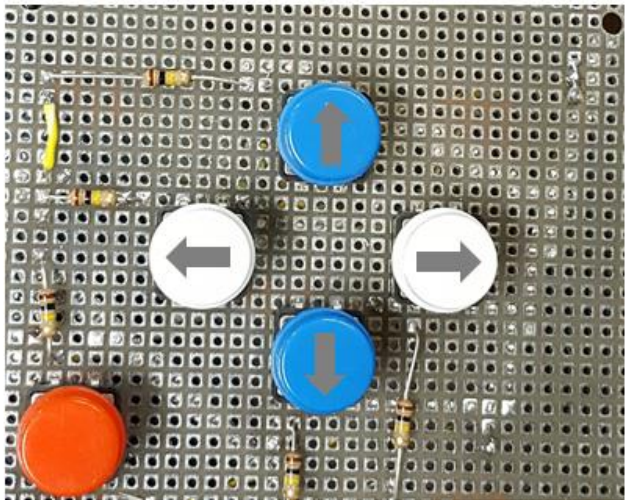


Figure 11: User interface

The prototype consists of a user interface, an Arduino, an H-bridge and a power source. Above is illustrated the user interface that consists of five buttons that control the speed and direction of the drill's movements. The white and blue buttons control the direction of the drill's movement. The red button toggles the speed of the drill between operating at 50% and 98% power. The amount of power sent to the drill is directly related to the speed.

The Arduino reads the input from the user interface and outputs the appropriate control signals to the H-bridge. The H-bridge then boosts the power of the control signals. Lastly, the more powerful control signals go to the motors. The direction and speed at which the motors spin is determined by the control signals. The Arduino also receives feedback from for limit switches. These switches inform the controller whenever it has moved to its limit in any of the four directions. In the case that the drill has moved to its limit, the controller then backs the spindle or base away from the edge to prevent damage to the drill.

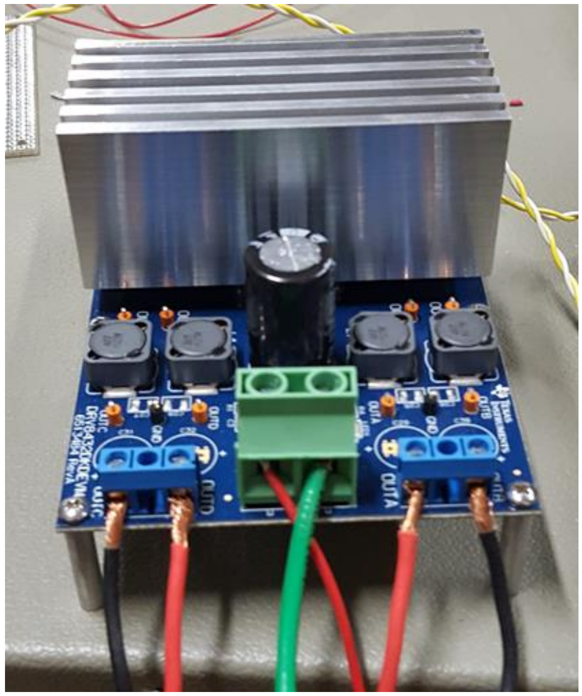


Figure 12: H-bridge

Pictured above is the H-bridge with the wires that run to the two separate motors. Originally we were going to have a relay circuit that would select which motor the H-bridge would be connected to. However, during testing we discovered that our H-bridge had enough power to control both motors simultaneously. This was because we originally thought the motors would require more power, which would require the H-bridge to be run in a high power mode. But we found out that the motors would operate on significantly lower power, which enabled us to use the H-bridge in dual mode.

At the launch of the project we met with industry experts (Duane Stanke and Chris Mann) from i3 who gave us an introductory explanation about the drill. The information was very helpful and gave us a good starting point and enabled us to come up with a plan for the project. During the project we also received a lot of feedback from the experienced engineers at CT&I about our designs and troubleshooting the controller. Bob Arnold, one of the engineers at CT&I, was able to give us mathematical equations for the mechanical time constant of the motors. This verified that what we were doing empirically was in fact accurate.

4. Evaluation

4.1 Overview

The testing we are undergoing mostly revolves around the function of the Spindle Drill's X and Y motor controls. After consulting with industry experts, Chris Mann and Duane Stanke from I3 along with several engineers at CT&I, we were able to conclude that several of our conditional requirements would not need to be fulfilled to accomplish our overarching goal of making a Proof of Concept Controller. Therefore, when tasked with writing requirements in the primitive stages of this project, some of them (Appendix B) became highly irrelevant to our goals. A main example of this is that the drills pneumatic and cooling systems are not required for what we are repurposing the drill for and will not require further testing.

We have a multitude of conditional requirements, most of which ended up not needing to be applied to our design. Because of this, several of the remaining ones have been expanded to incorporate more testing (Appendix B). Even with several removed, the main requirements presented to us will all be fulfilled, as seen in Appendix A. The vast majority of our testing revolves around testing the duty cycles and frequencies we shall be sending to the drill motors in order to ascertain a functional range in which it can operate. These shall be tested by slowly incrementing the duty cycle until the drill can move at an adequate speed for the user. Before this can be tested, another major test we must undergo is testing our failsafes. Getting the limit switches on the drill to work and integrating them into our system is vital to getting our controller finished. In order to test this, the drill will be moving at the lowest possible speed and the limit switches will be activated to test that the drill ceases operation. Beyond the limit switches, we will test an emergency stop button to shut off power to all systems. Finally we shall demonstrate the effectiveness of our Theory of Operations manual by having it approved by industry experts.

4.2 Testing and Results

Table 2: Requirement Tests

Test	Requirement(s)
WCP04-T-01	WCP04-R-01, WCP04-R-05, WCP04-R-06 WCP04-R-07,WCP04-R-10, WCP04-R-11, WCP04-R-13 WCP04-R-15, WCP04-R-16
WCP04-T-02	WCP04-R-02,WCP04-R-03
WCP04-T-02a	WCP04-R-03,WCP04-R-08
WCP04-T-02b	WCP04-R-03, WCP04-R-08
WCP04-T02c	WCP04-R-03, WCP04-R-13
WCP04-T-03	WCP04-R-04
Not Applicable	WCP04-R-09,WCP04-R-12,WCP04-R-14

Requirement: WCP04-R-01
Allocated Test: WCP04-T-01

This requirement required us to document all drill capabilities and interfaces in a Theory of Operations manual. We did this by consulting both the I3 engineers and CT&I engineers (Duane Stanke, Chris Mann, Art Law, Bob Lusch, and Bob Arnold) as well as referencing old handbooks provided for our drill. As the test states we then demonstrated the correctness of our Manual by demonstrating how it applied to our drill to members of CT&I. They verified that our Manual did in fact adequately document the drill and it's functions.

Requirement: WCP04-R-02
Allocated Test: WCP04-T-02

This requirement was to show the correctness of the Theory of Operations Manual by developing a Proof of Concept Controller to move the drill in the x and y axes. We were able to construct the Proof of Concept Controller and tested it in front of CT&I employees by demonstrating the capabilities of the drill in all four directions, and at different speeds. The drill's successful capabilities demonstrated that the Theory of Operations Manual was correct.

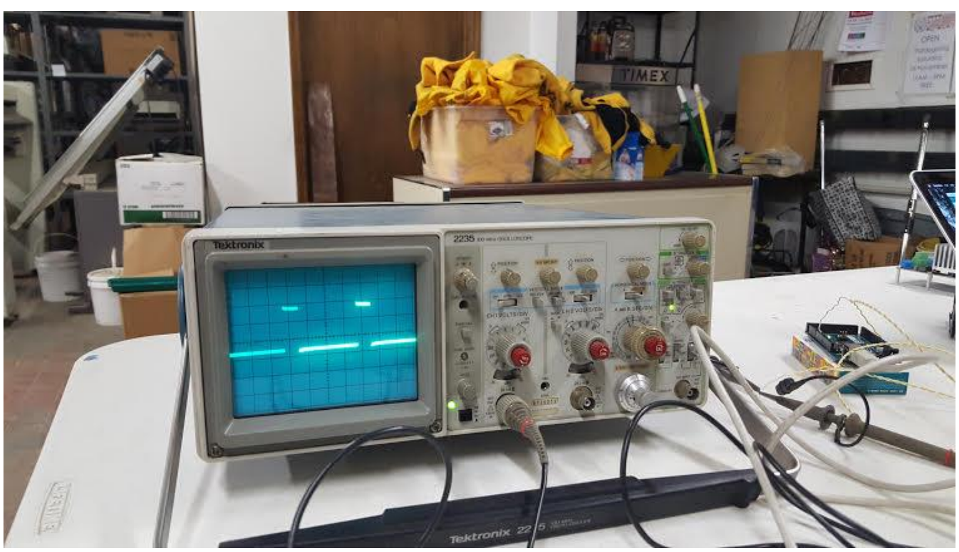


Figure 13:Oscilloscope readings of our generated PWM waves

Requirement: WCP04-R-03
Allocated Test: WCP04-T-02

This requirement required us to use our Proof of Concept Controller to show the correctness of our Theory of Operations Manual. We tested this by following the WCP04-T-02a-c test that had use upload our code to our Arduino, then demonstrate the full functionality of our controller to CT&I members. By strictly following the test, the Theory of Operations Manual, and by observing the current and voltage present on the motors, we were able to prove that our Theory of Operations Manual was correct via our Proof of Concept Controller.

Requirement: WCP04-R-04
Allocated Test: WCP04-T-03

To meet this requirement we presented the members of CT&I with a concept for a software package that detailed how next year's team would be able to use the existing code and controller as long as implement it into a game. The concept and ideas that we presented to the members of CT&I are outlined in Appendix __. The members of CT&I have reviewed our presented concept and will decide which will be implemented in the future. We also went through our existing code with them as outlined in WCP04-T-03 and explained how it works. The code can be found in Appendix __

Requirement: WCP04-R-05
Allocated Test: WCP04-T-01

This requirement stated that we must develop an adequate understanding of the drill's power, cooling, and pneumatic systems. This was done by many hours of research that entailed looking through old documents on the drill, finding information online, emailing engineers who worked on drills like ours, and even by emailing the original manufacturer of the drill. We tested this knowledge by placing it into our Theory of Operations Manual, and by following the WCP04-T-01 procedure we were able to get verification from CT&I that our understanding of these systems was sufficient.

Requirement: WCP04-R-06
Allocated Test: WCP04-T-01

For this requirement we needed to show our understanding of the cooling system and how it functions during operation of the drill. Through our investigation we came to the conclusion that the cooling system would not be necessary for movement in the x and y axes. The information of the cooling system's functions and parts are provided in the Theory of Operations Manual which has been tested and proved to be correct via WCP04-T-01.

Requirement: WCP04-R-07
Allocated Test: WCP04-T-01

To fulfill this requirement we needed to figure out how each system of the drill interacted with each other when the drill was fully operational. By researching we were able to document all of this information inside of our Theory of Operations Manual and by following the guidelines within WCP04-T-01 we received approval and confirmation that our analysis was in fact correct.

Requirement: WCP04-R-08
Allocated Test: WCP04-T-02b

In order to meet this requirement we had to show that the drill moved in both the x and y directions To do this we used test WCP04-T-02b, which required us to press each button on the directional pad and observe the results after each button was pressed. For the four directions the drill was able to move successfully.

Requirement: WCP04-R-09
Allocated Test: Not Applicable

This requirement revolved around testing the provided controller chassis that came with the drill to determine whether or not it had the capability to control the Spindle Drill functions. Through our preliminary observations we realized that not only did the chassis not have the ability to control the Spindle Drill functions, it was a completely defunct piece of hardware that would have no use at all in our project. Because of this there were no further tests we could conduct that would yield useful results.

Requirement: WCP04-R-10
Allocated Test: WCP04-T-01

To fulfill this requirement, we needed to understand how the cooling system works, and what systems it applied to. This information was researched and obtained and then finally placed inside our Theory of Operations Manual, where through WCP04-T-01 we demonstrated this knowledge to CT&I where they then were satisfied by our understanding.

Requirement: WCP04-R-11
Allocated Test: WCP04-T-01

This requirement was met by outlining in detailing the which coolant was typically used in the drill's cooling system. This information was provided in the Theory of Operations Manual and the correctness of this information was verified by test WCP04-T-01.

Requirement: WCP04-R-12
Allocated Test: Not Applicable

Implementing the cooling system into our design was the main task of this requirement. However after we discovered that in order to operate the X and Y motors of the drill, as our controller does, there is no need to use the cooling system. It is for this reason that we did not utilize it, and therefore there were no tests conducted upon it.

Requirement: WCP04-R-13
Allocated Test: WCP04-T-02c

To fulfill this requirement we had to record the voltage levels that were being inputted into the different components that were listed in the requirement. In order to do this we used a multimeter to determine observe the voltage levels when testing the movement of the drill. When we would attempt to move the drill we would have the multimeter set up at either the Arduino, H-bridge power, H-bridge control, or the motor. We would test one component at a time and log each trial. Once the required levels were met we would move to test the next component in order to complete test WCP04-T-02c.

Requirement: WCP04-R-14
Allocated Test: Not Applicable

This requirement dictated that we test the provided controller chassis to determine its power regulating capabilities. The chassis was proven to be defunct and unusable in any fashion, which caused us to not be able to run any tests on it.

Requirement: WCP04-R-15
Allocated Test: WCP04-T-01

In order to satisfy this requirement, we had to figure out how many of the drills functions were controlled by pneumatics. This was done through research of the drill handbooks and through the internet. Once we found this data we placed it into our Theory of Operations Manual. We then followed WCP04-T-01 and demonstrated this knowledge to CT&I, who deemed our knowledge of pneumatics to be satisfactory.

Requirement: WCP04-R-16
Allocated Test: WCP04-T-01

This requirement was met by researching and gathering information on the drill's pneumatic system and conveying that information clearly in the Theory of Operations Manual. The detailed information that we provided on the pneumatics functions and parts was deemed correct by test, WCP04-T-01, by industry experts.

4.3 Assessment

4.3.1 Fully Compliant Solution

The final solution that was designed and implemented fulfills the requirements of this project. The final Proof of Concept Controller design allows the Spindle Drill to be moved by a user in the X-Y plane, continuously, which fulfills the controller requirements. The Theory of Operations Manual fully describes in detail all of the components and functions of the Spindle Drill.

4.3.2 Z-Axis Refurbishment

One major change we encountered regarded the cooling and pneumatics systems of the drill. Upon inspection and after meeting with the I3 industry experts, a decision was made with the CT&I engineers to not implement the pneumatics and cooling at this time. Although the pneumatics and cooling systems of the drill are critical systems when the drill is fully functioning, they do not play a part in the X-Y plane movement, which is the Spindle Drill function that our team concentrated on. Because of this change, the refurbishment of the Z-Axis motor was no longer a goal of our controller.

5. Budget and Schedule

For our project a funding limit of $500 was given to us from the IEEE Binghamton chapter for the entire year to cover any expenses. Since the drill was obtained from an auction it was at no cost for us and the only spending we expect to have is for different parts in order to restore the drill to be able to function for the exhibit. We originally planned to divide items we needed into three groups: control parts, drill parts and pneumatic parts. These would be parts to build the controller, parts needed to add to the drill to allow it to move and parts for the pneumatic system in order to get the pneumatics functioning. After the scope of our project altered our budget did as well. We were able to run tests on the drill to discover the motors were functioning and learned that the pneumatics weren't needed for movement in the x and y axis. This resulted in a change in our budget, eliminating the need for drill and pneumatic parts. Table 3 shows the breakdown of our original estimates, how much we've spent to the current date, and our estimate at completion.

Table 3 also shows that we've only spent money on controller parts, spending $325, with an estimate of $350 at the completion of the project. We had initially estimated $150 for controller parts however once the focus of the project was movement in the x and y axes we needed to increase the money used for the controller.

Table 3: Project Budget (Next Page)

Item	Original Estimate	Actual to date($)	Estimate to Completion ($)	Estimate at Completion ($)
Controller Parts	150	325.00	25.00	350
Drill Parts	100	0	0	0
Pneumatic Parts	100	0	0	0
Total	350	325.00	350	350

Budget	**500**		**Reserve**	**150**

Table 4 below gives the breakdown of the different parts we purchased to build the controller along with the price for each item. These nine parts totaled to $325.00 and the biggest component was the H-bridge, which cost more than our original estimate. The controller part purchases ended up being the only purchases we needed to make and we were able to stay way under budget in completing our goal.

Table 4: Controller Part Purchases

Part	**Price**
H-Bridge	168
Arduino Mega	50
Volt Converter	20
IDC	37
Ribbon Cable	8
Buttons	10
Emergency Stop Button	12
Breadboard	10
Wire Head	10
Price Total	325
Budget Remaining	175

The schedule for the year consisted of four different items. These items are Project Launch, Requirements Analysis, Venture Capitalist Presentation, Interim Presentation, Reverse

Engineering, Theory of Operations Manual and Proof of Concept Controller. Of these items all have been completed in time. The first four items were general requirements given to each team while the last three are specific to our project. Throughout this year we have been working on reverse engineering the drill in order to be able to create the Theory of Operations Manual. We decided not to take the drill apart because we do not want to further damage the Spindle Drill. The Theory of Operations Manual is also complete. The manual was a major aspect for the project and we worked on it both this semester and the previous one. While working on the Theory of Operations Manual, we also worked on developing our Proof of Concept Controller, the last item on the schedule list and the focus point of our project. The table below shows each of these items with their percent complete and the date that the item was completed.

Table 5: Project Schedule

Description	Percent Complete	Date Completed
Project Launch	100	September 9, 2015
Requirements Analysis	100	October 10, 2015
Venture Capitalist Presentation	100	March 18, 2016
Reverse Engineering	100	February 15, 2016
Theory Of Operations Manual	100	April 25, 2016
Proof of Concept Controller	100	April 27, 2016
Testing	100	April 18, 2016
Prototype Software	100	April 18, 2016
Prototype User Interface	100	April 27, 2016

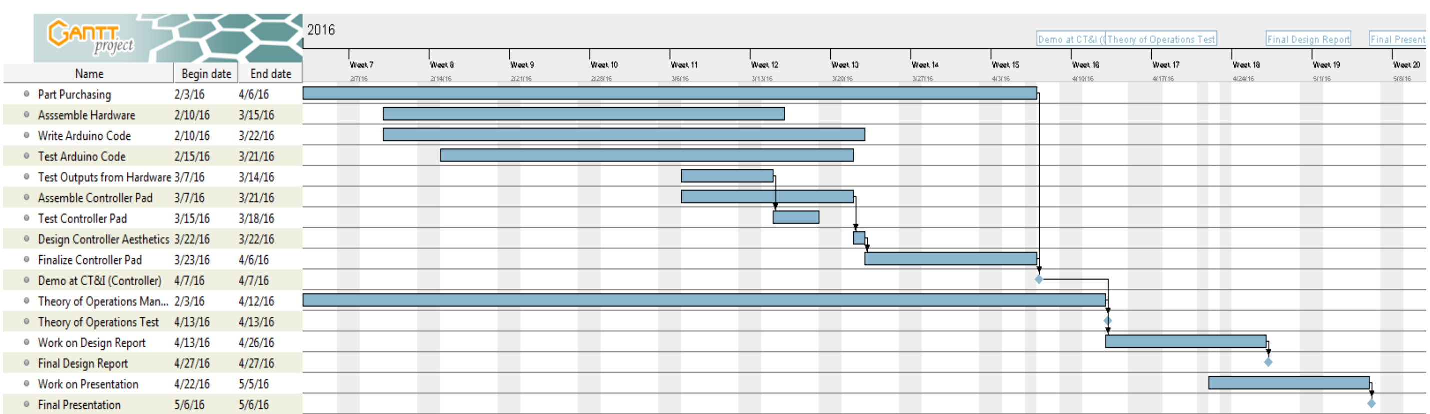


Figure 14: Gantt Chart

6. Future Plans

The Proof of Concept Controller we have now completely matches all of the requirements for this project. However in order for the drill to be used in a museum setting, further changes will have to be made by next year's WCP team. For example, they will need to purchase another H-Drive so they can move the drill in the X and Y plane simultaneously. Furthermore, research needs to be conducted into the Z motor in order for an adequate game to be played. Appendix E contains several suggestions for next year's team to consider when designing their exhibit.

References

[1] Watson Capstone Projects. (2015). *Design Report Guidelines* [Online]. Available FTP: https://drive.google.com/a/binghamton.edu/folderview?id=0B_iXL_NWiSsgbW5fOFJDdGdNczA&usp=sharing&tid=0B60cSzRIKL-5QnF6VGtrWWEtVzg

[2]100MD Series Maintenance Manual, 3rd ed., ESI-Advanced Packaging Products Division., Santa Ana, CA, 1998, pp. 1–150.

[3]Dynamotion Series Maintenance Manual, 1st ed., Dynamotion., Unlisted, USA, 1993, pp. 1–200.

Appendix A: Project Proposal

Watson Capstone Projects
Project Proposal Form

Computer, Electrical, and Mechanical Engineering
2015-2016 Version

*Please complete the following to submit a project proposal for a multidisciplinary senior capstone project team. In order to be guaranteed consideration, submission should be received by **August 15st**. You will be notified when this form is received, and then again in early September to indicate whether or not the project has been approved.*

Please submit this form via email to watson.capstone@binghamton.edu, with an updated filename and email subject line.

1. **Project Title**
   Center for Technology and Innovation (CT&I) Spindle Drill Controller

2. **Organization Name and Address**
   IEEE Binghamton Section

3. **Contact Names, Phone, Email Address**
   a. **Sponsor Management Representative:**
      Daniel Sniezek
      desniezek@yahoo.com
   b. **Sponsor Technical Representative:**
      Tommy Lam
      tlam14@binghamton.edu
   c. **CT&I Engineering Advisor:**
      Arthur Law
      (607) 725-9306
      alaw@stny.rr.com

4. Project Description

CT&I has acquired an Electro Scientific Industries (ESI), Inc., Spindle Drill that is used for drilling holes with very high accuracy in Printed Circuit Boards (PCBs). The Spindle Drill can move in the X-Y direction and commanded to select and mount different size drill bits. This proposed project is a two year project to develop a Spindle Drill Controller to control the Spindle Drill (Year 1) and then to develop visitor interactive demonstrations/games using the Spindle Drill suitable for use in a museum setting (Year 2).

5. Project Requirements

These are the project design objectives and describe what the device/program shall do as well as other items such as operating environment, standards, etc. Use the word "shall" for hard requirements that must be met and the word "should" for requirements that are desirable but not absolutely necessary (stretch goals).

Requirements should be unambiguous, verifiable (testable), goal-oriented (desired goal, not how to achieve it), and realistic. Some areas to be considered are performance, functionality, economics, energy, environment (impact on earth resources), health and safety, reliability, maintainability, manufacturability, operationality (e.g. temperature, humidity), and usability. Please be as specific as possible. The project team will develop these requirements into a formal project requirements specification.

Pictures of the spindle drill is provided in the PowerPoint presentation embedded at the end of this proposal.

The spindle drill consists of:

1. DC Servo motors that move the drill in the X-Y direction over an area of approximately 20 x 20 inches.
2. Control of the drill in the Z direction through a magnetic solenoid.
3. Pneumatic control of the drill to select and insert a drill bit.
4. Control of fluid that is used to cool the drill. Whether the cooling fluid is required will depend on the kinds of demonstrations/games implemented.

This project is anticipated to be a two year project. The objective of Year 1 of the project (the subject of this proposal) is investigation, discovery, and demonstration on how to control the Spindle Drill.

2. Create a simplified spindle controller that shall demonstrate:
    a. Control the XYZ movement of the spindle drill
    b. Control of the spindle drill drilling functions

The objective of Year 2 (the subject of next year's proposal) of the project is development of a computer based Spindle Drill Controller and creation of visitor interactive demonstrations/games:

1. Create a computer based controller that is demonstrates increased capability and accuracy in the control of the XYZ movement of the spindle drill and drilling capabilities
2. Create a generalized control interface in software to make the development of demonstrations and games easier
3. Creation of demonstrations & games suitable for visitor interaction

The total project is divided into the following steps. At each step there will be a team discussion between WCP Team, CT&I, and Triple Cities Makerspace. At each step we will define the specific goals, technical challenges, specific requirements, and division of requirements between the WCP Team, CT&I, Triple Cities Makerspace.

Step 1 (Year 1): Investigation of the Spindle Drill

The WCP Team shall determine the required signals to operate the Spindle Drill. Operation of the Spindle Drill includes:

a. Movement of the Spindle Drill in the X-Y direction. Determine how fast and how accurate the Spindle Drill can be moved.
b. Movement of the Spindle Drill in the Z direction. Determine vertical limits and accuracy of the Spindle Drill.
c. Determine how limit sensors operate. The limit sensors limit the movement of the drill in the X-Y direction.
d. How to command the Spindle Drill to select and insert a drill bit.
e. Control of drilling operation
f. Determine the need for and operation of the cooling fluid

Results of the investigation and discovery shall be documented in a Theory of Operation document.

Step 2 (Year 1): Simplified Controller

The purpose of Step 2 is to demonstrate that the WCP Team has an understanding of how the Spindle Drill operates. Based on the results of Step 1 the WCP Team shall build a simplified controller that will move the Spindle Drill in the X-Y direction and up/down direction. The movement of the Spindle Drill shall be within the operational limits and be constrained by the limit sensors. The controller shall be able to control the drilling capability and bit selection of the Spindle Drill. The controller can be an integrated device or it can be multiple devices that each demonstrates control of one or subset of the Spindle Drill functions.

Step 3 (Year 2): Computer Based Spindle Drill Controller

The WCP Team shall build a computer based controller to operate the Spindle Drill. The computer based controller shall allow for more complex motions of the Spindle Drill. The Spindle Drill Controller is divided into two parts.

a. Develop computer software and electronics that shall control the Spindle Drill.

b. Develop a user interface that shall allow a visitor to control the Spindle Drill. The nature of the user interface can take many forms. Listed below are the types of input and use.

    a. Joystick input to drive the spindle in the X-Y direction.

    b. On a display allow the user to select "command blocks" that are linked together which command the Spindle Drill in the specified sequence of operations.

    c. Input text such as a name. The Spindle Drill will then drill or carve the text into metal or wood.

    d. Control of the Spindle Drill based on the output of an Xbox Kinect motion sensor

There shall be a clear divide between the software and electronics that drive the Spindle Drill and the user interface software so that multiple user interfaces can be implemented.

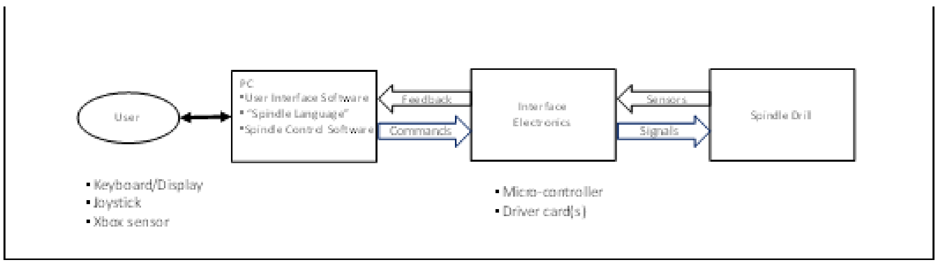
Step 4 (Year 2): Demonstrations/Games

The WCP Team shall propose demonstrations/games that shall be implemented on the Spindle Drill under the control of the computer controller. The selection of the demonstrations/games to be implemented shall be jointly made by the WCP Team, CT&I, and Triple Cities Makerspace. Examples of demonstrations/games are:

1. Etch-a-Sketch
2. Have the spindle drill push a ball through a maze
3. Carve simplified 3-D figures in wood or plastic
4. Drill/carve letters onto a slab of wood based on input by the visitor

6. Project Graphic

Please include a system diagram, flow chart, or mechanical layout drawing.



System Diagram Of The Final Year 2 Computer Based Spindle Drill Controller

7. Budget

Please provide the students' total budget amount for the project, along with estimates for any large ticket items as well as an amount for small items, prototyping, rework, and consumables (typically $50 to $100 per student). This budget may be refined during the project startup phase.

Our normal practice is for the students to make all purchases for their projects and be reimbursed by the university; we then invoice you at the end of the project. Please indicate if you desire an alternate arrangement.

It is anticipated that a budget of approximately $500 is sufficient to purchase the components and supplies for the Year 1 project. The components and supplies will be used to probe and experiment with the Spindle Drill and create the demonstration controller:

1. Prototyping boards
2. Wires
3. Connectors
4. Discrete components
5. Printed Circuit boards
6. Micro-controller such as an Arduino or chipKit

8. Deliverables and Meetings

Please be as specific as possible, especially considering user manuals and installation guides as project appropriate. Describe your expected meeting schedule and locations.

The resulting project system will be delivered to you, if you like, or the non-profit "client" organization, if applicable.

Deliverables for Year 1 project:
1. Theory of Spindle Drill operation
2. Simplified controller including all schematics, documentation, and (if applicable) software

Periodic meetings will be held at the Center for Technology & Innovation at 321 Water St, Binghamton NY. Meetings shall be weekly at the start of the project and transition to bi-weekly at a mutually agreed point in the project.

9. Recommended Team Composition (3-5 students)

Please indicate the desired number of students from each discipline. Note that occasionally Biomedical Engineering, Computer Science, or Systems Engineering students are also available.

Mechanical Engr: 1 Electrical Engr: 1-2 Computer Engr: 1-2

10. Citizenship Requirements (if any)

No requirement

11. Team Members (optional)

Indicate the names, emails, and major of student(s) (if any) that you request to be on your team. It is not guaranteed that these students will be on the team as their skills may be needed elsewhere.

Typically this field is left blank unless this project is student-initiated or a continuation of a working relationship you have with a student.

Appendix B: Requirements

ID #	Req. Description	Source of Req.	Acceptable Value Range	Qualification Method	Test ID #	Pass /Fail
WCP04-R-01	Document drill capabilities/interfaces in Theory of Operations Manual	Provided by Client	N/A	Demonstration	WCP04-T-01	Pass
WCP04-R-02	Use Proof of Concept Controller to demonstrate Theory of Operations Manual	Provided by Client	N/A	Demonstration	WCP04-T-02	Pass
WCP04-R-03	Proof of Concept Controller will have enough capability to show correctness of Theory of Op. Manual	Provided by Client	N/A	Demonstration	WCP04-T-02	Pass
WCP04-R-04	Provide a conceptual software package for user/Drill Controller interaction	Provided by Client	N/A	Demonstration	WCP04-T-03	Pass
WCP04-R-05	Develop understanding of all Spindle Drill controller, power, & pneumatics	Created by team	N/A	Analysis	WCP04-T-01	Pass
WCP04-R-06	Develop understanding of Spindle Drill cooling	Created by team	N/A	Analysis	WCP04-T-01	Pass

WCP04-R-07	Gain detailed knowledge of how each component of drill works together	Created by team	N/A	Analysis	WCP04-T-01	Pass
WCP04-R-08	Develop a controller that moves spindle drill on X-Y plane	Created by team	N/A	Test	WCP04-T-02b	Pass
WCP04-R-09	Test provided controller chassis to determine its ability to serve as spindle controller	Created by team	N/A	Test	N/A	N/A
WCP04-R-10	Develop understanding of how drill cooling system works/ what operations require it	Created by team	N/A	Analysis	WCP04-T-01	Pass
WCP04-R-11	Identify if necessary, what coolant will be needed	Created by team	N/A	Analysis	WCP04-T-01	Pass
WCP04-R-12	If cooling is required, use proper coolant for necessary operations	Created by team	N/A	Demonstr ation	N/A	N/A
WCP04-R-13	Identify optimal voltages for each component	Created by team	TBD	Test	WCP04-T-02c	Pass
WCP04-R-14	Test provided controller chassis to determine its ability to regulate drill power	Created by team	N/A	Test	N/A	N/A

WCP04-R-15	Identify to what extent drill operation is controlled by pneumatics	Created by team	N/A	Inspection	WCP04-T-01	Pass
WCP04-R-16	Develop understanding of how drill pneumatics system works/ what operations require it	Created by team	N/A	Analysis	WCP04-T-01	Pass

WCP04-R-01-04 : Sponsor Requirements

WCP04-R-01 We shall document the capabilities and interfaces in a Theory of Operations manual.

WCP04-R-02 We shall demonstrate the correctness of the Theory of Operations manual by developing a Proof of Concept Controller.

WCP04-R-03 The Proof of Concept Controller shall have just enough capability to demonstrate the correctness of the Theory of Operations manual.

WCP04-R-04 We shall provide a concept for a software package that will interface between the user and the Spindle Controller. The purpose of the software package is to facilitate the development of games and demonstrations. The concept for the software package shall be guided by input from CT&I as to the types of games and demonstrations desired and by input from our teams investigation of the Spindle Drill.

WCP04-R-05-07 : General Understanding and of the Spindle Drill Components

WCP04-R-05 As a team, we shall develop a good understanding of the Spindle Drill Controller, power and pneumatics.

WCP04-R-06 We should develop an understanding of the Spindle Drill cooling system provided that it is necessary to the operation of the Spindle Drill.

WCP04-R-07 We shall have detailed knowledge of how each component of the Spindle Drill should work with the others so that the Spindle Drill can function, as demonstrated in the Theory of Operations Manual.

WCP04-R-08-09 : Drill Controller

WCP04-R-08 We should develop a controller that will be able to move the Spindle Drill in the x and y directions.

WCP04-R-09 We shall test the provided controller chassis to determine if it has the capability to control the Spindle Drill functions. If the chassis proves unusable, we shall implement our own device controller.

WCP04-R-10-12 : Drill Cooling

WCP04-R-10 We shall develop a good understanding of how the Spindle Drill cooling system works, what drill operations it is required for.

WCP04-R-11 We should identify what coolant(s) is(are) used to cool the Spindle Drill.

WCP04-R-12 We should implement the cooling system using the identified coolant if cooling is required for the Spindle Drill operations that we plan on utilizing.

WCP04-R-13-14 : Drill Power

WCP04-R-13 We shall identify the different voltages required by each component to function.

WCP04-R-14 We shall test the provided controller chassis to determine if it has the capability to regulate power. If the provided power control chassis proves unusable, we shall implement our own power regulating device.

WCP04-R-15-16 : Drill Pneumatics

WCP04-R-15 We shall identify how much of the drill's operation is controlled by pneumatics.

WCP04-R-16 We shall develop a good understanding of how the Spindle Drill pneumatics work, what drill operations it is required for.

Appendix C: Test Procedures

Table 2: Requirement Tests

Test	Requirement(s)
WCP04-T-01	WCP04-R-01, WCP04-R-05, WCP04-R-06 WCP04-R-07,WCP04-R-10, WCP04-R-11, WCP04-R-13 WCP04-R-15, WCP04-R-16
WCP04-T-02	WCP04-R-02,WCP04-R-03
WCP04-T-02a	WCP04-R-03,WCP04-R-08
WCP04-T-02b	WCP04-R-03, WCP04-R-08
WCP04-T02c	WCP04-R-03, WCP04-R-13
WCP04-T-03	WCP04-R-04
Not Applicable	WCP04-R-09,WCP04-R-12,WCP04-R-14

WCP04-T-01

We will test the correctness of the Theory of Operations Manual. This will include testing the information about the operations and functions of the drill as it previously worked in an industry setting as well as its current functions for the museum exhibit.

Equipment:

1. Theory of Operations Manual
2. CT&I members
3. Spindle Drill (unplugged, for reference)
4. Industry Experts (i3 employees)

Procedure:

1. Meet with CT&I members and industry experts at CT&I with the spindle drill present.
2. Distribute copies of Theory of Operations Manual to all present members.
3. Describe each component of the Spindle Drill, detailing how it works and its relation to the overall function of the drill.
    a. X motor
    b. Y motor

c. Z motor
d. Cooling System
e. Pneumatics
f. Power supplied to different drill systems
g. Feedback System
h. Limit Switches
i. Tachometer
j. Spindle

4. Receive feedback for steps 3 a through j, from industry experts and CT&I members.
5. Determine if Theory of Operations Manual meets satisfactory correctness level based on feedback.

WCP04-T-02

We will test all aspects of our Proof of Concept Controller. This will include checking it's ability to control the drill, and making sure that it functions correctly in respect to the parameters of the drill described in the Theory of Operations Manual.

Table 6: Arduino Instructions

1- Connect Arduino to PC.
2- Install Arduino software from https://www.arduino.cc/en/Main/Software.
3- Open "YOUR_FILE_NAME".c using this .downloaded software.
4- Upload this code to the arduino by pressing the Upload Button on the top right of the program. (Shaped like an arrow)
5- Unplug Arduino from PC after waiting 5 seconds.
6- Connect Arduino to a 5-12V Power supply, your uploaded code should now run.

Equipment:

1. Proof of Concept Controller
2. Spindle Drill
3. Computer (arduino software)
4. Power Source
5. Theory of Operations Manual
6. Multimeter

7. Controller Pad

Procedure:

1. Plug in Power supply
2. Turn on 12V power source that is connected to H-bridge.
3. Turn on 48V power source connected to drill.
4. Follow Table 1.2 to upload controller configuration software (Controller.c).

WCP04-T-02a

Procedure:

1. 2On the controller pad press the right button, moving the drill to the right.
2. On the controller pad press the left button, moving the drill to the left.
3. On the controller pad press the button that changes PWM frequency to alter drill speed.
4. Observe if all buttons correctly functioned.

WCP04-T-02b

Procedure:

1. On the controller pad press the up button, moving the drill platform backwards (away from front of drill).
2. On the controller pad press the down button, moving the drill platform forward (towards front of drill).
3. On the controller pad press the button that changes PWM frequency to alter drill platform speed.
4. Observe if all buttons correctly functioned.

WCP04-T-02c

Procedure:

1. Using a multimeter, determine if 12V is being inputted into the Arduino.
2. Using a multimeter, determine if 12V is being inputted into the H-Bridge power.
3. Using a multimeter, determine if 3.3V is being inputted into the H-Bridge control.
4. Using a multimeter, make sure at least 8V is being outputted by the H-Bridge into the spindle drill.

WCP04-T-03

We shall present to CT&I a concept of a software package that they can observe, and ascertain if it will be a viable blueprint for next year’s team to follow.

Equipment:

1. PC
2. Arduino Software
3. Prototype Software
4. CT&I Members

Procedure:

1. Follow steps 2 and 3 from table 1.2 to display prototype.c software on PC.
2. Using code as a guide, run through each function within code and how it would help to create an immersive game.
3. While running through this code step by step, listen for feedback from CT&I members on if they think the prototype game being presented will suffice.
4. If CT&I members agree that the prototype software presented will be a good blueprint to follow for next year, send them the code for their own archives.

Appendix D: Arduino Code

```
//WCP04 Spindle Drill Controller Software



//spindle pins
  const int right_spindle_pin = 11;
  const int left_spindle_pin = 9;
  const int forward_base_pin = 5;
  const int backward_base_pin = 3;

  //user input buttons:
  const int right_button = A1;
  const int left_button = 2;
  const int forward_button = 4;
  const int back_button = 6;
  const int red_button = 7;

  //limit switches
  const int left_limit_switch = 8;
  const int right_limit_switch = 10;
  const int back_limit_switch = 12;
  const int forward_limit_switch = 13;

  int speed;


void setup() {

  //functions
  void move_spindle_left(int speed);
  void move_spindle_right(int speed);
  void move_base_backward(int speed);
  void move_base_forward(int speed);

  //initialize buttons
  pinMode(forward_button, INPUT);
  pinMode(back_button, INPUT);
  pinMode(right_button, INPUT);
  pinMode(left_button, INPUT);
  pinMode(red_button, INPUT);

  pinMode(13, OUTPUT); //onboard led

  //initialize switches
  pinMode(right_limit_switch , INPUT);
  pinMode(left_limit_switch , INPUT);
  pinMode(forward_limit_switch , INPUT);
  pinMode(back_limit_switch , INPUT);

  //initialize motor pins
  pinMode(right_spindle_pin, OUTPUT);
  pinMode(left_spindle_pin, OUTPUT);
  pinMode(forward_base_pin, OUTPUT);
  pinMode(backward_base_pin, OUTPUT);


  //set pins low
  stop_spindle();
  stop_base();


}

void loop() {


        stop_spindle();
```

```
stop_base();
speed = 100;

while(1){


  stop_base();
  stop_spindle();
  delay(40);

  //speed adjust button
  if(digitalRead(red_button) == HIGH){
    if (speed > 120){
      speed = 100;
    }
    else if (speed <= 120){
      speed = 250;
    }
    delay(400);
  }



  //=============================================================

  //left button
  while(digitalRead(left_button) == HIGH){
            if(digitalRead(left_limit_switch) == LOW){
              stop_spindle();
              delay(200);
             move_spindle_right(speed);
             delay(2000);
              stop_spindle();
              delay(1200);
           }
            move_spindle_left(speed);
           delay(50);
            //stop_spindle();
            //delay(0);
  }
  stop_spindle();

  //right button
  while(digitalRead(right_button) == HIGH){
            if(digitalRead(right_limit_switch) == LOW){
              stop_spindle();
              delay(200);
             move_spindle_left(speed);
             delay(2000);
              stop_spindle();
              delay(1200);
           }
            move_spindle_right(speed);
           delay(50);
            //stop_spindle();
            //delay(1200);
  }
  stop_spindle();

  //=============================================================

  //forward button
  while(digitalRead(forward_button) == HIGH){
            if(digitalRead(forward_limit_switch) == LOW){
              stop_base();
              delay(200);
             move_base_backward(speed);
             delay(2000);
              stop_base();
              delay(1200);
           }
```

```
                    move_base_forward(speed);
                   delay(50);
                    //stop_base();
                    //delay(1200);
          }
          stop_base();

          //back button
          while(digitalRead(back_button) == HIGH){
                    if(digitalRead(back_limit_switch) == LOW){
                      stop_base();
                      delay(200);
                     move_base_forward(speed);
                     delay(2000);
                      stop_base();
                      delay(1200);
                    }
                    move_base_backward(speed);
                   delay(50);
                    //stop_base();
                    //delay(1200);
          }
          stop_base();

         }
}// end main


void stop_spindle(){
        analogWrite(left_spindle_pin, 0);
        analogWrite(right_spindle_pin, 0);
        digitalWrite(right_spindle_pin, LOW);
       digitalWrite(left_spindle_pin, LOW);
        delay(10);
}

void move_spindle_left(int speed){
  digitalWrite(right_spindle_pin, LOW);
  analogWrite(left_spindle_pin, speed);
}

void move_spindle_right(int speed){
   digitalWrite(left_spindle_pin, LOW);
   analogWrite(right_spindle_pin, speed);
}



void stop_base(){
  digitalWrite(forward_base_pin, LOW);
  digitalWrite(backward_base_pin, LOW);
  analogWrite(backward_base_pin, 0);
  analogWrite(forward_base_pin, 0);
  delay(10);
}

void move_base_backward(int speed){
  digitalWrite(forward_base_pin, LOW);
  analogWrite(backward_base_pin, speed);
}

void move_base_forward(int speed){
   digitalWrite(backward_base_pin, LOW);
   analogWrite(forward_base_pin, speed);
}
```

Appendix E: Proposed Software Ideas

Possible Software/Exhibits for Next Year

1.) Using interrupts or some other method, a code could be written that allows for diagonal movement. This can be useful for the exhibit, an example would be a game where a writing utensil was attached to the spindle and children could try to write their names on a piece of paper on the drill's base.

2.) In the code you could make the base of the drill continuously move back and forth by changing direction each time it hits a limit switch. This, coupled with human controller X movement, would allow for games where the user could move the drill side to side while avoiding set obstacles on the autonomously moving base.

3.) Using the software that is available now, you could allow the user full control over both X and Y movement. This would allow for games where the user tries to use the drill and base to move an object, such as a golf ball, across a track and into a hole. By implementing a sensor on the hole and starting position, the user's time could be tracked. The code would also need to autonomously move the drill back through the course after each round was completed. This would probably require tachometer support to track the drill's position.

4.) By upgrading the controller to a Raspberry Pi, you could create a software where a simple black and white picture was uploaded to the Pi, and then the drill would draw the picture out on paper. This would require knowledge of image processing software as well as feedback from the drill that would allow the software to know the position of the drill with a high level of precision.