ECE 445 Spring 2021

More Than A Chopping Board

Design Document

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Table of Contents

1. Introduction

1.1. Problem and Overview

A study done in 2012 [1] found that there were about 1190 cases of knife-related injuries per day, with about 280 cases occurring in the kitchen with lacerations on fingers/hands. One can assume that those injuries were caused by cutting items on the chopping board and missing the object, resulting in wounds on the hand.

There has been a significant increase in the population staying at home and cooking due to the massive shutdowns of restaurants and health concerns due to the COVID-19 pandemic. Seventy-one percent of consumers [2] stated that they will continue to cook at home more often even after the pandemic is over.

Along with the more statistical background of the problem at hand, we also have personal relationships with this problem, as university students. Many students are starting to cook by themselves for possibly the first time. This comes with plenty of mistakes and injuries in the process of getting used to cooking. With our project we plan to minimize the injuries and preparation time that comes with chopping, so that cutting vegetables is not what gets in the way of cooking a meal.

With the consideration of the growing number of individuals cooking as well as the need to have safety precautions due to the pandemic in restaurants, our solution offers a unique and helpful product to help navigate the kitchen with more safety and ease.

Our product, More than a chopping board, helps chefs, amateurs and pros, cook easier and better by giving them a tool to automate cutting vegetables. In restaurants, we see the demand for less pre-handled ingredients to curb the spread of covid. In households, we see the rise of cooking in general and those who want to experiment and create recipes with greater ease. With our product, we can allow consumers to cut six types of vegetables in four different ways by the press of a button. This will allow restaurants to have less direct hand-contact with the ingredients and allow household consumers to easily and safely cut their vegetables for their next meal.

The novelty of our product comes from the fact that there are plenty of vegetable cutters, mandolin, choppers, yet no one universal product to execute different chopping methods automatically. We also see that the products currently on the market only cater to select vegetables. With our project, we aim to combine the functionality of multiple vegetable cutters/handlers and provide the consumers even more options to chop them up into different styles.

1.2. Visual Aid

Figure 1: Person in kitchen using the vegetable cutter
Source: Adapted from [3]

Figure 1 shows a conceptual use of our product. Instead of juggling between multiple tasks in the kitchen and risking an injury, the user can use the vegetable chopper to handle the chopping for them. The acrylic screen hinges at the top of the frame so the user can insert a vegetable of their choice (a cucumber in the illustration in Figure 1), close the screen, select the chopping style and press start.

1.3. High-Level Requirements List

- Our assembly must be able to recognize when a vegetable has been inserted. It must also be able to distinguish between **six** common vegetables: potatoes, tomatoes, onions, lettuce, cucumbers, and cabbage. Our system must offer among **four** different chopping styles along with specific recommendations for the detected vegetable: large dice, medium dice, small dice, and Batonnet [4].
- Our assembly should achieve **75%** accuracy in the dimension of the chopped vegetable when compared to the dimensions defined in French cooking [4].
- Our system should be able to finish the entire process, from when the vegetable has been placed on the chopping board to when the chopping is done, in **6 minutes**. In calculating this value, we have assumed a runtime of 0.5 minutes for our vegetable detection program, 0.5 minutes for the user to confirm the style of chopping, and 4 minutes for chopping the vegetable under ideal conditions, and an additional minute for any delays on the user's end.

2. Design

2.1. Block Diagram

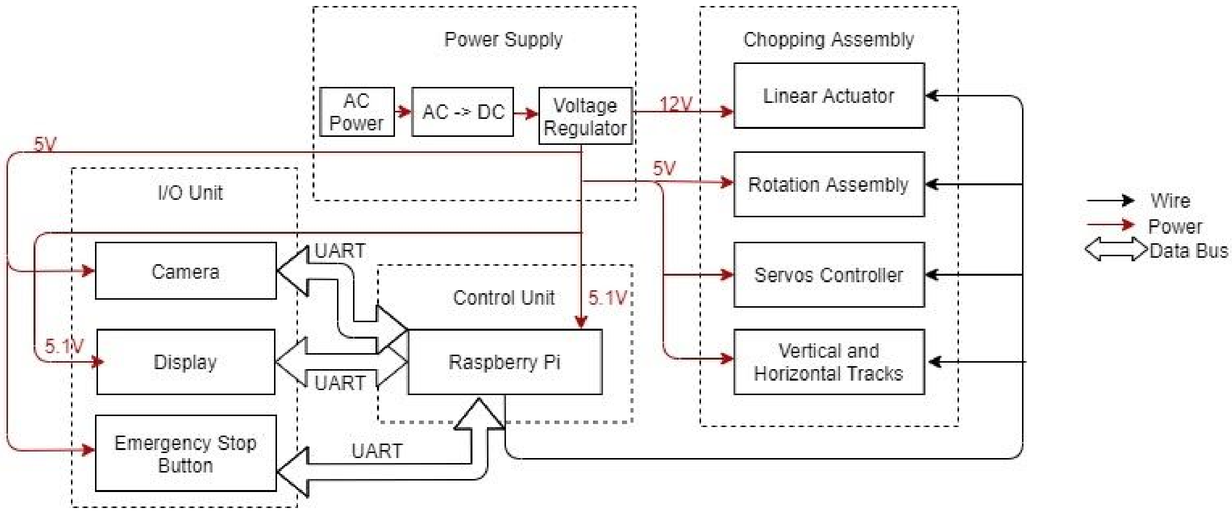

Figure 2: Block Diagram for More Than A Chopping Board

Our project comprises four main units as seen in the block diagram (Figure 2): Power Supply, I/O Unit, Chopping Assembly, and Control Unit. The I/O Unit and control unit work together to detect and distinguish the vegetables placed in the chopping region from our list of six vegetables mentioned in the high-level requirements. The I/O unit, chopping assembly and control unit together allow the user to select the chopping style, from the four chopping styles offered in the high-level requirements and chop the vegetable accordingly. The chopping assembly and control unit ensure that the vegetables are chopped with the highest level of accuracy in dimension as mentioned previously in the high-level requirements section. The power unit powers up all the other units by providing the specific voltage and current required for each of the subsystems to work efficiently. All of these units together achieve the high-level requirements set for the system.

2.2. Physical Design

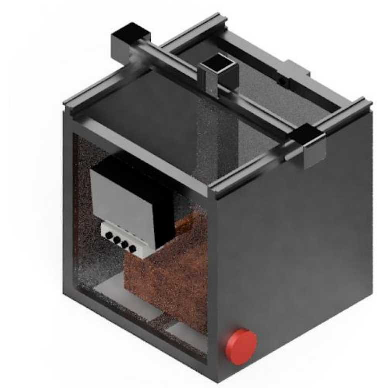

Figure 3: Fully rendered image view of More than a Chopping Board

Figure 3 is the 3D model of our physical design. The overall dimensions of this product are 30x30x30cm. It features three motors at the top, that help guide the motion along the x and y axis. Motion on the y-axis is controlled by two motors working together, and motion on the x-axis is controlled by the horizontal rail that is connected to the motor, the linear actuator, and the attached blade. The front and back of the assembly have acrylic screens. The user will be able to lift the front screen to insert the vegetable. This hinged screen provides a convenient way to insert the vegetable into the system. It also prevents vegetable juice, which might spurt out of vegetables while chopping, from spilling out of the assembly when it is shut. The display unit is attached to this front screen for ease of access to the user. This display is a touchscreen display, but to ensure that the assembly is waterproof, we will place this display in a casing and provide physical push buttons for user input.

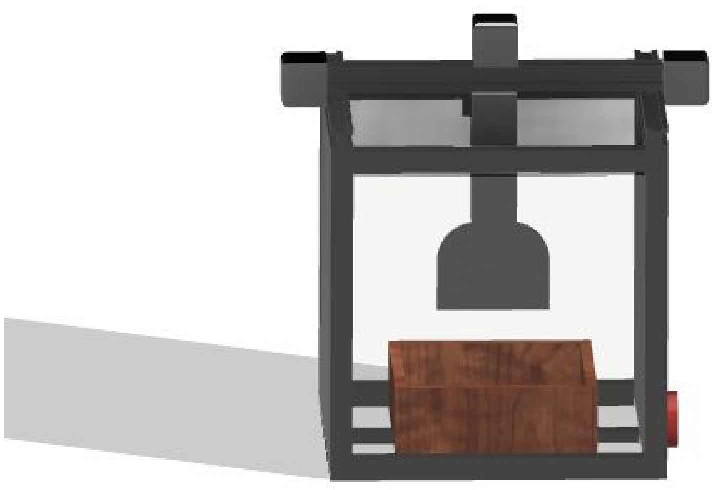

Figure 4: Front view of More Than a Chopping Board

Figure 4 is the rendering of the assembly without the display and buttons. Figure 4 provides a clearer view of the design of chopping assembly. The chopping assembly comprises the motor attached to the rails, the actuator (the long prism in Figure 4), and the blade (a sharpened putty knife). The chopping board, shown in Figure 4 and Figure 5, has guard rails, which are adjustable (not shown in Figure 4), to control the dimensions of the chopping region. The base is an 18x18cm chopping board with 6cm walls. Additionally, there is another servo motor at the bottom of the chopping board, which rotates the chopping board as required for the selected chopping style. This design choice was made because rotating the chopping board instead of rotating the blade reduces the load on the actuator-motor setup.

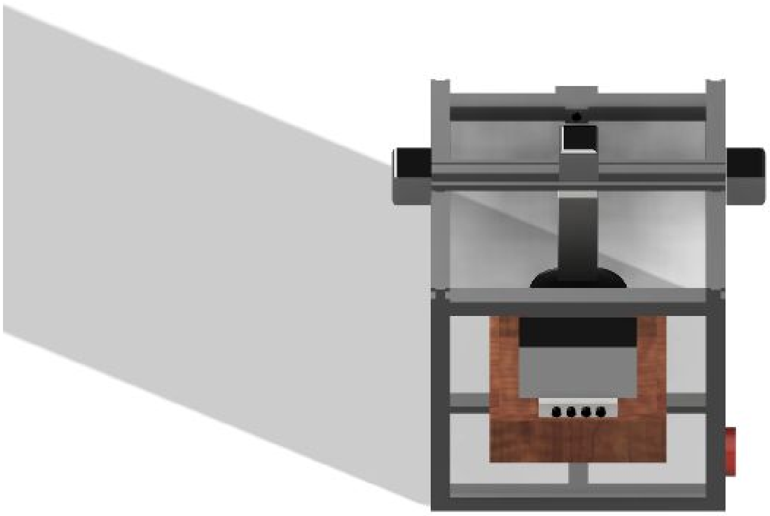

Figure 5: Birds-eye view of More Than a Chopping Board

As seen in Figure 5, there is a camera unit attached to the back frame. The camera will have a full view of the chopping board.

2.3. Subsystem Design

2.3.1. Power Supply

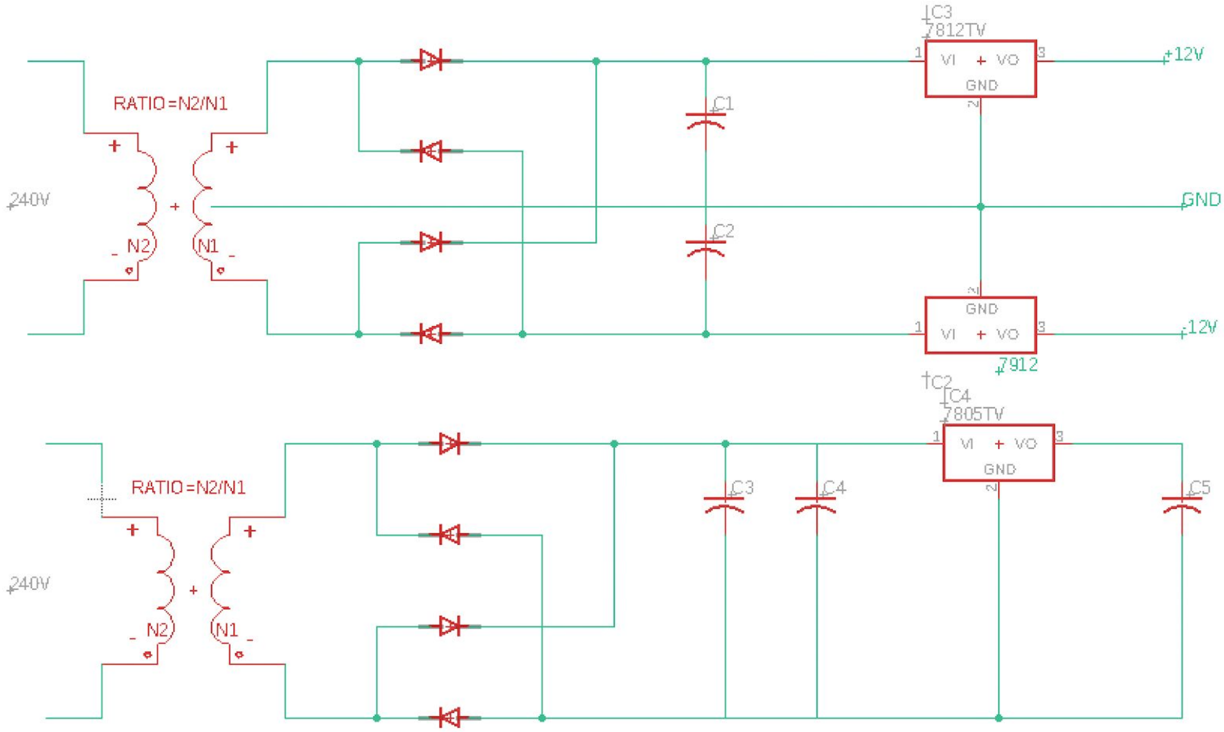

Figure 6: AC to DC Multi Power Supply (Output 5V and 12V)

The power supply, as shown in Figure 6, will draw power from a wall outlet and subsequently use voltage regulators to supply the specific power required by the subsystems and their respective components in the assembly. This custom power supply is needed since we have a lot of different components using varying voltages, primarily 5V and +/-12V. This circuit will use the 7812, 7912 and 7805 ICs with rectifier circuits, capacitors and transformers to convert the input 240V AC voltage into the required ones. Table 1 describes the requirements for this unit and the relevant methods of verification.

Table 1: Requirements and verification table for the power supply unit

Requirements	Verification
1. Must supply at least 5.1V at 3A to the Raspberry Pi	Connect the power supply to an AC outlet and subsequently test the line of power supply to the Raspberry Pi using a digital multimeter. Ensure that it reads at least 5.1V at 3A
2. Must supply 12V at up to 3A to the linear actuator	Use a digital multimeter to test the line of power supply to the linear actuator after connecting the power supply to an AC outlet. Ensure that it reads 12V at not more than 3A
3. Must supply 5V at 5.1A to the rest of the chopping assembly	After connecting the power supply to an AC outlet, use a digital multimeter to measure the line of power supply to the chopping assembly. Ensure that it measures 5V at 5.1A
4. Must supply 5V at 2A to camera and 5.1V at 2.5A to display in the I/O unit	Test the line of power supply to the camera and display unit to make sure they measure 5V at 2A and 5.1V at 2.5A, respectively

2.3.2 Control Unit

The Raspberry Pi will be the focal point of the project. Using the visual feed from the camera and computer vision, it will recognize the vegetables placed on the chopping board. It will also drive the display unit to accept and confirm user choices. With the information from the initial vegetable detection and the user input, it will control the chopping assembly to chop the vegetable in the selected chopping style.

The control unit will interact with the power supply, I/O unit and the chopping assembly. In combination with all these blocks, the control unit will be able to achieve two of the high-level requirements: detecting the type of vegetable placed on the chopping board, and chopping the vegetables with dimensions that are at least 75% accurate in comparison to the standards of french cooking. Table 2 describes the requirements for this unit and the relevant methods of verification.

The control unit will additionally provide a testing mode in the testing phase of the product. In the testing mode, the assembly will perform a single cut. The blade will rise back up and drop again when a button is pressed. The button that will allow the repeated drop of the blade will be mentioned on the display unit.

Table 2: Requirements and verification table for the control unit

Requirements	Verification
1. Must be able to recognize and differentiate between 6 different vegetables	Test the algorithm on one of the 6 types of vegetables. Ensure the vegetable has been detected and the type of vegetable detected matches the one placed in the assembly. Perform this verification on all 6 types of vegetables.
2. Send commands to control the motion of the blade for the selected chopping style	Insert stick of cold butter (to prevent sticking) in assembly and sequentially test all the different chopping styles.

2.3.2.1. Vegetable Detection Algorithm

As mentioned, the type of vegetable inserted into the chopping area will be determined by our control unit. For this to occur, It has to work with the camera and the display unit. The display unit will ask users if they want the assembly to detect the vegetable for them and give recommendations for the style of cut deemed fit for it. If the user presses yes, the signal will be transmitted to the Raspberry Pi then to take a capture of what is right now in the cutting area.

To identify between the 6 types of vegetable as in our high-level requirements, We will be using OpenCV's dnn module to load a pre-trained network that exists using deep learning object detection module since this is an available resource. We will be using the following libraries in addition to the OpenCV modules:

- Numpy
- argparse
- PiCamera
- Etc.

We will be adding more libraries to import as required, but above are the essential libraries to allow us to detect the vegetable inserted. Figure 7 below is the rough outline of the algorithm that will be used to detect the vegetable and suggest the chopping style of which it should be cut.

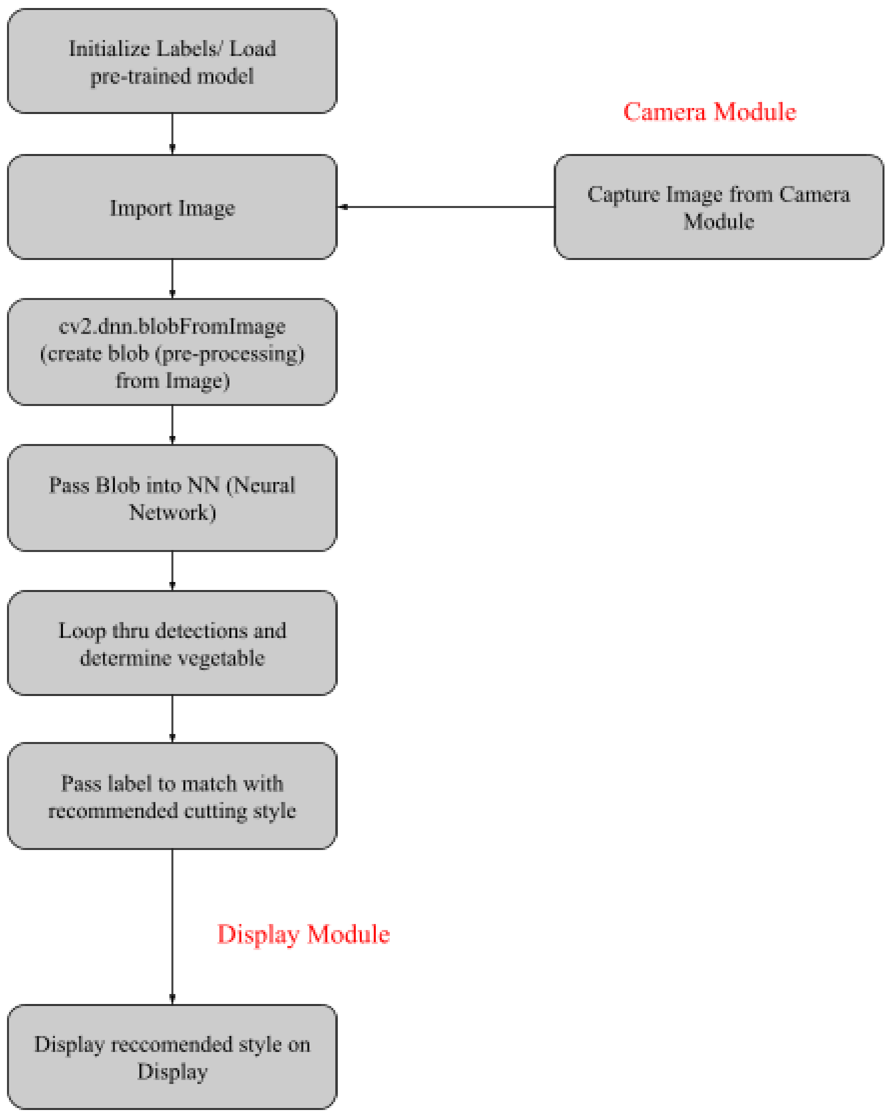

Figure 7: Algorithm for detecting vegetable
Derived with the help of [11]

With the label on the identified vegetable, the control unit will send out the recommended cut style as the following:

- Potatoes: Batonette
- Tomatoes: Medium Dice
- Onions: Fine Dice
- Lettuce: Batonette
- Cucumber: Batonette
- Cabbage: Batonette

Table 3: Requirements and verification table for the detection subunit

Requirements	Verification
1. Able to detect using pre-trained model of vegetable inserted with confidence=0.96	Insert and test all 6 vegetables in different styles of cuts (whole, cut in half) using a pre-trained model and extract accuracy given to each vegetable, to be greater than 96%.
2. Able to give recommended style of cut based on vegetable detected	Test as above, and read the display for the style of cut recommended with each vegetable. Check for 100% consistency with each tested vegetable (whole and cut in half), matching with the above recommended cut style for each vegetable.

2.3.2.2. Edge Detection Algorithm

In addition to detecting the vegetable itself we'll also need to detect its size and distance from a reference point in order to provide the correct offsets to the chopping assembly to use as the starting point of its operations. We will achieve this by using a reference sticker on our chopping area with a predetermined size and subsequently using OpenCV to get the distance of the recognized vegetable from it. By having a dark enough chopping area, most vegetables and their varieties off the ones that we have outlined in the high level requirements will contrast enough with the background for us to detect their edges iterate over the identified contours to find the coordinates to be inputted to the chopping assembly.

Table 4: Requirements and verification table for the detection subunit

Requirements	Verification
1. Identify the reference sticker consistently and measure its size and the pixels per inch ratio.	Test reference stickers of different styles and sizes and measure accuracy of the algorithm against known quantities.
2. Use the reference sticker to measure the distance of the object inside the chopping assembly from the center to define offsets.	Place objects at known distances and compare the accuracy of the system against what was measured.

2.3.3 Chopping Assembly

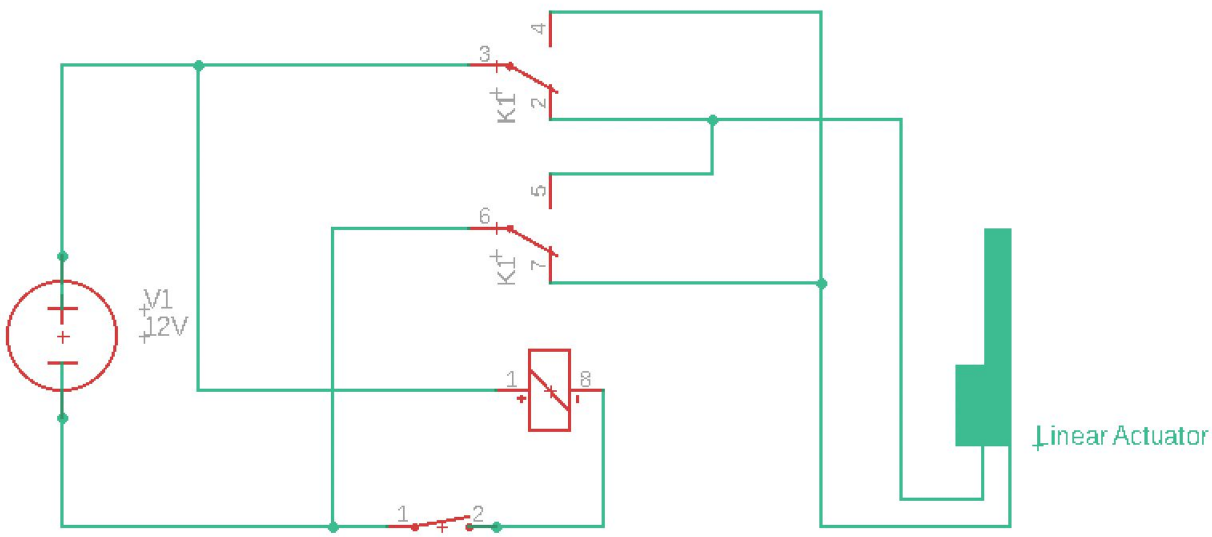

Figure 8: 12V DPDT Relay Controlled Linear Actuator

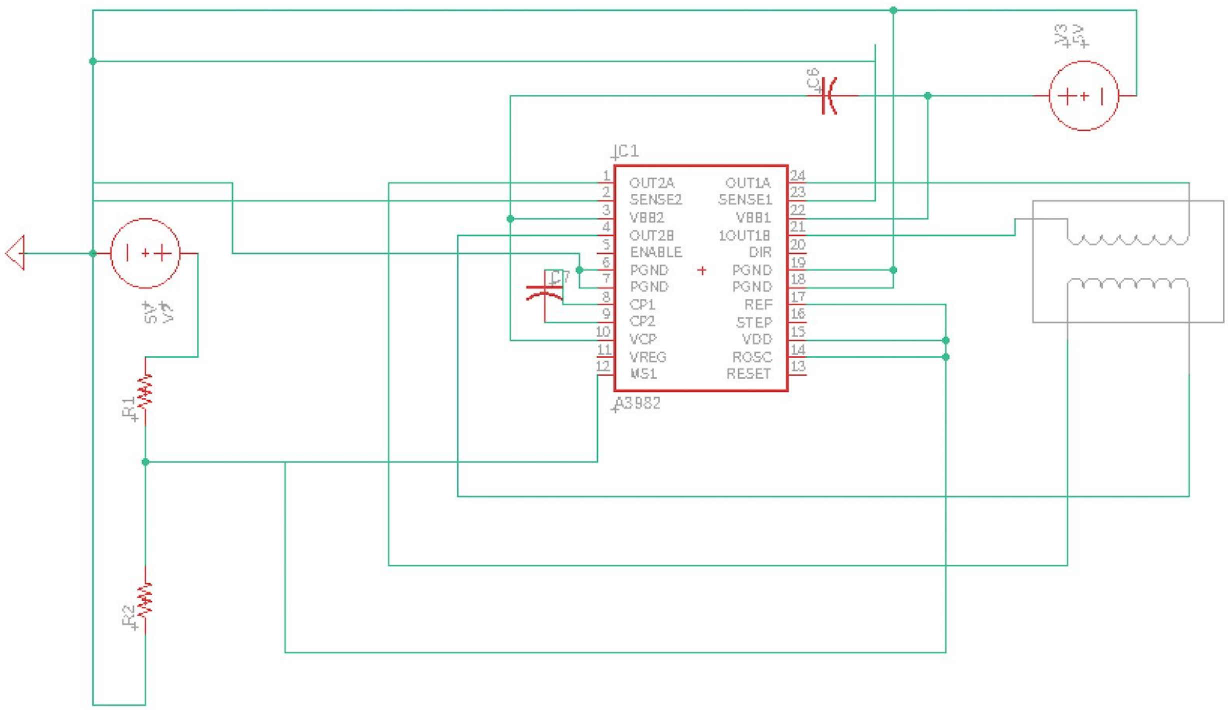

Figure 9: A3982 Driven Stepper Motor (Enable, Step, and Dir from Raspberry Pi)

The chopping assembly will perform the function of actually chopping the vegetables in accordance with the standards set in French cooking [4] to a 75% degree of accuracy. This assembly will be made of horizontal and vertical tracks attached to the linear actuator, such as the GR9863. Then the end of the linear actuator will be attached to the putty knife blade.

In addition, at the base of the chopping board, there will be a servo motor, that rotates 90 degrees to ensure cuts can be made in both directions. In total, we can control all 3D motion. The x-axis and y-axis motion is controlled by the stepper motors overhead, as shown in Figure 8. The z-axis will be handled by the actuator, shown in Figure 7. Additionally, the base being able to rotate gives us an even higher accuracy in chopping the four different styles. For testing this assembly, we will be putting to test a stick of butter, to ensure that the actuator has enough force to cut through a softer object first. If that succeeds, we will be able to move to tougher produce, such as a cucumber. Table 4 describes the requirements for this unit and the relevant methods of verification.

Table 5: Requirements and verification table for the chopping assembly

Requirements	**Verification**
1. Must be able to exert a maximum of 300N of force on the vegetables [5]	Placing a weighing scale under the assembly without the blade to ensure the exerted force does not exceed 300N
2. Must operate by drawing not more than 5V at 3A in total	Use a multimeter to measure the power drawn by the assembly
3. Must chop the vegetables within 4 minutes with 75% accuracy according to the chopping dimension standards set in French Cooking [4]	Select 1 of the 4 chopping styles. Measure the chopped vegetables to ensure they are at least 75% accurate in dimension when compared to the standards set by French Cooking [4]. Perform this verification one by one on all the 4 chopping styles.

2.3.4. I/O Unit

The I/O Unit will comprise the camera and the display unit. The display unit will provide a user interface to the system. The camera and the display unit will provide input to the control unit. The specific purpose and description of the components are provided below.

2.3.4.1. Camera

The camera will be placed inside the casing and will be positioned as shown in Figure *5*. We will be using the Arducam B0033 Camera Module [6] for this setting. The camera will supply live footage of the object placed on the chopping board to the control unit. This feed will then be used to determine the type of vegetable that has been placed on the board using computer vision.

The camera is crucial to the detection of vegetables, which is one of the high-level requirements for this project. The camera will only interact with the power supply and the control unit for the scope of this project. Table 6 describes the requirements for this unit and the relevant methods of verification.

Table 6: Requirements and verification table for the camera unit

Requirements	**Verification**
1. Must be able to capture the chopping region and send to the Raspberry Pi a. Capture once when user presses on detect vegetable on display b. Capture once every time the actuator comes back up to detect edges	1. Connect Raspberry Pi to computer a. Insert test code to display image after vegetable capture `cv2.imshow(cv2.WINDOW_NORMAL, image)` b. Insert above test code for the purpose of edge detection.

2.3.4.2. Display

Figure 10: Picture of the screen being used for the display unit.
Source: Adapted from [7]

The display unit will display the vegetable that has been detected by the control unit. It will also allow the user to select the chopping style for the vegetable either from the options provided based on the detected vegetable or a different one from the available chopping styles. It will also have the option to start and stop the chopping process to account for the safety of the user.

The display unit will serve as the primary source of interaction between the rest of the system and the user. A 3.5 inch LCD screen will be used to display the menu, task status, and system messages to the user. Figure 10 shows the E361 LCD screen and Raspberry Pi 4 case unit which will be used as the screen. As seen in Figure 5, the buttons will be placed in a casing below the screen. There will be four buttons: power, confirm input, move left, and move right. Regular push buttons will be used as the buttons and labels will be placed under each button.

The screen will serve several purposes. Figure 11 uses a flowchart to summarize the various functions of the screen and the sequence of messages to the user, and inputs from the user.

In the testing phase of the project, the screen will also display an option to start in testing mode. The details of the testing mode have been discussed in the control unit. To get out of the testing mode, the system will have to power off and start up again. Although our choice of display has a touch screen feature, we will disable this feature by placing a layer of protection over the screen.

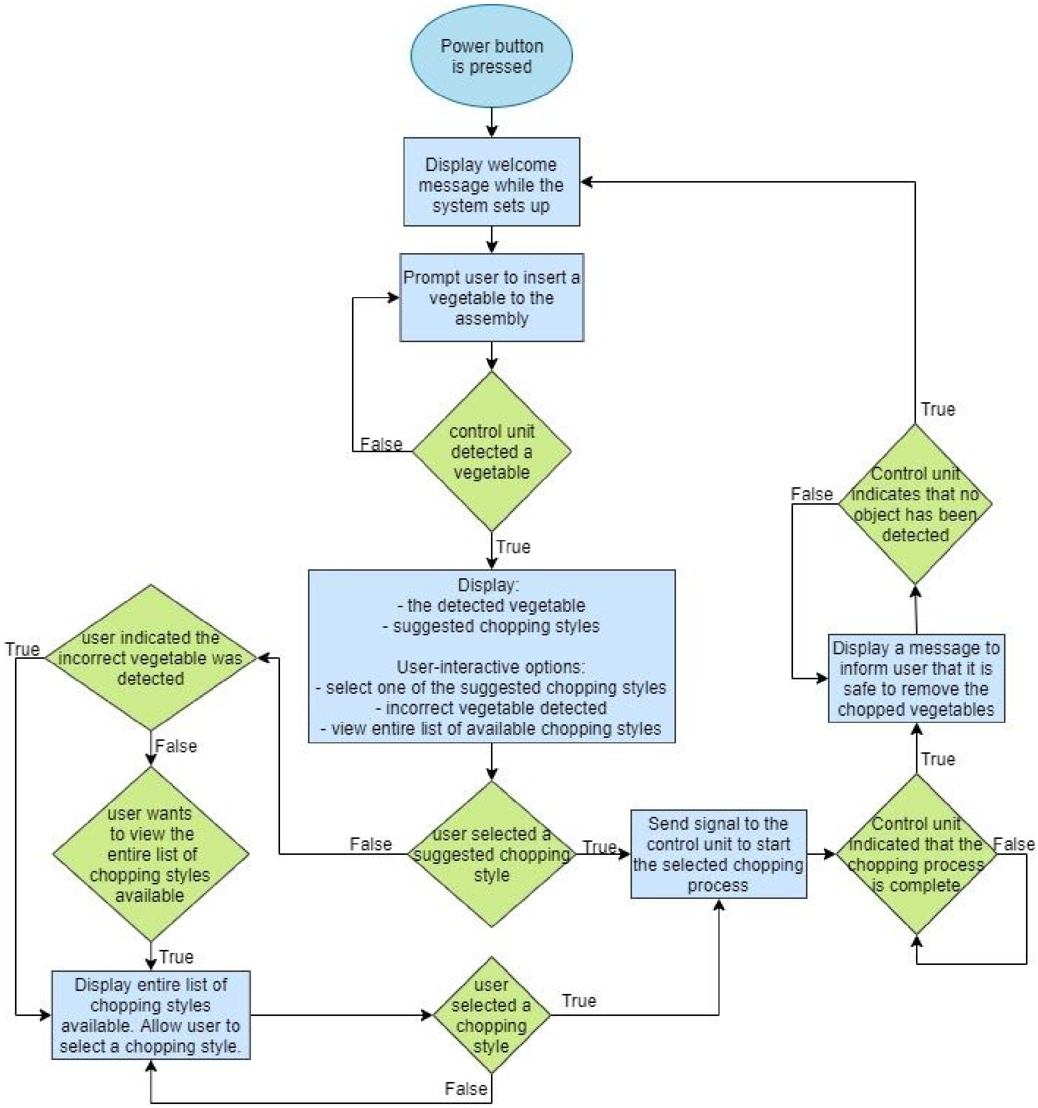

Figure 11: Flowchart for the functionality of the screen

The power button is used to switch the system on/off. The confirm input button serves as the 'select' button for the user to confirm their choice. The move left and move right buttons will be used by the user to navigate the options on the screen.

The display unit will interact only with the control unit and the power supply. The control unit will provide the display unit with the chopping styles that need to be displayed and establish user interaction through messages to the user and inputs from the user. Table 7 describes the requirements for this unit and the relevant methods of verification.

Table 7: Requirements and verification table for the display unit

Requirements	Verification
1. Must display the option to select cutting style and view recommended cutting style	Be able to view recommended cutting style and toggle between different cutting styles
2. Must allow users to confirm selected vegetable and cutting style to start	Push the confirm button after selecting a chopping style. The chopping assembly should start chopping in the selected style

2.3.4.3. Emergency Stop Button

This unit uses a red push button. This unit is connected to the control unit and power supply. Pushing this button will immediately stop the chopping process. As seen in Figure 5, this button will be placed on the side of the assembly for quick and easy access to the user. The primary purpose of this button is to ensure the user's safety. If any emergency occurs once the chopping process has started, this button provides a quick way to stop the process. Table 8 describes the requirements for this unit and the relevant methods of verification.

Table 8: Requirements and verification table for the emergency stop button

Requirements	Verification
1. Must immediately stop all chopping processes as soon as the button is pressed.	The system is instructed to start a chopping process. The red button is pressed. The chopping process stops immediately.

2.4.Tolerace Analysis

The chopping assembly is integral to the success of our project. The precision of the chopping assembly ensures that regular customers get precisely chopped vegetables, which is the ultimate goal of our project. The time taken by this unit to completely chop a vegetable is also crucial to drive value for the users. Therefore, our tolerance analysis is based on the precision and the speed of the chopping assembly.

Precision:
The Nema 17 stepper motor has a 1.8 degree step angle which means the stepper takes $\frac{360}{1.8} = 200$ steps per revolution. The finest cut in our high level requirements is the small dice cut, which requires the side post chopping to measure 1/4 inches (6.35mm). Assuming our chopping assembly is 8 inches long, it will take 32 steps (each measuring 1/4 inch) to cover the length of the assembly. With 1.8 degrees corresponding to each step on the stepper motor the belt drive will have to be designed to operate such that each step in the x/y axis of the chopping board, will take 5 steps of the step motor, i.e 9 degrees of rotation. This way the stepper motor can cover $\frac{360}{9} \times 0.25 = 10\ inches$ in a full rotation which will be more than enough to cover the area of the chopping board and give us fine control over the size of our vegetables. By using 5 rotations per step we will also be able to operate the assembly slightly faster thereby saving the consumer a lot of time.

Time:
The linear actuator selected for the project has a 2 inch stroke length with a travel speed of 12mm/s. Thus the linear actuator will take a total of 4.23s per extension. Since an up and down motion is required, therefore the total time per stroke will be 2*4.23 ≃ 8.5s. This gives us a total of 28 strokes in the 240s time limit allotted to the chopping assembly. This is almost equal to the number of rotation steps (32) needed to cover the 8 inch chopping board in 1/4 inch steps. This ensures we can cut the largest possible vegetable that can be fit into the setup with the greatest possible precision.

3. Cost and Schedule

3.1.Cost Analysis

The group comprises two Computer Engineering majors and one Electrical Engineering major. The average salary for a UIUC Computer Engineering graduate is $106,551 which corresponds to $51.23 hourly. The average salary for an Electrical Engineering graduate is $79,714 which corresponds to $38.32 hourly. Thus, assuming 15 hours of work per week for 12 weeks this semester, the total wages for the development of this prototype would be

$51.23 * 2 * 15 * 12 + 38.32 * 15 * 12 = \$25,340$

Table 9: Cost breakdowns for parts needed

Part Name	Cost of the part
Linear Actuator	$43
Nema 17 Stepper Motor (3 pack)	$24
Raspberry Pi 4B (4GB)	$35
Raspberry Pi Camera Module	$18
3.5 inch screen with case for Raspberry Pi 4	$30
ICs (7812, 7912, 7805)	$2
Stepper Motor Driver	$5
Total Cost	**$157**

3.2. Schedule

Table 10: Schedule for the remainder of the project

Week	Suzy (Online)	Rishabh (In-Person)	Vatsala (In-Person)
3/8/21	Brainstorm approach to the code for vegetable detection, help with PCB Design, Send Machine shop final design and tweak if necessary	Start brainstorming the PCB Design, help brainstorming the approach for the code for vegetable detection, order parts	Brainstorm approach to the code for vegetable detection, help with PCB Design
3/15/21	Software for vegetable detection/ hand detection	Complete the PCB Design and submit the first round order, bring parts in to Machine Shop	Complete the PCB Design and submit the first round order
3/22/21	Start on chopping mechanism code	Submit second PCB if needed, help with chopping mechanism code, check with machine shop for mechanical product	Help with chopping mechanism code, check with machine shop for mechanical product
3/29/21	Finalize chopping mechanism code / soft test with motors	Put together the chopping assembly	Put together the chopping assembly
4/5/21	Software for LCD/ guide full integration with hardware	Integrate chopping unit with software / test for accuracy	Integrate chopping unit with software / test for accuracy
4/12/21	Testing week for fully integrated product, Refine prototype if needed	Testing week for fully integrated product, Refine prototype if needed	Testing week for fully integrated product, Refine prototype if needed
4/19/21	Work for Mock Demo/ Finalize system	Work for Mock Demo/ Finalize system	Work for Mock Demo/ Finalize system
4/26/21	Work on the Final Report and Presentation	Work on the Final Report and Presentation	Work on the Final Report and Presentation
5/3/21	Final Report/Presentation	Final Report/Presentation	Final Report/Presentation

4. Ethics and Safety

Possible safety concerns of this project include injuries caused due to sharp objects. In the ACM Code of Ethics 1.2 [8], we are to “Avoid Harm”. Since we plan on providing blades along with the assembly of our project, we, along with the consumers, will have to exercise the same precautions as we would around any other sharp objects.

Consumers could be harmed in the process of inserting the blade in while the machine is operating, or hurt themselves while in the process of initially inserting the vegetable to cut their wanted object. We plan to eliminate this danger by making sure the users confirm their choice to chop on the display with an additional button. Along with this, we will provide the packaging of the blade with designated cases for the blade portion of the chopping assembly. This way when the user wants to take the blade out, they will have a safe spot to return it to. Among specific accommodations for the knife, there are a few general precautions necessary when operating this machine. It should be used only on top of a cutting board that is given on a flat surface. Small children should be prevented from operating this machine. The product will have an acrylic door in the front which needs to be opened before the chopping area can be accessed. In addition, the high guard rails designed to prevent the slipping of the vegetables have been calibrated such that it will be very difficult for someone to unintentionally put their hand in the 2inches of spaces between the blade and the board.

Considering an even better failsafe, we hope to implement an emergency stop if all else fails and if the users assume they will hurt themselves accidentally. We could build an infrared cage around the chopping assembly, which, when breached while the chopping is still in progress, would activate a circuit breaker to immediately stop the chopping.

Along with the issue of safety, this assembly could also cause electric shock if mishandled, especially in its intended environment, the kitchen. Since the vegetable inserted should ideally be washed, the product should be able to handle the contact of water between the blade and the vegetable. This problem is dealt with because the blade is waterproof. This product should ideally not be submerged under water at any point. The user might shock themselves if the device is near water or the user has an excessive amount of water on their hands to operate it. We plan on providing a waterproof coat to the outer and inner portions of the product, to make it water-resistant for the occasional contact of water. Although we are using a touchscreen display, we are planning to wrap the display in acrylic, therefore minimizing direct content with water. Consumers will be able to control the content of the display with physical buttons that are much safer.

Unfortunately, there are ethically gray areas about developing such products. Since we are not able to detect much more than an object and hand inserted, we cannot foresee what sort of objects are going to be cut. This product is only intended to be used on vegetables, but since we do not have control over what gets put into this assembly, we cannot guarantee that it will be a vegetable. This product is only suitable for food use and to avoid ethical breaches, there will be a written warning to insert only food items into the board to urge users to only put in items they deem appropriate.

The user will additionally be provided with a safety manual which will include warnings and precautions that need to be taken while using the product.

For the testing of this project, we will be implementing a mode on our cutting manual to only cut once, and halt until a resume button is pressed, and additionally confirmed. In addition, we will be wearing protective goggles and gloves while testing the blade mechanics. We will abide by the ethics guidelines set by IEEE and ACM to best bring this product into the best light.

References

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