Industrial Wire Cutting Machine: A Senior Capstone Design Project

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Abstract

Manual wire cutting with poorly designed manual wire cutters presents many work-related health issues for electricians. Repetitively cutting wires with such tools can result in injuries to the hands and wrists of the individual. Additionally, manual wire cutting can be inaccurate and is time consuming, which can represent a loss of revenue from the time utilized in the process. Automatic wire cutting machines help to significantly reduce the number of occupational injuries, and improve the accuracy and efficiency of wire cutting. There are a variety of industrial wire cutting and stripping machines on the market. Unfortunately, these machines are expensive, and many electrical contractors and small technical shops cannot afford them. As a result, old and outdated automatic wire cutting machines are widely utilized by technicians, manufacturing workers and electrical contractors. These machines are not very efficient and tend to be slower in operation and are subject to technical issues such as jamming.

As a result of empirical observations and personal experiences with manual wire cutters and old automatic wire cutting machines, a team of students in the EET Senior Capstone Design Project course at Kennesaw State University embarked on the design of a cost-effective industrial wire cutting machine with the goal of improving productivity, performance, accuracy, ease of use, and maintainability while at the same time reducing the cost of manufacturing such a machine. Their design utilizes a spool of wire of the type in automation assembly plant processes, an Arduino microcontroller, and other hardware components such as an LCD screen, push buttons, power supply, motor driver, servo motor, DC motor and DC-to-DC step-down converters. C/C++ functions were developed for the software portion of the project. This paper presents preliminary results from their design project.

Index Terms *– Senior Capstone Design Project, Engineering Technology (ET, Industrial Wire Cutting Tool*

I. Introduction

Wire cutters, also known as diagonal pliers, and wire strippers are two of the most often used portable handheld tools in a wide range of industries. Wire cutters consist of pliers that have sharp jaw edges that cut a portion of industrial wires. Similarly, wire strippers remove the protective coating of wires or strips the end portions of the wire to connect them to terminals, breadboards, other wires, etc. Use of an early wire cutter design (Figure 1 [1]) involved applying an unnecessary amount of force to bend a wire back and forth until the wire was broken. This left a burr on the cut pieces that needed to be smoothed off with a file. Current hand-held cutters are much improved from this initial design, but there are still concerns about the impact of the repetitive task of cutting on the upper-extremity musculoskeletal structure. Using poorly designed manual wire strippers can cause physical health issues over a long period of time such as arthritis, wrist tendinitis and other such disorders. The overall cost of reported injuries to the upper extremities in the U.S. is at least $6.5 billion per year [2].

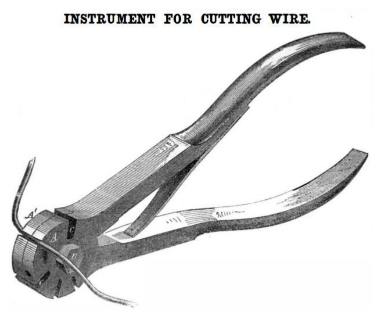

Figure 1. "Improved Wire Cutter" [1].

Originally, started, hand tools were designed based on the human body dimensions of the person who would use the tool. These hand tools that were manufactured for the anatomic and physiological characteristics of the individuals would help them to perform their job without creating stress to the musculoskeletal structure of the individuals. Modern hand-held tool design practices create standard products that can be used by everyone. Poorly shaped wire cutters, or even wire cutters that do not "fit properly" the user's grasp can increase the risk of injury and occupational illnesses [3]. Several ergonomic research studies have examined hand tools' effects on human health with the aim of making better devices for the users. Research studies by Kluth at al. [4], recorded physiological data as study subjects were provided with eight typical wire cutters and asked to cut wire. Tool design elements such as length and cross-section dimensions of the handle, notably affected the grasping and cutting force requirements, which is translated into different levels of mechanical stress on the hand of the user. Automation has several advantages that include safety, better product quality, more efficiency, less waste of material, and higher production rates. Repetitive tasks such as cutting large amounts of wires were a perfect candidate for automation. Commercial automatic wire cutters are widely available, where wire is used to assemble products, or replace other wires. A wire cutting machine "typically feeds the wire in on a reel, marks the wire using an inkjet or hot stamp printing mechanism, cuts the wire, and then coils the finished product on another reel or stacks it in a guide channel" [5]. A wire cutting/stripping machine usually has a rotating blade that follows the input cable and strips or cuts away the insulation. Small commercial or residential workshops may not have the economic resources to afford expensive, new automatic wire cutters when they already have hand-held tools available. For example, the Model WS-212 wire stripping machine by Bluerock Tools costs $ 1,299.00. This price may be excessive for many small electrical contractors. Additionally, the machine weighs 200 pounds, which is not convenient for field service engineers. The main issue with old wire cutting machines are the fact that they are not accurate or reliable. They tend to waste material that can cost the company or the contractor. There is lost time every time an old wire cutter jams or cuts a wire too short for it be used, so a new wire must be cut.

Figure 2. Older/Outdated industrial wire cutter.

Figure 3. Model WS-212 wire stripping machine [7].

Therefore, one of the main goals of the wire cutting machine design proposed in this document is to help electrical workers and contractors to stay safe, healthy, and productive in the field. The machine will be a valuable tool that will improve the way people do their jobs and run their business.

II. Objective

The proposed industrial wire cutting machine is economically feasible, portable and easy to use.

By using this new wire cutting machine design, injuries related to the long-term use of handheld wire cutters for extended periods of time will be significantly reduced in the field, in technical shops, and in manufacturing plants. The main goals of our design are to improve productivity, reduce human labor, and save money. This product is also an environmentally friendly and affordable machine.

The machine strips and cuts 16-gauge wire using an aluminum wheel and a DC-Motor to feed the wire through the wire cutting mechanism. The device prompts the user to input values for the desired length of the wire in centimeters, and the quantity that the user wants. This requires the use of the buttons on an input panel on the device itself to increment a value, decrement a value, go to the next prompt or go back to the next prompt. The system records each value inserted and displays them on an LCD screen. Once the user inputs values into the system, it prompts the user to confirm their values or go back to change a value. If the user presses confirm, the stripping and cutting process will begin.

Due to a time restriction imposed by the senior capstone design project course, and due to problems during the hardware construction, the machine design was modified from the original proposal. The original design utilized four different types of wire instead of just one single wire. This design utilized a sliding mechanism used from a dismantled printer. The original system required the use of a pulley and a stepper motor to cycle through the four wires. The wires within the system would be named "Wire A/B/C/D" with Wire A being the first wire, Wire B being the second wire and so on. After one wire would be stripped and cut the stepper motor would activate and cause the sliding mechanism to move upwards to the next wire. The system would prompt the user to insert values for the next wire and continue the process as described previously. After each wire has been cut to its desired lengths and quantities, the stepper motor would reset the mechanism to its original position.

The device was also intended to be portable and easy to use. The idea was to allow the user to be able to carry the device around and use it whenever needed. Installation of metallic legs with wheels would make the machine mobile for easier transportation. This was not accomplished due to time constraints, and the individual schedules of group members. It was decided that installation of the legs would occur at a later time in the future.

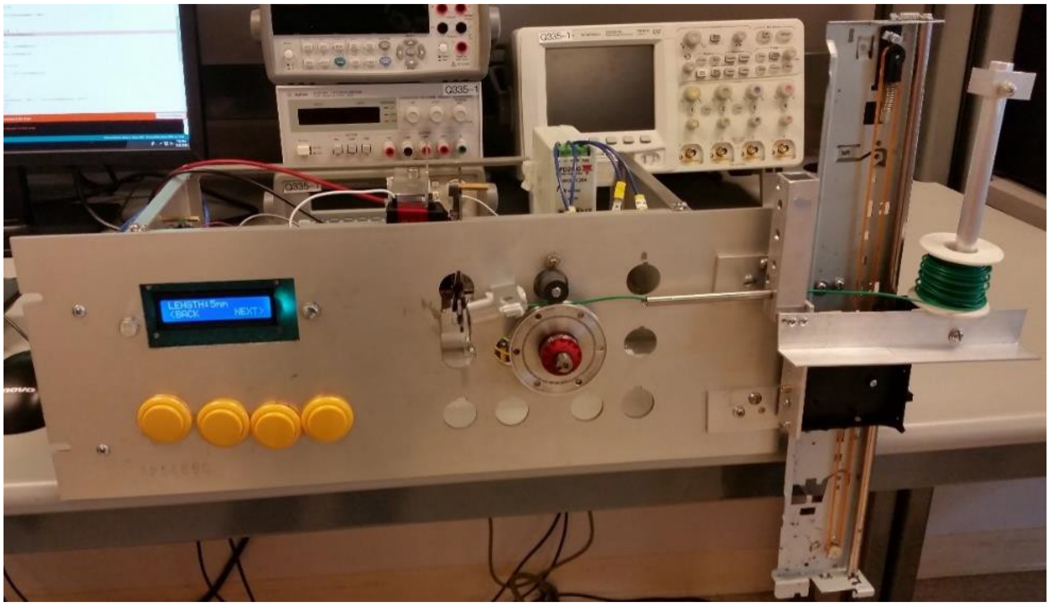

Figure 4. Industrial wire cutting machine with original sliding mechanism.

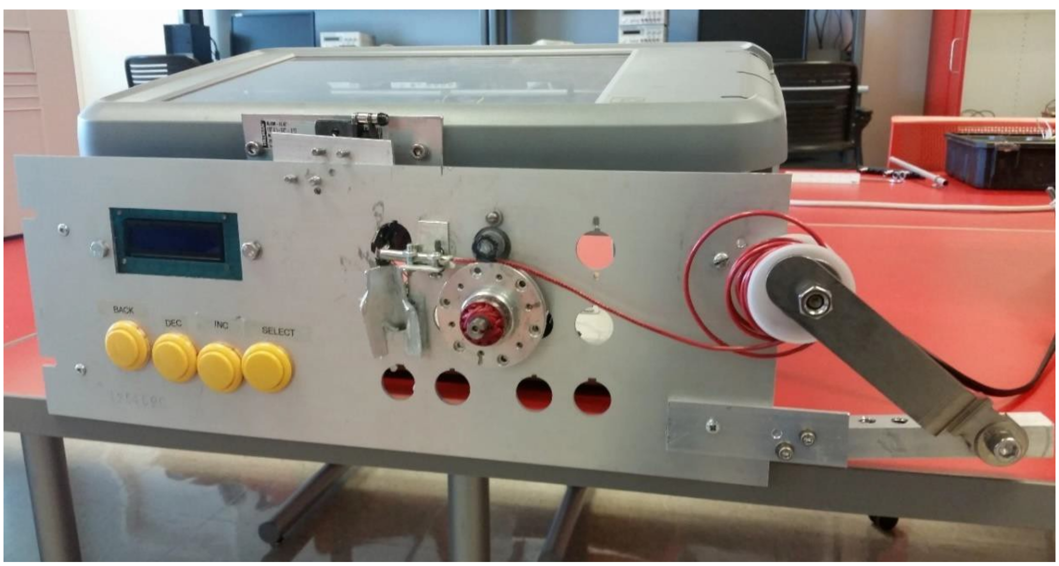

Figure 5. Industrial wire cutting machine with the final wire feeding mechanism.

III. Design

The design of the wire cutting machine is broken into two main parts: hardware and software. This approach facilitated the completion of the project.

III.1 Hardware

III.1.1 Initial Design

The initial design proposal statement was as follows:
"The hardware will be a combination of recycled parts and new parts for critical functions of the wire cutter machine. By using old parts that have been scrapped, this machine will be economical, and environmentally friendly. The main components of the machine are stepper motors, servo motors, stepper motor drivers, Arduino Nano boards, a Raspberry Pi 3B, a power supply, and wire cutters. The Raspberry Pi board will be the intermediate point between the user inputs and the Arduino Nano microcontrollers that will control the mechanical aspect of the machine. The wire strippers and cutters are going to be used to strip and cut the wires that the user desires. The overall system will be comprised of four cutting modules. The preliminary phase of the project will consist of having a functional module before assembling the final prototype."

III.1.2 Final Design

The original design called for the use of the Arduino Nano board and a Raspberry Pi for the controller used to control the wire. After experimenting with the Arduino Nano board to control the A4988 stepper motor driver, a couple of problems were found. First, the testing of the motor driver was not successful, and the communication between the Arduino Nano and the Raspberry Pi represented a challenge that could negatively affect the project schedule. The number of pins of the Arduino Nano was less than the pins we would require originally for the project. As a result, it was decided that the Arduino Mega 2560 controller would be used instead to provide all the functions required for this system. 54 digital input/output pins are provided by the Arduino Mega 2560, of which 15 pins provide PWM output for the servo motor. Having a large quantity of digital input/output pins was the main reason to choose the Arduino Mega 2560 board because it offers the flexibility of adding more elements to the system. To reduce the clutter and help with the organization of electrical components, a PCB was used to attach the potentiometer and the buttons. Using brass standoffs, the switch was able to be easily connected along with the power and grounded wires. The wires were connected from behind the device to the 24-V power supply. This component contains two positive nodes and two negative nodes. This component also contains an

N (Neutral) and L (Line). The ground connects from the switch to the N and the power connects from the switch to the L. The connections are then made from the two positives and two negatives to connect to the terminal blocks. The terminal blocks act as voltage (24-V) nodes and ground nodes for the DC-DC converters. Each DC-DC converter has separate voltages from each other; 9-V for the Arduino MEGA, 5.8-V for the servo motor connected to the wire cutting mechanism, and 17-V for the stepper motor for the wire feeding mechanism. The DC-DC converters are stacked upon each other and were tuned before assembly. The 9-V DC-DC converter, it is used to power the Arduino MEGA. The Arduino MEGA contains 54 digital input/output pins which are used for the potentiometer for the LCD, the buttons used for the system navigation properties, and the LCD itself which are connected to the PCB installed. The Arduino MEGA can output 5-V for the potentiometer and the LCD display. Each button utilizes a digital pin from the Arduino MEGA and various pins from the LCD also utilize digital pins from the Arduino MEGA.

The 5.8-V DC-DC converter controls the servo motor and uses the Arduino MEGA for digital pins to control via code. Once again, this DC-DC converter is connected to a terminal block that uses the 24-V power supply. The servo motor controls the wire cutting mechanism for the device itself. Once the system confirms its values, the servo motor will turn at a certain angle based on the code designed for the system. The servo motor goes back to its original position once the operation is done. The 17-V DC-DC converter controls the DC motor that feeds the wire to the wire cutting mechanism. This DC-DC converter is connected to a L298N Motor Drive that is then connected via digital pins onto the Arduino MEGA. The DC-DC converter is tuned to properly power the DC motor. Based on the code, the DC Motor will run at a set speed to feed the wire through the device. This will help give the user a proper length and a proper quantity when their values are inserted into the system's prompts.

The major hardware change that was made was to the sliding mechanism that was used to create a tubing for four wires instead of one. The wires were controlled by a stepper motor that was disassembled from a printer to cycle through 4 wire tubes. Due to time constraints and difficulties assembling the hardware, this aspect of the project could not be implemented. A significant hardware change was made to a system such that there is only one spool of wire for the system. Only one arm is used for attaching a spool of wire for the feeding mechanism. Secondly, a door was installed for the safety of users while the cutting/stripping operation is occurring, using two metal plates to keep the door from closing completely and interfering. The last thing installed as a hardware alteration was the tubing used for feeding the mechanism which was altered to give the user the correct amount of lengths for each wire that is stripped and cut.

The system block diagram is shown in Figure 6. There are four different types of connections in the system. The first one is electrical connection (black line) and connects each of the components that require a power source. The AC to DC power supply is used to convert 120 Vac at 60 Hz to 24 Vdc with a rated current of 1.5 amps. Subsequently, the DC to DC step-down converters provide the power needed for the servo motor, Arduino Mega 2560 board and the L298N driver motor module. The second line is the unidirectional control line (blue) which indicates that the controller sends commands, but it does not receive feedback from the device that is controlled. This is the case for the Arduino Mega 2560 board that controls the servo motor, the LDC display and the L298N motor driver. Another case is the L298N motor driver module that sends a voltage or ground signal to the motor. The duration of the sent signal depends on the length of the wire that the user desires; however, this decision is made by the controller (Arduino Mega).

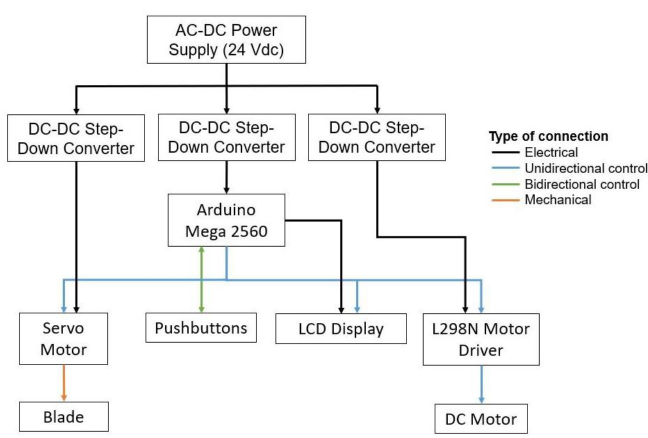

Figure 6. System block diagram.

A drawing of the top, side and front view of the machine is presented in Figure 7. The electrical schematic that shows the connections between all the components of the system is shown in Figure 8. Figure 9 corresponds to the wiring diagram where it is shown how the components look, and how they are wired in the machine. The final prototype is illustrated in Figures 10 and 11 below.

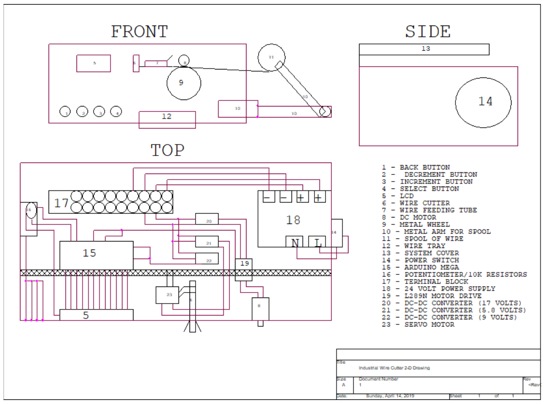

Figure 7. Machine drawing views.

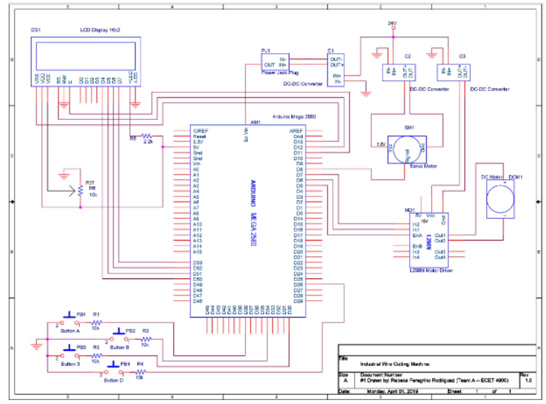

Figure 8. Electrical schematic of the system.

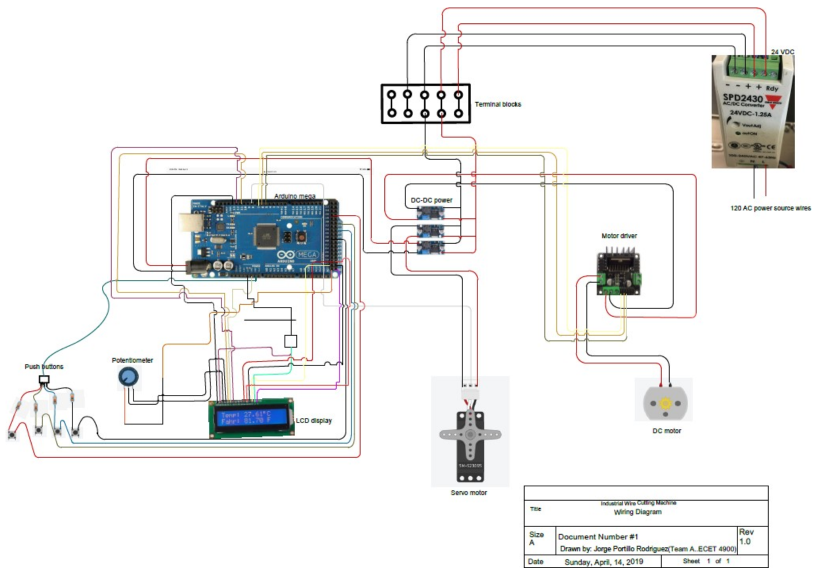

Figure 9. Wiring diagram of the components in the system.

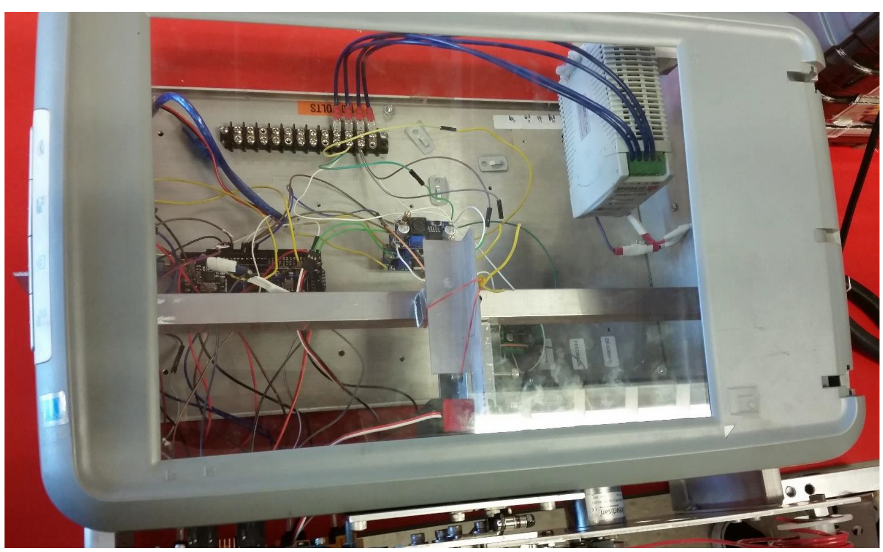

Figure 10. Top view with cover of the final prototype.

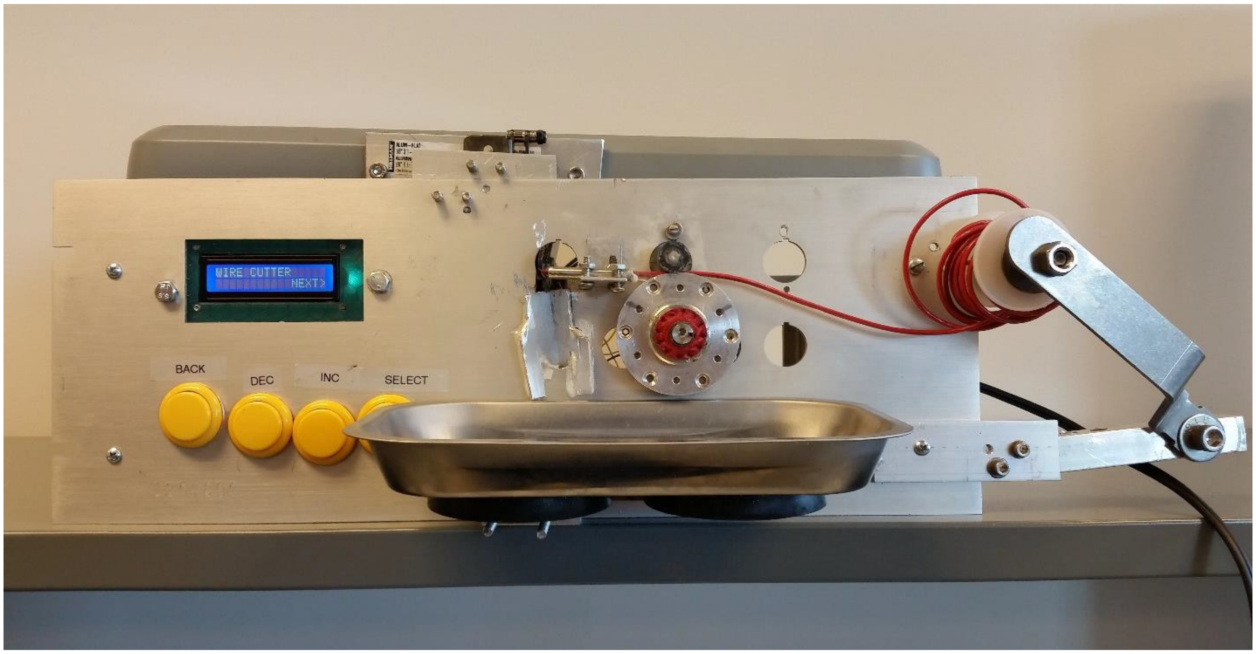

Figure 11. Front view of the final prototype

III.2 Software

Basic Structure (Pseudocode)

This design utilizes a microcontroller, the Arduino Mega 2560, and the program is written in C++. This design does utilize an L298N motor driver module because the board cannot supply enough voltage to the DC motor. The DC motor requires a voltage of 12 volts to operate properly. The motor driver receives instructions from the Arduino Mega 2560; for example, the microcontroller sends the time that the DC motor should be on to move the wire to the cutting blades. Thus, all the code is still on the Arduino Mega 2560. The following diagram is a flow chart made to show the key elements of the code.

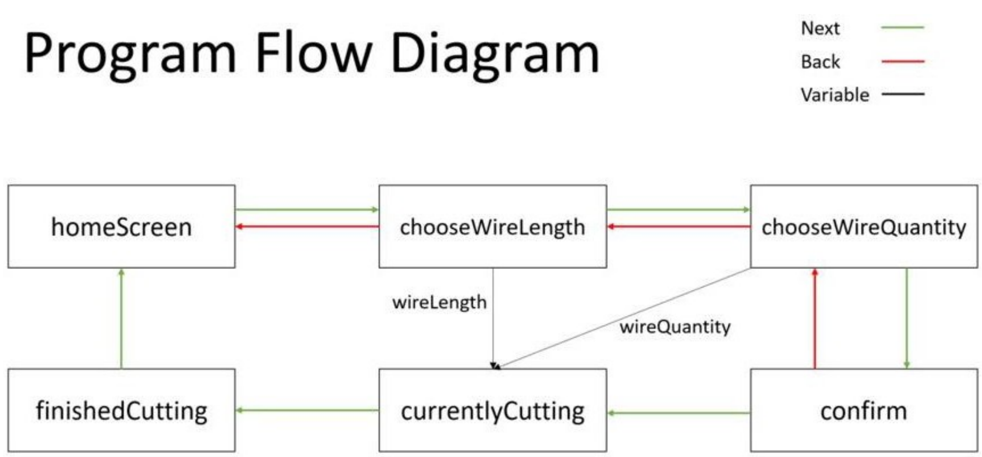

Figure 12. Flowchart of the C++ program.

The program begins in the top left at the "homeScreen". Pressing the next button on the face of the machine will increment the state variable, and the program will move to the next method in the code (this process is shown with the green arrows). In both "chooseWireLength" and "chooseWireQuantity", the user is prompted to choose any values that they wish. Pressing the increment button in either of these methods will increase the respective values by one, and the decrement button decreases the value by one (minimum of zero in both methods). The "confirm" screen displays the variables that the user has chosen in order to ensure that the values are correct. Pressing back while on the "chooseWireLength", "chooseWireQuantity", and "confirm" screens will take the user to the previous screen (shown in red). This function is only available on these three screens. Pressing next on the confirm screen ensures the variables are correct and begins the cutting process and actively displays how many wires have been cut. Once this process is finished, the "finishedCutting" method begins without the user needing to press the next button. After pressing next on the "finishedCutting" screen, the user is returned to the "homeScreen" and the process can be repeated as needed. Note that pressing back is not available on "homeScreen", "currentlyCutting", or "finishedCutting", and pressing the back button during any of these methods will not do anything.

The following instructions are written in pseudocode and are used to illustrate the flow of the overall program, as well as the individual methods in more detail than the Program Flow Diagram.

- Open UI with a display of "**WIRE CUTTER**" and "**NEXT>**", this is the home screen Pressing the NEXT button goes to the next screen
- Pressing the next button opens a screen for "**CHOOSE WIRELENGTH**" Increment and Decrement buttons change the value for **wireLength**
- Back button goes back to home screen, and the next button goes to the choose wire quantity
- The wire quantity screen works the same way as wire length, but controls **wireQuantity** instead
- Pressing back goes to the wire length screen, and pressing next goes to confirm screen Displays "**A cm x B pcs**" where A is **wireLength** and B is **wireQuantity**
- Pressing back goes to the wire quantity screen, and pressing next goes to the currently cutting.
- Initially display a screen that shows "**0/X**" where X is **wireQuantity**
- Turn the DC motor on and keep it on so that one centimeter of wire moves forward, then turn the motor off.
- Move the servo motor to a position that pushes the wire cutter enough to cut through insulation, but not enough to cut through conductor.
- Turn the DC motor on, and keep it on so that the desired wire length moves forward, then turn the motor off
- This delay is calculated by multiplying the selected wire length by the delay used for stripping (i.e. one centimeter)
- Move the servo motor to a position that pushes the wire cutter enough to cut through the insulation and the conductor
- Increment the number on the display to show "1/X" where X is the wire length
- Repeat this process for the desired wire quantity
- This is done by using a for loop, initializing a variable, setting the condition of the loop to be "**initialized variable < wireQuantity**" so it will stop after the machine has cut the selected amount of wires.
- Once all the wire has been cut, update the display to show "**FINISHED CUTTING**" and "**NEXT**>"
- The back button does nothing here, and the next button returns the user to the home screen
- This entire process can be repeated as necessary.

IV.2 Budget

The budget for this project is presented in Table 1 below.

Table 1. Project budget.

Item #	Part Number	Manufacturer	Vendor	Description	Unit Cost ($) +Taxes	Quantity	Item Total Cost ($)
1	2560 R3	Elegoo	Amazon	Arduino Mega 2560	14.83	1	14.83
2	MTD-01	Osepp	Amazon	L298N motor driver module	4.00	1	4.00
3	DS3218 MG	Annimos	Amazon	High-torque servo motor 270°	17.89	1	17.89
4	B072KN G6NT	Greartisan	Amazon	12V 15RPM gear high-torque DC motor	15.49	1	15.49
5	43211-13461	eBoot	Amazon	DC-DC converter	1.78	3	5.33
6	1182	Elegoo	Amazon	Double sided PCB board	0.60	1	0.60
7	LCD-01	Elegoo	Amazon	16x2 LCD display module	7.99	1	7.99
8	CE1008 21	Irwin Tools	Amazon	Wire stripper and cutter	6.29	1	6.29
9	3010150 0	Steelworks	Lowe's	L x 0.75-in W x 0.75-in H aluminum plain square tube	10.99	1	10.99
10	3010150 1	Steelworks	Lowe's	3-ft x 0.75-in aluminum metal flat bar	4.49	1	4.49
11	B01EV7 0C78	Elegoo	Amazon	120pcs multicolored dupont wire	7.98	1	7.98
12	HB234-1	Hilitchi	Amazon	360pcs M2 M3 M4 male female brass spacer standoff	19.98	1	19.98
13	1001372 033	Everbilt	Home Depot	Zinc-plated machine screw kit (405-piece)	6.98	1	6.98
14	–	Ram-pro	Walmart	Magnetic tray	6.35	1	6.35
15	–	Newark Electronics	–	AC-DC Power Supply 24V	42.39	1	42.39
15	–	–	–	Pushbuttons, wheels, power cord, cover, wire spool and holder and aluminum box	–	–	–
Total						$171.58	

The real cost of this project may be higher because the hardware is a combination of recycled parts and new parts. One of the goals of the industrial wire cutting machine was to be environmentally friendly by utilizing parts of machines that were not used anymore. For example, the small wheel and wire sliding mechanism were from an old printer.

V. Future Work

Although the goal of cutting four different wires at the same time was not achieved as it was stated in the original proposal, the machine cuts and strips accurately one wire at a time. If work on this project was continued, the machine would have four different tubes mounted on a circular plate, such that a tube would be placed at 0 degrees, 90 degrees, 180 degrees, and 270 degrees. This metal plate would be controlled with a servo motor such that if the user wants wire 1, the servo motor would move to 0 degrees, if the user wants wire 2 the servo would move to 90 degrees, etc. Each wire would also need a small DC motor to push the wire up to the main DC motor. Within the coding, another switch case would need to be added, and a screen for wire selection would be added.

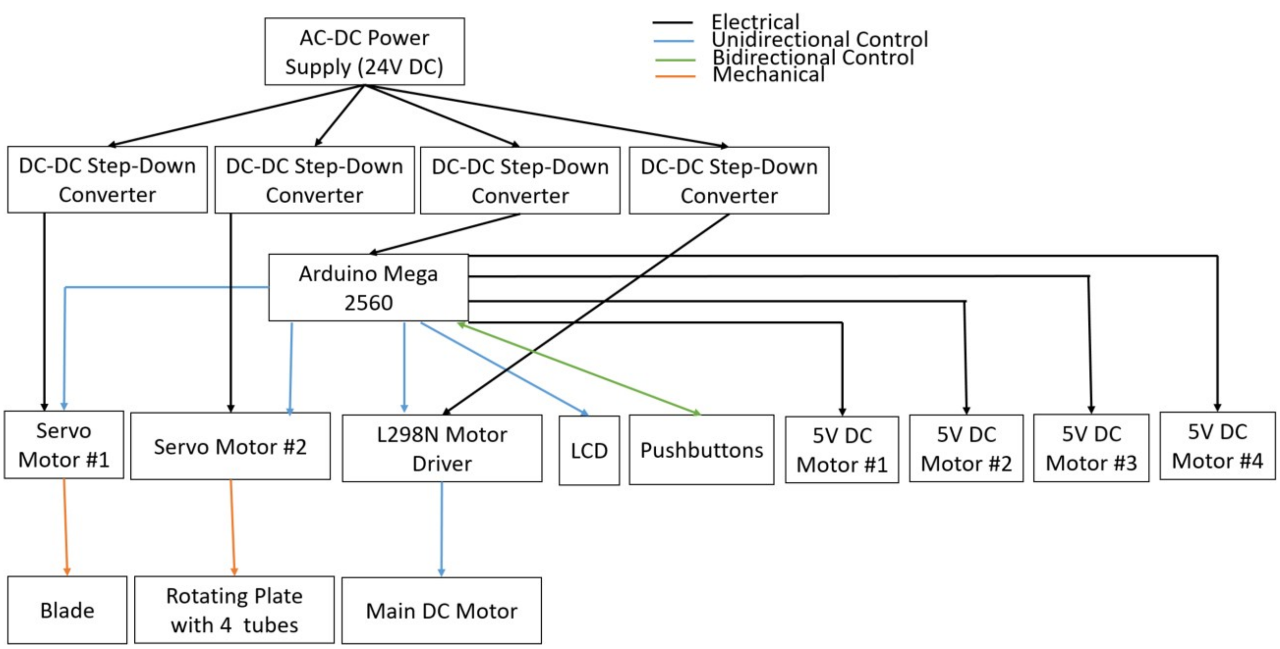

Figure 13. System block diagram of the final project design that would cut multiple wires.

Figure 13 above is a block diagram representation of the projected final design that would cut multiple wires. The Arduino Mega 2560 now would control a second servo motor, as well as 4 more DC motors. The added servo motor would be connected to the plate with 4 tubes and rotates depending on which wire the user wants to cut. This servo motor would be powered by a fourth DC-DC step converter. Each of the DC motors would be powered and controlled by the Arduino Mega 2560 board. When a given wire is selected, it would be pushed forward towards the main DC motor so that it could be stripped and cut.

VI. Conclusion

Wire cutters are hand tools used in a wide range of industries, and they are very often used in a daily basis. Unfortunately, handheld wire cutters used in repetitive tasks can potentially increase health issues. On the other hand, outdated and old industrial wire cutting machines that are still used in industry are very slow, not accurate and jam several times. This type of machine is widely used in manufacturing plants, technical shops and electrical contracting business. New wire cutting machines are usually expensive, and small manufacturing plants or technical shops prefer to continue using their old equipment. The wire cutting machine design presented in this paper will benefit technicians, electricians, and manufacturing workers by providing a user- friendly and low-cost efficient device that will accurately and efficiently cut one wire. The automated industrial wire cutting machine also decreases manual labor; as a result, it increases productivity.

There are cost-effective ways to improve this prototype that can increase productivity even more significantly. Even though the machine prototype was only able to cut and strip one wire at a time, it is more accurate and efficient than most machines in the market at a fraction of the price. As mentioned in the future work section there is a plan to make it a 4-wire machine that will beat any competitor in the market. It is hoped that this work will be extended further to produce the 4-wire version of this design.

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