Boston University
Electrical & Computer Engineering
EC464 Capstone Senior Design Project

User's Manual

Submitted to

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by

Team #35
RoboSaw

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RoboSaw User Manual

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Executive Summary

Construction workers at the jobsite performing the task of framing, assembling wooden structures that shape the interior and exterior of a building, face the risk of injury, most commonly from interaction with equipment, including circular saws, miter saws, and table saws. RoboSaw is a robot miter saw designed to eliminate the repetitive, time-consuming and potentially dangerous task of cutting dimensional lumber by automating the process. Using a computer vision system consisting of three cameras, RoboSaw can identify and perform cuts at intervals marked with a pen or pencil or cut wood based on a preset cut list autonomously. As a result, the construction worker can focus entirely on structure assembly, a task that is notoriously difficult for robots to accomplish by themselves, especially in unpredictable environments such as a jobsite. RoboSaw is capable of processing lumber up to 8ft in length and can cut a wide variety of lumber sizes at angles up to 52 degrees. Although RoboSaw is designed to cut wood without human intervention, to improve safety and usability it has a remote-control pendant that enables a construction worker to confirm, or skip marked cuts and shut off the robot from a distance in case of an emergency. By automating the processing of lumber at the jobsite, RoboSaw can improve construction speeds, eliminate the risks of injury, and reduce operating costs for employers and other stakeholders. At present, a fully functioning prototype of RoboSaw has been completed by our team. The robot is currently undergoing benchmarking against a conventional framing workflow to quantify how its use may impact the speed and efficiency of wood construction at the jobsite.

1 Introduction

Construction workers encounter numerous risks at the jobsite while under pressure to complete projects on schedule. RoboSaw is designed to minimize safety risks and improve jobsite efficiency by semi-autonomously performing the cutting operations traditionally performed by the construction worker. Using the included miter saw stand, RoboSaw is capable of processing wood stock up to 8 ft in length with nominal dimensions of 2x4, 2x6, and 4x4 in. Wood stock can be fed in at a rate of 4 ft/s and cuts can be performed in approximately 6 seconds. To use the RoboSaw, a construction worker simply feeds wood stock into the machine marked with a pen or pencil at the location of the desired cut. The RoboSaw then performs the cuts automatically and ejects the cut wood. A three-camera computer vision system is used to detect the presence of wood in the intake, the drawn line and its angle, and finally align the line drawn on the wood with the blade.

Using a computer vision system to guide and control a miter saw raises safety concerns. In response to these concerns, additional safety features have been added to RoboSaw. There are three layers to the safety of this device; user error, hardware failure, and cybersecurity breaches. To mitigate the potential for operator error, the user interface for RoboSaw is simple, consisting of a teach pendant with ‘Run/Skip’, ‘Confirm’, ‘Eject’ and emergency stop buttons. To ensure that at least one button is within reach of the operator at all times an additional emergency stop button is mounted directly to the front of the RoboSaw. After powering on the RoboSaw the user presses the ‘Run/Skip’ button which begins to feed the wood into the machine and positions the hand-drawn line underneath the blade. Once the wood is positioned, the user must press the ‘Confirm’ button to initiate the cut. The emergency stop button on the control pendant cuts power to the entire system at any point. If the RoboSaw detects an unintended line or if the line is not correctly positioned under the blade, the user has the option to press the ‘Run/Skip’ button again to find the next line or the ‘Eject’ button to drive the intake wheels manually for as long as the button is depressed.

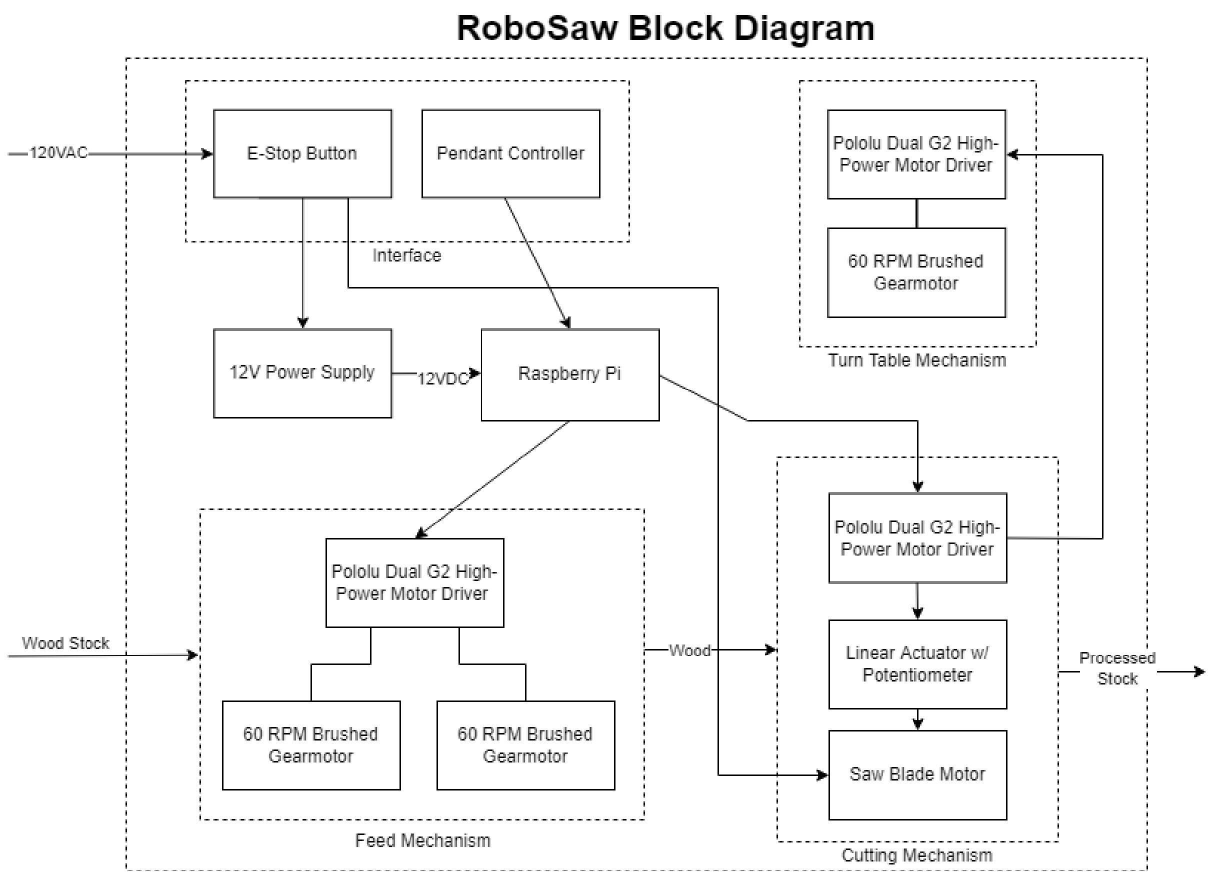
RoboSaw is equipped with hardware mechanisms designed to improve the safety of operating a miter saw. A blade guard covers the miter saw blade in its upright position and during the cut. The frame of RoboSaw prevents a user from accidentally putting their fingers too close to the saw blade. An emergency stop switch on the control pendant and the saw itself enables the user to disconnect all power to the saw and electronics in the case of an emergency or saw failure.

Finally, to reduce the attack surface of the RoboSaw program, the RoboSaw system is air-gapped. The wireless capabilities of the Raspberry Pi that controls the RoboSaw are disabled, so that the only way to interact with the saw’s operating system is by attaching hardware peripherals to perform tasks such as camera calibration.

2 System Overview and Installation

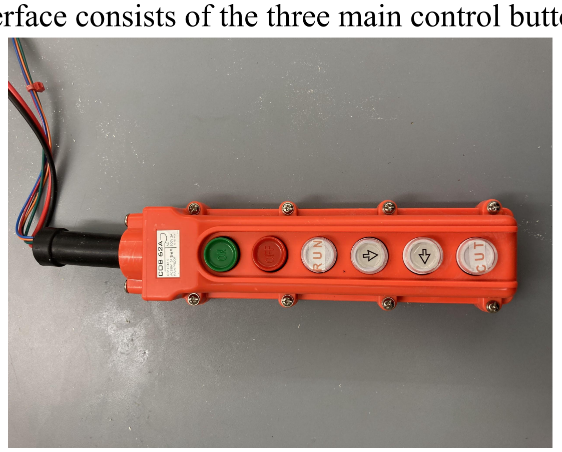
[This section should tell the user how to install and set up the system. Some descriptive material is included here to make the system's structure more apparent.]

2.1 Overview block diagram



2.2 User interface.

The RoboSaw user interface consists of the three main control buttons (fig 1)



(fig 1: image of 3 interface buttons, front view, labeled)

2.3 *Physical description.*

The RoboSaw has several physical components that allow it to perform cuts on wood stock. There are motors and a linear actuator that automate all the movements of a traditional miter saw. There is a camera system which is integral to performing an accurate cut. As well as a lighting system to ensure the cameras have enough light to distinguish between any line.

The entire RoboSaw is mounted to an 80/20 frame to allow for easy expansion and modification in any situation.This allows the RoboSaw to be easily mounted to a miter saw stand to be moved around. There is a handle with a button to allow the miter saw stand to be raised and lowered to the desired work height.

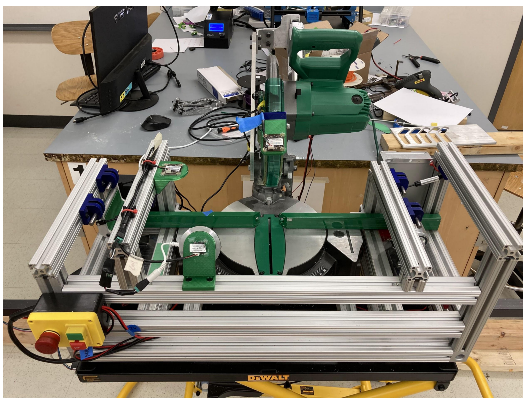


Figure 2: RoboSaw frame. Figure 3: Height adjustment handle

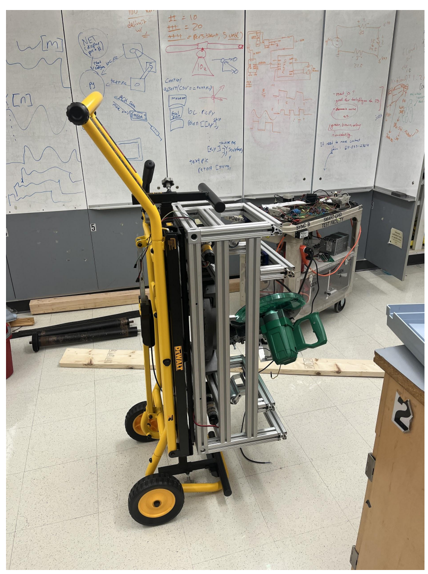


Figure 4: RoboSaw stand

In order for the wood to be advanced through the system RoboSaw has an intake and outake motor. The motors are mounted at an angle to ensure that the wood is always pressed up against the backside of the fence. This is another safety element which makes sure the wood does not fly out of the miter saw during cutting.

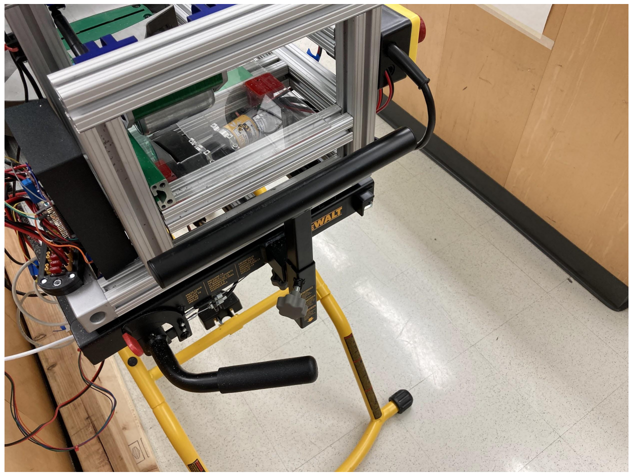


Figure 5: View of the RoboSaw intake motors.

The RoboSaw has a linear actuator to bring the blade down once the line is identified. This is mounted to the backside of the miter saw on a rigid aluminum fixture.

Figure 6: RoboSaw linear actuator mount for blade.

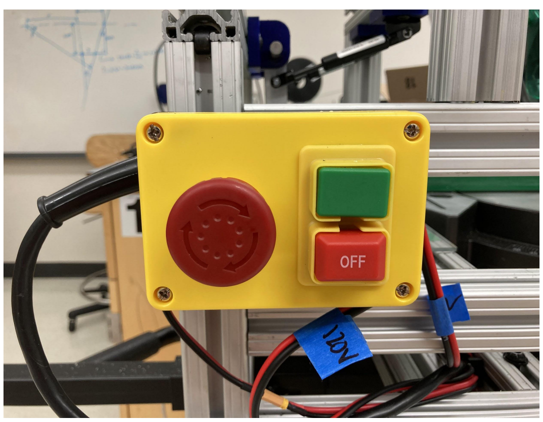
The final piece to the RoboSaw is the three cameras used to align the wood and the line for the cut. There are three cameras for the RoboVision system. There is one to identify the wood, one to identify the line, and another to ensure the line is aligned correctly with the blade. These three cameras are mounted all around the RoboSaw and come with a light system.

2.4 Installation, setup, and support

The RoboSaw system requires little assembly by the user. The electronics are assembled, along with all the intake, blade actuation, and lighting systems. There are some accessories that will need to be attached once the RoboSaw arrives at its destination. This includes items that would be dangerous to transport in the saw.

The first step to having a functioning RoboSaw is to install the blade. First remove the screw underneath the blade cover. This screw is reverse threaded so turning it to the right will loosen the screw. Once the screw is removed, place the blade into position keeping in mind the orientation of the teeth. The arrow on the blade should be pointing clockwise if installed correctly. Once the blade is in position, tighten the screw and hold down the button on the motor to make sure the blade is tightened into position. The button next to the blade prevents the blade from spinning when you are tightening the blade. After the blade is installed, you can begin the safety checks and electronics setup.

The next step is to ensure all of the motors spin freely and without any obstruction. This is important to ensure the wood is fed incorrectly and the cut is clean. Make sure all of the cameras are free of debris and that the lighting is not obstructed. Once the machine is clear of any debris, you can plug in the RoboSaw into any 120V outlet. The emergency stop buttons should be in the out position and the green buttons on both the emergency stop and pendant should be pressed. Observe the power LED and ensure that it is illuminated.



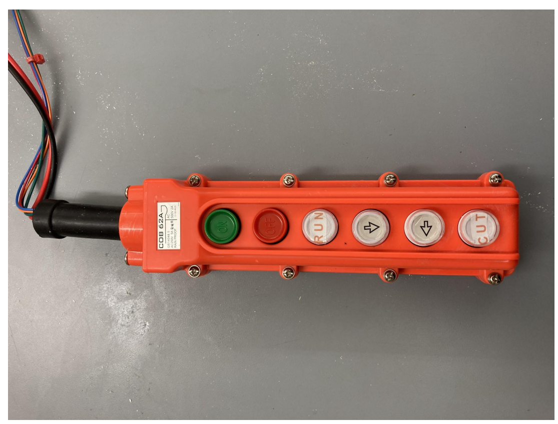


Figure 7 and 8: RoboSaw emergency stop and pendant.

The final step to ensuring a proper RoboSaw cut , is to adjust the supports for the wood stock. Since RoboSaw can accommodate long pieces of wood there needs to be support in order for the intake mechanism to pull the wood in. The three types of wood that RoboSaw supports can vary in weight so the height needs to be adjusted accordingly. Make sure the support is pushing the wood up slightly on each side so the wood is not hanging off the edges completely.

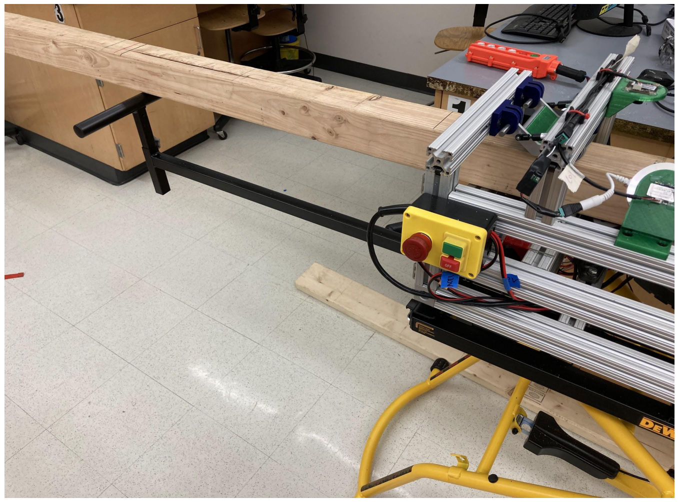


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Figure 9: RoboSaw stock support.

The software setup is explained in section 3.3 of this manual. It involves calibration of the cameras and adjusting the region of interest for the computer vision.

3 Operation of the Project

[This section describes how to use the project. Anticipate what the User needs to know and do Set-up and configuration were discussed in Section 2 already.]

3.1 Operating Mode 'Run/Skip': Normal Operation

1. Make sure all e-stop buttons are in the unlocked and armed position.
2. Extend the wood supports so that they are long enough to support the wood on both sides of the saw.
3. Put on safety glasses. Remove loose clothing and jewelry.
4. Power on the RoboSaw by pressing the green 'ON' button.
5. Press the 'Run/Skip' button to begin idling the intake feeding mechanism.
6. Push the wood into the intake side, making sure it is against the fence and that there are no obstructions on the wood such as staples, large chips, or other objects that could interfere with the RoboSaw mechanisms.
7. Push the wood in until the RoboSaw begins to pull it. Once it is pulling the wood, let go and allow the RoboSaw to handle the wood on its own.
8. Stand back and observe the wood as it is fed.
9. Once the line is centered under the blade, press the 'Confirm' button to make the cut.
10. After the blade is back in the upright position and has stopped spinning, hold the 'Eject' button to push the wood out. Alternatively, press the 'Run/Skip' button to cut the next line on the wood.

3.2 Operating Mode 2: Abnormal Operations

- RoboSaw's line detection algorithm, RoboVision, is not reliable if there are multiple lines within 1 foot of each other. It may skip over one of the lines if it is too close to another line.
- If the hand-drawn line has a greater angle than the saw is able to cut, the RoboVision system will ignore it.
- RoboVision may detect labels on the wood. To avoid this, make sure to draw the line on the unlabeled side of the wood or at least 1 foot away from the label if the line is on the same side. If a label or other unintended line is detected, press the 'Run/Skip' button to find the next line.

3.3 Operating Mode 3: Calibration

The RoboSaw comes fully calibrated. However, there may be times when it needs to be recalibrated. Calibration issues could occur if a camera is moved.
The calibration process is a bit involved. It is strongly recommended for this process to be performed by a RoboSaw technician.

1. Plug in a usb mouse and keyboard to the usb type-A ports on the RoboSaw.
2. Connect a monitor using the HDMI port.
3. Turn on the RoboSaw.
4. You should see the Raspberry Pi boot up on the screen.
5. Open the terminal and enter `cd robosaw`

6. This directory is where the calibration scripts are located. Run these in this order to recalibrate the RoboVision system.
    a. Run python3 set_cam_index.py first to tell RoboVision which camera is used for each task. The color-cam is the one facing the fence, the angle-cam is the one that is closest to the intake side of the saw, and the center-cam is the one attached to the blade guard.
    b. Run python3 tune_color_key_top.py to isolate the green color. Adjust the sliders until only the green is visible.
    c. Run python3 tune_color_key_bottom.py to isolate the green color. Adjust the sliders until only the green is visible.
    d. Run python3 crop_angle_cam.py to crop the area viewed by the angle detector. Make sure that the camera only sees the wood when the wood is loaded.
    e. Run python3 crop_center_cam.py to crop the area viewed by the center camera which positions the wood under the blade. Make sure the centerline is in the middle of the blade slot and that the camera does not detect the table of the saw while a 2x4 is under the blade.
    f. Run python3 crop_color_cam_bottom.py to isolate a small area on the green fence which, when blocked by a piece of wood, will tell the RoboVision program that the wood is past the angle detector.
    g. Run python3 crop_color_cam_top.py to isolate a small area on the green fence which, when blocked by a piece of wood, will tell the RoboVision program that the wood is under the blade.

3.4 Safety Issues

Any operation of the RoboSaw requires constant user supervision. This is a powerful and dangerous device.

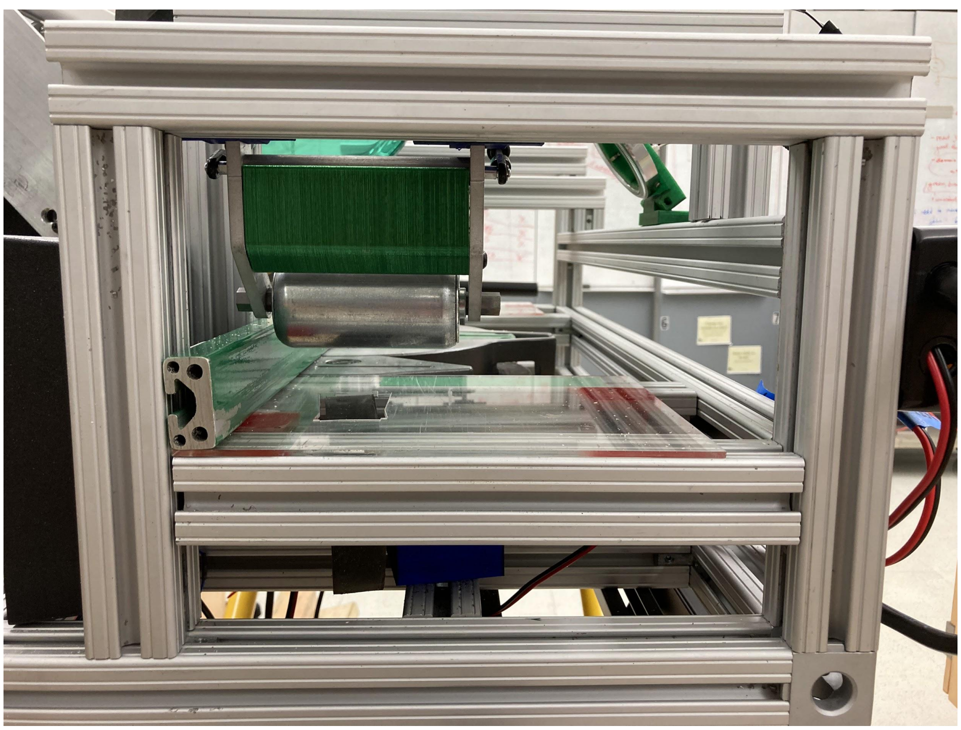
1. Do not wear loose clothing or jewelry while operating this device. Tie up long hair.
2. Do not operate under the influence of psychoactive substances.
3. Wear safety glasses at all times.
4. Ensure that all emergency stops are enabled before plugging the RoboSaw into a 120V AC outlet.
5. Ensure the RoboSaw is completely off before installing or removing the miter saw blade.
6. If you must reach into the RoboSaw to dislodge wood pieces or for any other reason, turn the RoboSaw off completely before putting anything or any body part into the RoboSaw.
7. For all safety concerns regarding the Metabo HPT C10FCGS Miter Saw, please refer to the manufacturer's user manual.
8. For all safety concerns regarding the Dewalt DWX726 Rolling Miter Saw Stand, please refer to the manufacturer's user manual.

4 Technical Background

4.1 Electromechanical Component

RoboSaw’s hardware subsystems are designed with the principle of being as simple and robust as possible while still accomplishing the task of processing wood stock. RoboSaw has two main mechanical components: the roller intake mechanism and the saw actuation mechanism. The roller intake mechanism is designed to handle wood stock of various sizes and lengths. A gas spring conveyor roller clamps the wood stock from above with 8 lb of force and keeps the wood securely in place during a cut. Direct drive urethane wheels underneath the frame push the wood through the intake and outtake. Each wheel is angled by 10 degrees towards the saw fence such that a portion of their force is directed at pushing the wood stock against the fence. This portion of the wheel's force helps secure the wood in place and ensures that it is aligned with the frame as it is being pushed through the RoboSaw.

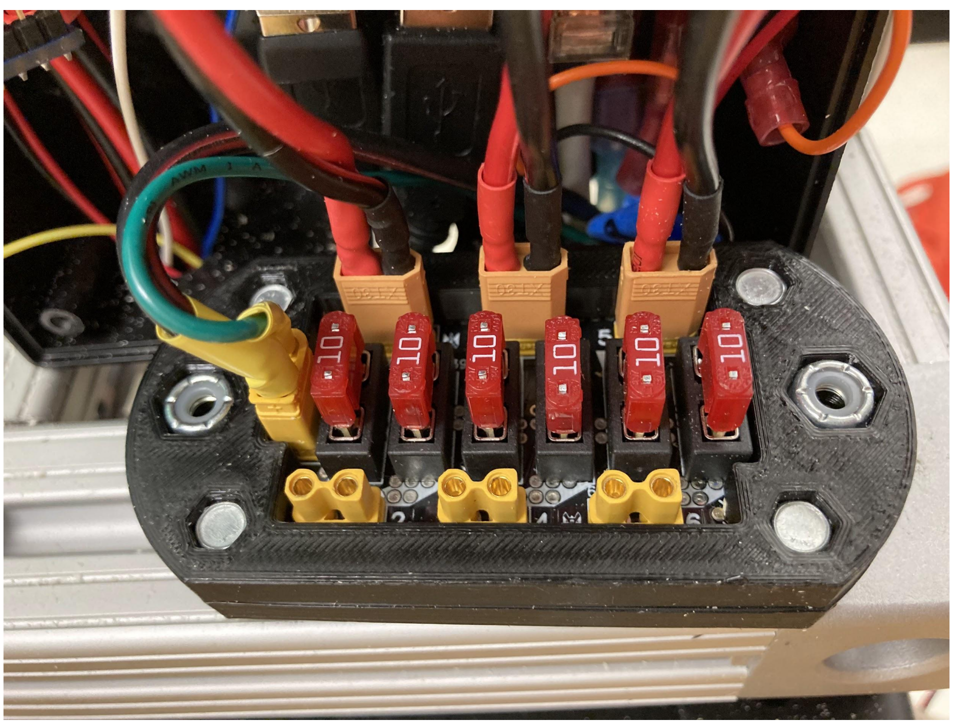
The saw actuation mechanism is controlled by a 12V linear 6 in nominal stroke linear actuator. As the linear actuator extends, the miter saw lowers and cuts the wood. A potentiometer within the linear actuator is used to determine the absolute position of the saw blade.



The roller intake mechanism of the RoboSaw. Wood is inserted into the intake which secures the wood firmly in place and pushes it through the saw frame using two direct drive motors mounted underneath the frame. (fig 10)

4.2 Electrical Component

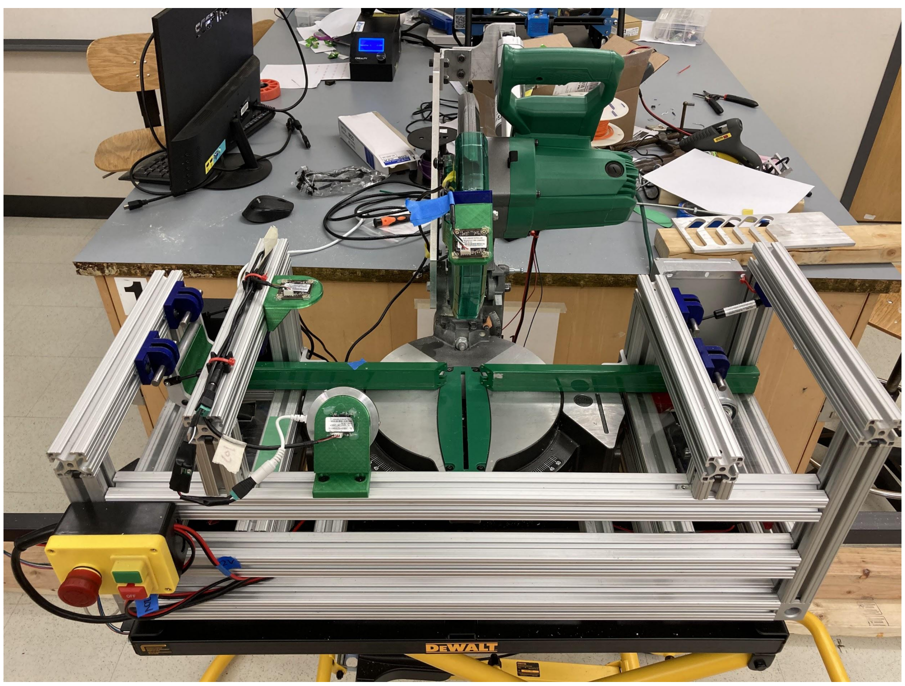
RoboSaw incorporates live DC and AC power systems in its design. Power from a 25A 12V AC to DC power supply is connected to a fused power distribution board. From there, power is distributed to the two motor controllers which drive the motors on the RoboSaw using DC pulse width modulation (PWM). Power is also supplied to the Raspberry Pi by means of a DC voltage step down regulator built into the motor controllers. The buttons on the pendant controller are connected directly to the GPIO pins of the Raspberry Pi with internal pullup resistors enabled in software. The miter saw blade is driven by a 120 V 60 Hz AC motor which is triggered by a 5 V normally open relay attached to the Raspberry Pi. Additionally, the miter saw blade motor is wired to an emergency stop button which disconnects both the AC and DC power from the RoboSaw simultaneously when triggered.



The fused power distribution board for the DC power subsystem of RoboSaw. Each connection is isolated by a 10 A fuse and each motor controller is connected to the power distribution board through a pair of XT 30 connectors. (fig 11)

4.3 Software Component

OpenCV, a popular open source computer vision library, is used in the image processing component of the RoboSaw software. The Python distribution of OpenCV is used because it is simpler and faster to prototype code in when compared to C++. The Python version of OpenCV is a wrapper of the C++ codebase so the performance penalty is less than 4% when using the Python library. This minor performance penalty was not a concern because we did not perform any intensive computer vision computations in the RoboSaw software program. To detect and track lines drawn on a piece of wood stock, first a canny edge detection filter is applied to generate a binary image containing many discontinuous line segments. Then, a Hough transform is applied to that binary image which finds equations to describe each line, essentially merging discontinuous lines into one if they all fall within a certain threshold for detection. The Hough transform outputs a list of lines, each described by their radius from the origin and their angle. These are used to determine the needed blade rotation and will assist in determining how far the piece needs to be fed along the saw table. In total, three cameras are used for sensing, image processing and aligning the blade with the line drawn on the piece of wood stock. An overhead camera is used to determine whether a drawn line is present on the wood and the line's angle. A secondary camera viewing the wood from across the miter saw fence determines whether the wood is present in the intake or not. Once a line is detected, a final camera mounted to the blade guard of the miter saw is used in a PID feedback loop to align the blade with the drawn line.



The three cameras used in the RoboSaw to detect the presence of wood stock and to align the drawn line on the wood with the miter saw blade. (fig 12)

5 Relevant Engineering Standards

Include a brief discussion of the most relevant engineering standards to your project. These can consist of standards related to electrical design and construction (eg. National Electrical Safety Code), software design, coding standards, communication and internet protocols, operational environment, governmental requirements, etc.

The standards for the emergency stop buttons used on RoboSaw are described below:

"NFPA79 and ISO 13850 detail the physical characteristics of a push button E-Stop, which will include a RED mushroom operator head with YELLOW background. The button must also be self-latching, meaning that once actuated, the Emergency Stop will remain in the actuated state until a voluntary and deliberate action is performed, such as twisting and/or pulling of the palm button for reset. In addition, this resetting of the E-Stop alone should not resume operation; instead a second deliberate action is needed, such as the pressing of a RESET button."

Furthermore, the specification for the physical placement of emergency stop buttons is defined as:

"OSHA and standards such as IEC 60204-1 state that an Emergency Stop must be readily accessible to the operator. This means that every operator station or any area of the machine worked on which is considered part of the normal operating procedure needs a means for an emergency stop. The Emergency Stop should be unobstructed and easily accessible without having to reach over, under or around to actuate." (Schmersal USA)

6 Cost Breakdown

The RoboSaw build of materials contains over 300 parts and nearly 100 custom fabricated components. A large portion of the costs for RoboSaw are devoted to raw materials stock, such as 80/20 aluminum extrusion, or aluminum bars. A redesign of the RoboSaw for cost could reduce expenses for raw materials significantly. Overall, about $500 in cost savings can be expected for a future prototype revision of RoboSaw when compared to the original alpha prototype.

Project Costs for Production of Beta Version (Next Unit after Prototype)				
Item	Quantity	Description	Unit Cost	Extended Cost
1	1	RoboSaw frame and stand	$800	$800
2	3	Cameras for computer vision	$50	$150
3	2	Direct drive roller intake	$100	$200
4	1	Saw actuation mechanism	$250	$250
5	2	Motor controller	$50	$100
6	1	Raspberry Pi	$50	$50
7	1	Miter saw	$120	$120
8	1	Safety electronics	$200	$200
9	1	Power supply	$50	$50
10	1	Miter saw turntable mechanism	$100	$100
			Beta Version-Total Cost	$2020

7 Appendices

7.1 Appendix A - Specifications

Requirements	**Value, range, tolerance, units**
RoboSaw Dimensions	33 in × 17 in × 16 in (L×W×H, without miter saw stand and with saw in lowered position)
Power Supply	2, 120V AC adapters
Cut Capabilities	Cutting speed: ● Maximum feed rate of 12 in/s ● Cutting time of 6 s Minimum cut spacing: 4 in (How far each drawn line must be separated from each other for RoboSaw to identify the line and perform a cut) Minimum distance from lumber ends: 4 in (How close a drawn line can be located to the edge of the wood stock)
Lumber Size	2×4, 2×6, 2×8 in dimensional lumber at up to 8 ft in length (with included miter saw stand)
Safety Features	● 2 Emergency Stop Buttons, one located on the pendant controller, and one on the frame ● AC Power to miter saw On/Off switch located on the frame mounted emergency stop switch
Pendant Controller	● 6 ft cord ● Three-button user interface (Run/skip, Confirm, Eject ● On/Off switch to RoboSaw DC power system

For specifications concerning the Metabo HPT C10FCGS Miter Saw, please refer to the manufacturer's user manual.

For specifications concerning the Dewalt DWX726 Rolling Miter Saw Stand, please refer to the manufacturer's user manual.

7.2 Appendix B – Team Information

RoboSaw was a self-proposed project created by an interdisciplinary team consisting of two Mechanical Engineering students, Pavel Gromov and Peter Siegel, Dylan Derose an Electrical Engineering student, and Theodor Waalberg, a Computer Engineering student.

Dylan Derose, Electrical Engineering:

Dylan worked on implementing all the electrical and electromechanical systems present in RoboSaw, including electrical wiring for safety mechanisms and input devices, motors and sensors. Dylan also contributed to the motor control programming component of the RoboSaw software application.

Pavel Gromov, Mechanical Engineering:

Pavel worked on the miter saw actuation mechanism and the miter saw turntable mechanism which allows the RoboSaw to perform angled cuts. Pavel used GibbsCAM to machine a majority of the components of the RoboSaw on the CNC mills in Boston University's Engineering Product Innovation Center (EPIC). After graduating Pavel plans to work as a mechanical engineer at Cana Technologies.

Peter Siegel, Mechanical Engineering:

Peter designed and manufactured the RoboSaw roller intake mechanism, the robot frame, and worked on the miter saw turntable mechanism. Additionally, Peter coordinated between team members working on the hardware, software and electrical components of the project. After graduating Peter will pursue a Master's Degree in Robotics, Systems and Control at ETH Zurich.

Theodor Waalberg, Computer Engineering:

Theodor worked on the computer vision and software components of the RoboSaw. Theodor wrote the line and angle finding algorithms for RoboSaw and algorithms for controlling the wood stock position, incorporating PID closed-loop feedback mechanisms.