Semi-Automated Soybean Cutting Device

Abstract

Farmers across Louisiana must test the quality of their crops to ensure that consumers are given what they know to be the best value of crops for their money. The problem lies in the variability in which the crops, specifically soybeans, are evaluated. While there are traditional markers that indicate whether a crop has been damaged, some of these markers are not obvious to the naked eye. Soybean evaluation is one of those processes that contain a high percentage variability when it comes to what is considered a bad trait or a good one. One such variability in this process comes in the very beginning stages. The method of cutting a soybean for evaluation varies from individual grader to individual grader. For example, the instruments may vary among many different utensils such as a kitchen knife, razor blade, or a scalpel.

The difference in the methodology used to split a soybean affects what the grader sees when looking for markers to indicate the quality of the soybean. To help lessen any differences caused by outside factors, this project created a device that can evenly split soybeans in half so that they may later be run through an image analysis processor to assess and grade the quality of the beans. This team has come up with a design that can cut up to five beans at once in an even method with a smooth enough cross section for later image processing.

Acknowledgements

The Soybean Cutting Device group would like to thank Dr. Kevin Hoffseth and Dr. Bruno Rego for being the main advisors on this project. Dr. Hoffseth's graduate students, Alexander Lee and Beatriz Garcia, have also helped this group with their design process, specifically regarding the emergency brake, electronics, and coding. The group would also like to extend a special thank you to Dr. Yongchan Kwon, Dr. Todd Monroe, and Dr. Phillip Jung for preparing them well throughout the semester through their teachings and feedback about engineering design processes. A huge thanks to Mr. Tom McClure in the BE Machine Shop for fabrication assistance including cutting acrylic panes for the safety shield. Lastly, the group would like to thank the LSU Biological and Agricultural Engineering department as a whole for helping each individual student reach where they are today and for providing the funds for this project.

Background

Louisiana is a state that relies heavily on its agricultural products to help boost its economy. The residents can get a lot of funding from farming and agricultural practice. One of the biggest exports in Louisiana other than natural gas or petroleum are soybeans. Soybeans are the third largest export in Louisiana and they bring in approximately $16.7 billion dollars annually {OEC, 2023}. Soybeans are mostly utilized in animal food and other food productions for human consumption such as oils used on salads or for frying food. This is a huge part of the economy for the state so it should be treated with care. The quality of each product that is sold to a consumer should be carefully analyzed to ensure they are getting the best quality for their money. One way that this is done traditionally is by assigning a grade to each load of soybeans that are being sold to the silo. The soybeans are given a grade, one through four with one being the best and four being the worst, and the farmers are then compensated based on the overall grade of the beans in their truck. The beans are graded based on any possible heat damage, filth, shape, cracks, and any other unknowns or impurities found within the beans. The closer the beans are to being uniform in shape the better grade they get and the more the farmer is paid for selling their crops. The problem is that not every silo has the same standards when it comes to grading beans.

Some silos are tougher when it comes to grading standards and farmers traditionally want the most money they can get for their products. As a result farmers will drive to multiple silos to receive multiple grades and evaluate which one gives the best grade as well as the most money for the product. This could involve multiple hours of driving between locations which means more gas, time, and resources are needed to ensure that the beans are transported in the fastest and quickest manner possible. This way the beans do not have any additional damage when they are being transported between locations. One way that this problem has been tackled is by using computer aided analysis of each bean. The computer is given information on how the bean should look according to the standards given and what any abnormalities in the beans could mean in terms of damage. By counting the abnormalities and grading the severity of these problems an accurate rating can be given so that farmers can get the money they deserve.

Before an image analysis can be performed, the beans must be cut in order to see the makeup of the inside of the bean. Due to a lack of consistency in the way the bean is cut in half, the image analysis may run into problems while trying to analyze each half. The beans need to be cut in such a way that variability from the blade can be minimized. This way the image analysis is only focused on aspects of the bean that were damaged due to nature or the environment and not man made factors such as an inaccurate cut. In order to mitigate any potential errors a semi-automated cutting method has been designed to cut some of the beans in half so they may be then analyzed. The cutting method will mimic that of the guillotine in which a blade will come directly down slicing the beans in half. Another force will be needed to keep the beans in place while the cutting is happening so that they do not slip under the blade. To hold the beans a case of some kind must be utilized so the beans are unable to move. This will also contain the beans so that when the halves are revealed they can almost instantaneously be transferred to the image analysis.

Problem Statement

Due to the inconsistency within the soybean grading process, a more consistent system is needed. Cutting soybeans by hand is also a time consuming and strenuous process. Soybeans graders often use handheld blades such as pocket knives to cut said soybeans. This method only allows for one soybean to be cut and graded at a time. They will then grade the soybeans by comparing them to previously graded bean images. This introduces personal bias into the soybean grading process.

An automated system for cutting and grading soybeans would combat these issues. The scope of this particular project is dedicated to the cutting aspect of this process. This project aimed to create a semi-automated device that will cut one soybean consistently and smoothly enough to allow for image processing downstream in the process.

Measurable Objectives

One goal of the machine was to limit the time needed to cut soybeans for the grading process. To assess this, the team did a comparison of cutting soybeans by hand with a pocket knife and cutting the same amount of soybeans with the machine. The less time that is used in cutting the beans, the more time that inspectors have to spend on checking on any irregularities within the bean and hopefully they can give a more accurate grade since they will not be as fatigued from the cutting process.

Another measurable objective that the team assessed was the smoothness of the cut beans. To achieve this, the team used a 105 millimeter Nikkor lens camera to photograph the cross section of the cut soybeans. This image was then input into the ImageJ software for further analysis.

The process must also be able to stop at a moment's notice if there is an emergency such as there being an obstacle in the way of the blade or a malfunction in the system that may cause harm to the user or the system as a whole. This is done with an emergency stop button.

Overall, this project is part of an initiative to better standardize the soybean grading process. In doing so, bias could be eliminated from the grading process and both time and money could be saved in the industry.

The apparatus must be at most the size of a bench top and three feet tall. The bench top is 29.25 inches wide, 24 inches long, and 2 inches tall. To ensure that the device is semi-portable or at least can be moved from one location or another it must fit these dimensions. This also ensures it does not take up too much space within the silo.

The maintenance on the machine must also be kept to a minimum. Since this is used by farmers not engineers they may not understand how to keep up with a machine that requires too much maintenance so to make sure the device is still user friendly, the maintenance that will be required the most must be something that can be completed by non-engineers.

These all need to be incorporated into the design to make sure all the objectives of the device are met for the farmers to be able to use and for the team as engineers to ensure the device is safe and ready for use.

Constraints

The team was required to stay under a budget of $1,200. The initial estimated budget for the project was projected at $918.57; however, after all design improvements, the team spent $1,133.29.

Timing was another constraint placed on this project. The team was allotted one semester for design and one semester for fabrication. This constrained the team when it came to design improvements after the initial machine was built and working.

For the specific design, the team was tasked with keeping the machine to a "benchtop table" sizing. This means that the machine could not exceed the size of a lab benchtop. The machine also could not be taller than three feet in order to keep it accessible and convenient for use.

The most prominent constraint is that the irregularly shaped soybeans must be cut in half in almost perfect fashion. This may prove to be difficult as soybeans do not come in a one size fits all manner. This makes the holding apparatus difficult to make since it has to be able to fit a majority of beans so they can be cut properly.

The beans have to be cut so that they can be processed by the imaging analysis device. This means a smooth even cut is needed so no shadows or manmade errors that disrupt the analysis process.

Lastly, the design and fabrication of this machine was not based on any previous design. All aspects of the design were completely original. This constrained the team more when it came to troubleshooting since they did not have previous groups' experiences to guide them.

Design

a. *The Frame*

To meet the constraints of the benchtop size and the semi-automated design, the team drafted a design in the Fall Semester that was similar to that of a guillotine (Figure 1). This design consisted of a frame that was constructed with aluminum t-slots. This frame was initially meant to be in a tent like configuration; however, during actual fabrication, the team decided that an A-frame (Figure 2) configuration would be

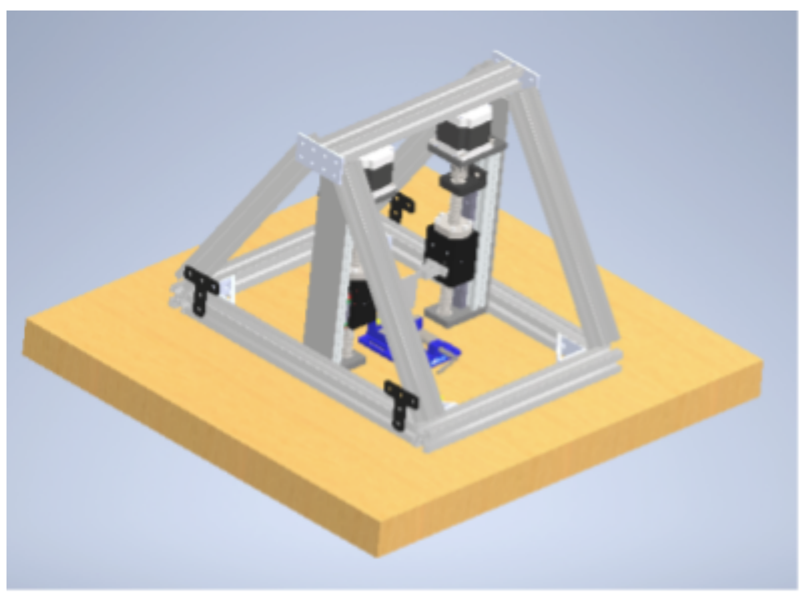

Figure 1: Initial machine design drawn in Autodesk Inventor.

a better suited design. Two linear actuators on ball screws were fastened to the inner parts of the A-frame. Between these two linear actuators, a jointer blade was placed. The linear actuators are able to move the blade up and down on an XY plane. Each linear actuator was connected to its own stepper motor to allow for movement down the ball screws. These stepper motors were then connected to a power supply and arduino that would communicate code and allow for the blade to move up and down. All of this design was fastened to a 24 inch by 24 inch by 23/32 inch plywood base. This base was lifted off the benchtop using three 2 inch by 4 inch wood pieces.

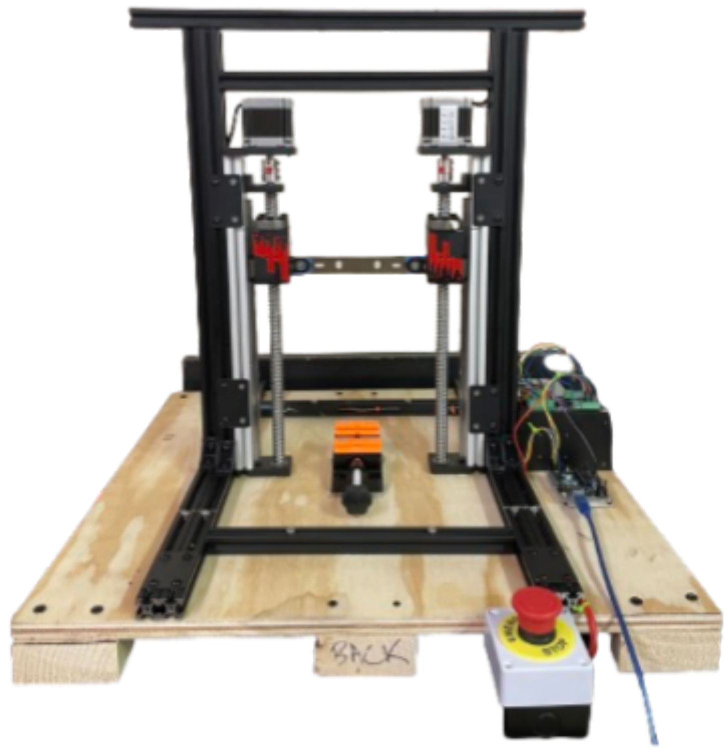

Figure 2: Final machine design and fabrication

The frame of the machine consisted of eight 600 millimeter t-slots. For each structural component, two 600 millimeter t-slots were fastened together to provide more stability for the height and base of the frame. The frame width was based on two 300 millimeter t-slots placed at the bottom of the frame, one towards the front and the other towards the back of the base. Another 300 millimeter t-slot was placed at the top of the frame. An additional 500 millimeter t-slot was placed at the very top of the frame to provide additional stability (Figure 2). All t-slots were connected together with 90° and linear brackets. This t-slot A-frame was bolted to the wooden base via holes drilled into the t-slots.

The jointer blade chosen for the design was picked for various reasons. This blade fits within the design of the frame and is similar to other cutting devices used for nuts that the team took precedence from. This blade is also easily accessible for replacement. If the user desired to replace the blade, they could easily order a two-pack off of Amazon. The bevel of this blade is not centered, so the vice of the machine was placed according to where the bevel best meets the center of the blade allowance of the soybean holder.

b. The Holder

The initial soybean holder design (Figure 3) created in November 2023 consisted of multiple rows of soybeans within a latched case. This design was ultimately scrapped after receiving feedback regarding the concerns about impurity transference. The first iteration of the new design consisted of a 3-D printed holder. This holder had a small divot for one soybean and a groove in the middle to allow the blade to pass through the soybean. After preliminary testing, it was found that the blade allowance was too small, leading the case to get stuck on the blade and come out of the vice. The second iteration (Figure 4) of the design widened this blade allowance and pushed up the bean slightly to allow for better removal of cut soybeans. After testing this design, some more minor changes were made. Figure 5 shows the final design for the soybean holder. This design consists of five small divots. It also has a widened groove for the blade to successfully pass through the soybean and a more shallow depth to ensure that the soybean does not get stuck within this holder. In addition to this printed holder, the team added spray foam into the groove. The team found that the softer surface allowed for more clean cuts of the soybeans. The team also added reusable gel pads to the top of this case. This allowed for a better grip of the soybean during the cutting process. A better grip of the soybean led to more clean cuts and ensured that the soybean would not shoot out of the case when cut. These gel pads also do better to accommodate the irregular shape of soybeans. The printed final iteration of the soybean case can be seen in Figure 6.

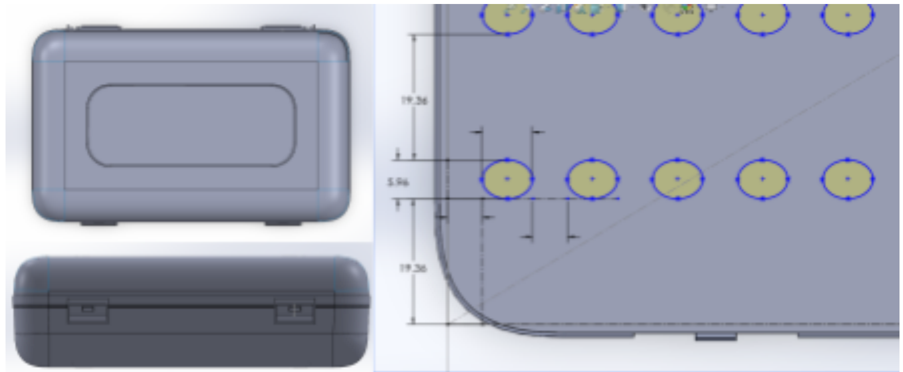

Figure 3: Original soybean holder design. This consisted of multiple rows of beans in divots in a pencil case like design. This was changed due to concerns about impurities transferring between rows via the jointer blade.

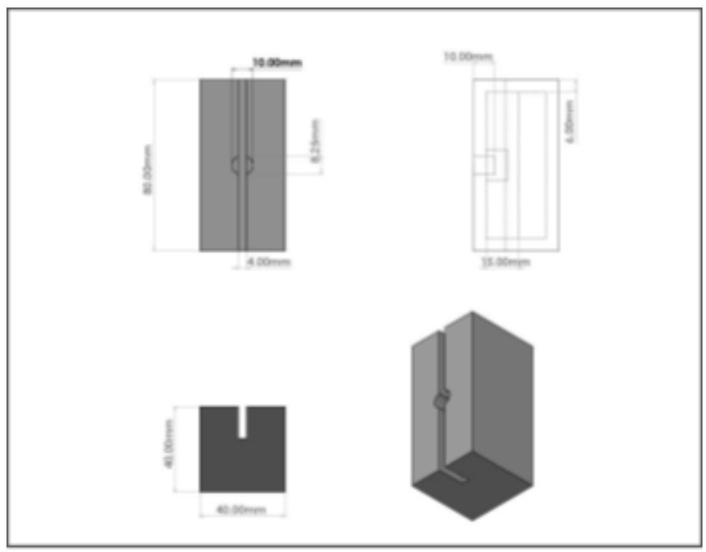

Figure 4: Soybean holder iteration 2.

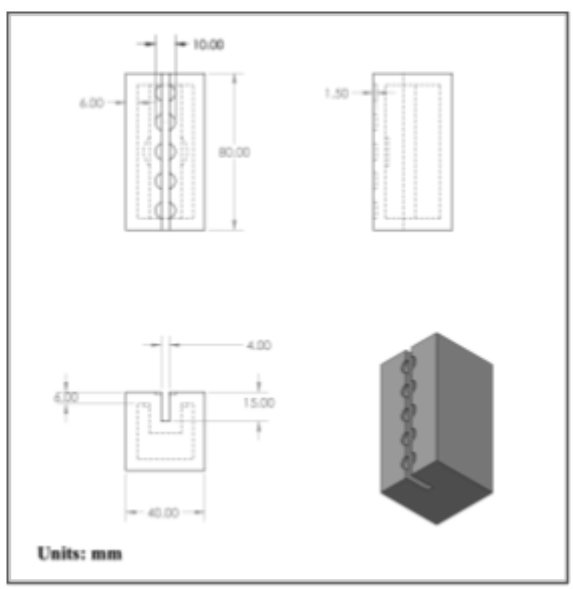

Figure 5: Final soybean holder iteration.

c. *Safety*

The team designed three layers of safety for the machine. The primary safety feature is an emergency stop button placed at the front of the machine, which can be seen in Figure 2. This would stop the machine from running if pressed. The second part of the safety design was an acrylic shield that encased the machine. This was meant to deter operators from placing their hands near the machine while it was running.

The first iteration of the shield design was to fasten multiple clear totes together and put those totes on a hinge connected to the plywood base. This iteration was ultimately moved on since the team was unable to find clear totes for a reasonable price. The second iteration (Figure 7) of the shield design consisted of four acrylic sheets fastened together using two 2 inch by 4 inch planks and four 300 millimeter t-slot. This encasement rests on a 31 inch by 31 inch wooden frame that encases the wooden base of the machine. This iteration was ultimately found to be too bulky. The last iteration of the shield design was to fasten 600 millimeter t-slots to the base. Using additional t-slots a frame would be created that would hold the acrylic panels.

The last aspect of the safety design is the emitter and receiver attached to the case. The front panel of the case is able to slide up and down along the t-slots, allowing access to the cutting area for loading and unloading soybeans. When running, the emitter emits a laser. If the receiver is not actively receiving the laser, then the machine will not run. This is to better ensure that the shield is closed while the machine is running. Both the third iteration of the safety shield and the laser safety check are not currently implemented into the fabricated machine; however, the team felt that the proposed designs are worth mentioning.

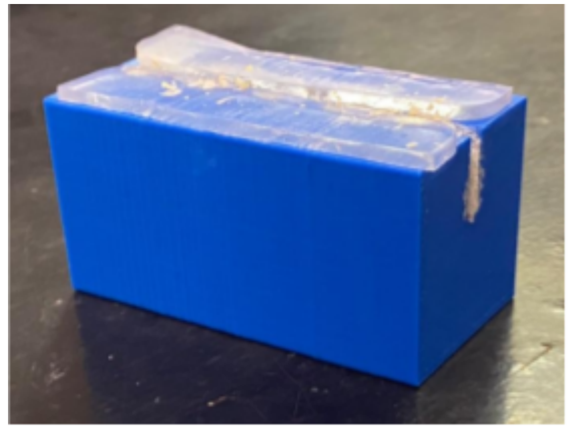

Figure 6: Oblique view of the 3-D printed soybean holder.

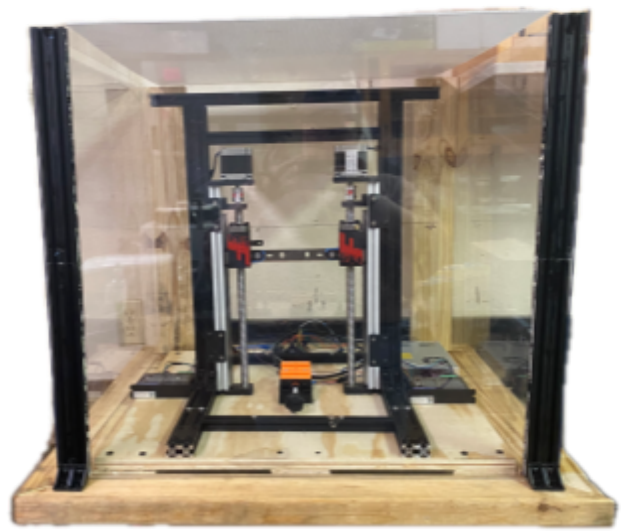

Figure 7: Current safety shield fabrication. Represents iteration #2 of the design

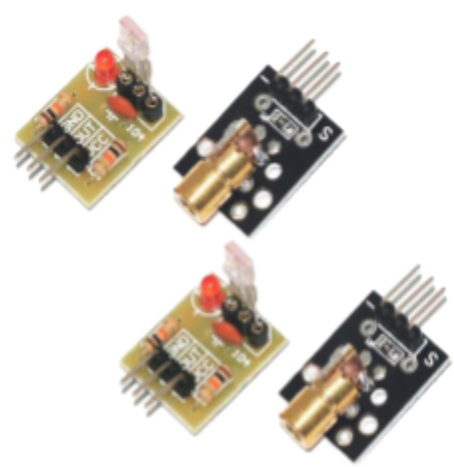

Figure 8: Emitter and receiver proposed for laser safety check.

d. Electronics

The ball screw linear actuators come equipped with NEMA 23 stepper motors. These motors require a rated current of 2 Amperes and operate within a driving voltage range of 24 to 48 volts. They can deliver a maximum thrust of 188 newtons and have a power range of 115 to 230 Watts. To power both motors, a power supply was chosen with an output voltage of 48 volts and a maximum current output of 7.3 amperes. For controlling the stepper motors, DM 556T digital stepper drivers were selected. These drivers can output currents ranging from 1.8 to 5.6 amperes and handle a voltage range of 20 to 50 volts. An emergency stop button was included in the setup, which consists of two normally closed emergency stop push button switches. These switches can handle voltages up to 660 volts and a rated current of up to 10 amperes. The Arduino UNO was chosen as the microcontroller due to its compatibility with the C++ language and ease of use with the selected stepper drivers. To connect all the components, 28 American Wire Gauge (AWG) wires were selected for the Arduino UNO to digital stepper connections, 22 AWG wires for the NEMA 23 stepper motors to stepper driver connections, and 18 AWG wires for the power supply to stepper drivers connections.

Fabrication

To achieve the fastening of t-slots together, the team used linear brackets and M4 screws. This allowed for the t-slots to stay together and provide additional support to the design. In order to fasten the frame of the machine to the plywood base, the team had holes drilled into the t-slots along the base. From there, the team used 3 inch bolts and nuts to secure the frame to the base. 90 degree brackets were used to connect the t-slots along the plywood base to the perpendicular t-slots.

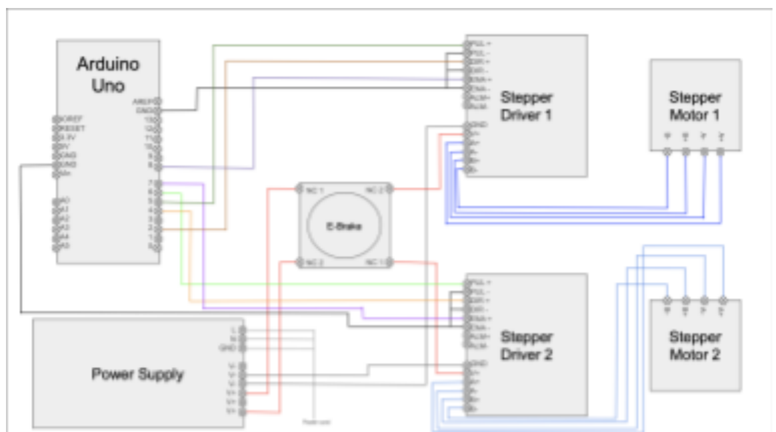

Figure 9: Wiring schematic

In the wiring schematic (Figure 9), the power supply features two live wires running in parallel, linked to the emergency stop push button switch. These live wires extend from the emergency stop to the V+ terminal in each digital stepper driver.

The ground wires from the power supply are directly connected to the ground terminal on the stepper drivers. Additionally, the A+, A-, B+, and B- wires are connected to their respective ports on each stepper driver. Finally, the positive pull, direction, and enable terminals are connected to the digital pins on the Arduino UNO. The negative pull, direction, and enable terminals are also connected to the ground on the Arduino.

To operate the machine, several codes were written, with the "run" command serving as the primary code for executing the cutting process. Starting the machine involves entering "run" into the serial monitor. This code initiates the motors to rotate clockwise, driving the blade downward for 3775 steps (equivalent to 18.875 revolutions), thereby cutting the soybeans in the holder. Subsequently, the motors reverse direction and rotate anticlockwise for 3775 steps to raise the blade back to its starting position. In case the emergency stop switch is activated, the main process for resetting the machine involves using the "ResetUP" command. This command directs the motors to rotate anticlockwise by the number of steps specified by the operator. To bring the blade back to its starting position, the operator measures the distance in centimeters from the top of the slide block to the starting marker and inputs this measurement into the "CM_CALC" command. This command then calculates the necessary number of steps to return the blade to its starting position based on the measurement provided by the operator. Additionally, there are other reset commands provided as helpful tools for the operator:

- "ResetDOWN": Resets the blade downwards (motors set to rotate anticlockwise) by the user-defined number of steps.
- "Step1UP": Resets motor 1 upward (rotating anticlockwise) by the user-defined number of steps.
- "Step1DOWN": Resets motor 1 downward (rotating clockwise) by the user-defined number of steps.
- "Step2UP": Resets motor 2 upward (rotating anticlockwise) by the user-defined number of steps.
- "Step2DOWN": Resets motor 2 downward (rotating clockwise) by the user-defined number of steps.
- "IN_CALC": Calculates the number of steps based on the distance (measured in inches) between the top of the slide block and the starting marker.

Budget and Accessibility

e. *Budget*

The team presenting this project has a total of $1200 to design and fabricate this machine. The main components consist of the linear actuators on threaded rods, the t-slots, and the

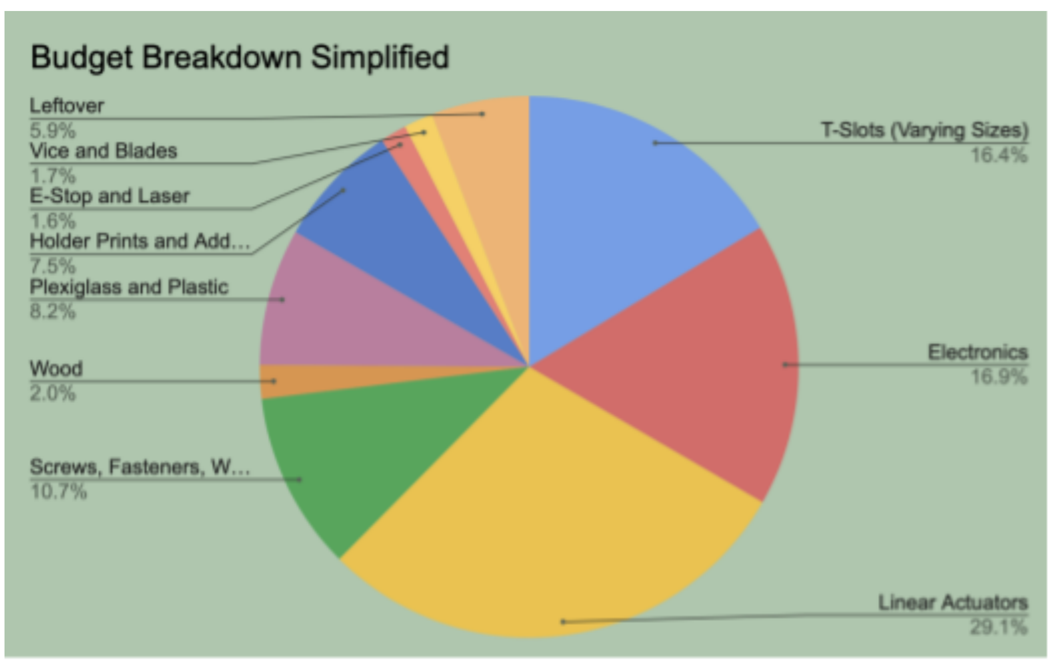

Figure 10: Simplified budget breakdown of the project. The group had $66.71 leftover out of the $1200 allotted

electronics. A simplified overview of purchased items can be seen in Figure 10.

f. Material Accessibility

An important consideration when designing this device was to make the material accessible. For example, the team originally considered custom ordering a blade for the device; however, the team decided against that since people utilizing the device should be able to easily repair components of it. Instead the team opted for a jointer blade that could be purchased off Amazon for about $10. Other similar design considerations consist of the reusable and easily replaceable gel pads on the soybean holder and the expense to print the soybean holder ($30 per holder).

g. *Machine Maintenance*

There is some basic machine maintenance that needs to be performed to ensure the efficiency of the machine. For the blade, simply wiping the blade down so that it is free of debris before each cut keeps the bladeThe blade will also need to be sharpened or replaced after multiple uses. The blade will get dull due to constant use so if the farmer is not able to sharpen the blade it will need to be replaced to get the best results.

The linear actuators will also need machine grease. The linear actuators rotate along a threaded rod so to ensure that the two metal components do not catch machine grease will make sure they are slick enough to rotate without interference. As for the holder, the gel pads will need to be washed and replaced. The gel pads are washable with water and can be reused multiple times but with all materials normal wear and tear happens. Eventually the gel pads will need to be replaced once enough damage has been done but in the meantime simply running it under water will do the trick.

Results and Discussions

h. Smoothness

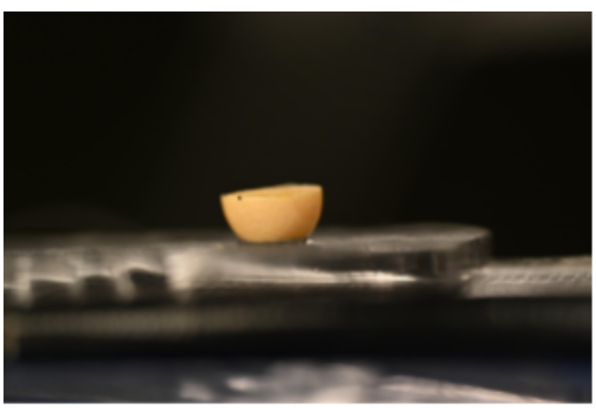

Figure 11: Soybean cut by machine on holding mechanism for imaging.

Figure 12: Soybean cut by hand on holding mechanism for image analysis

The main measurable objective of this project was to cut the soybean in such a way that it can be analyzed using image analysis. For this to happen, the cut surface must be relatively smooth with little to no shadows cast on the bean from irregularities since irregularities will distort the image. After all the beans were cut using a handheld blade, holder iteration two, and holder iteration three, the accuracy of the cut surfaces were quantified using image analysis through ImageJ. The pictures were taken using a Nikkor 105 millimeter lens with the following camera settings: Iso 800, Shutter Speed 1/400, and F stop 7.1. The camera was placed thirteen centimeters from the centerline of the soybeans to the centerline of the camera lens, seventeen centimeters from the table to the centerline of the lens, and at a 0 degree inclination as seen using a tripod with a level in it (Figure 13). An outline was created in ImageJ using the side profile perpendicular to the cut surface seen in Figure 16.

The outline was then made into a scatter plot by essentially tracing the side profile of the cut surface. Figures 14 through 15 show the process of transforming the image to an outline and finally to the scatter plot. Figures 17 and 18 show that the points from the outline were then used to make a line of best fit. Since the beans could not be placed perfectly parallel to the ground slope instead of horizontalness was used measured. The points should align closely to the line of best fit confirming that the cut is almost perfectly straight. The root mean square error was used to evaluate the cut.

The root mean square error accounts for the difference in the expected value from the actual value using the line of best fit. It is then square rooted to better compare the values to determine how close the points are to being in a perfectly straight line. Using this methods the results yielded that on average using a hand held blade yielded an average of 27.47854125 pixels for the root square mean error using the machine and case two a root square mean error of 20.57397826 pixels was found, and the machine plus case three had a root square mean error of 20.85054148 pixels. These values show that the cuts from the hand held blade deviated on average farther

Figure 13: Set up of soybean imaging.

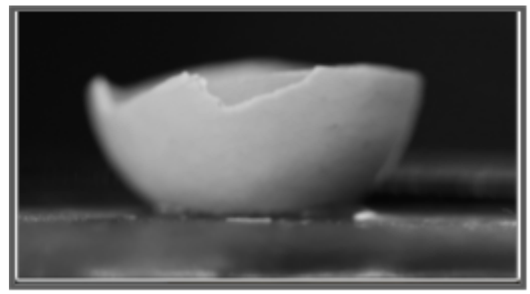

Figure 14: Greyscale image of cut soybean in ImageJ

Figure 15: Threshold image of cut soybean in ImageJ

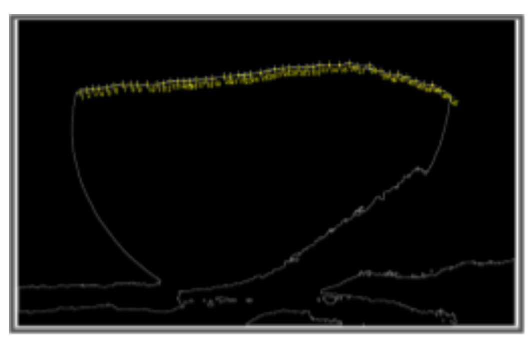

Figure 16: Plot of bean cut surface in ImageJ.

from the line of best fit and therefore farther from being in a straight line.

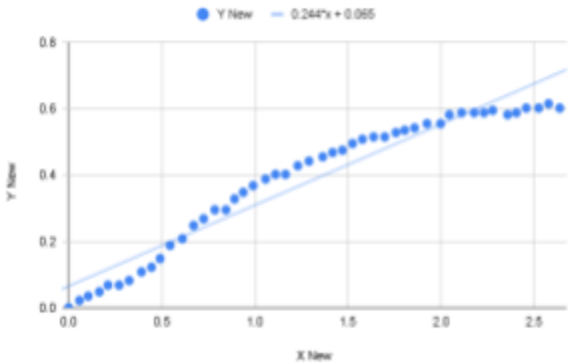

Figure 17: Cut of soybeans with a lower RMSE value (machine cut)

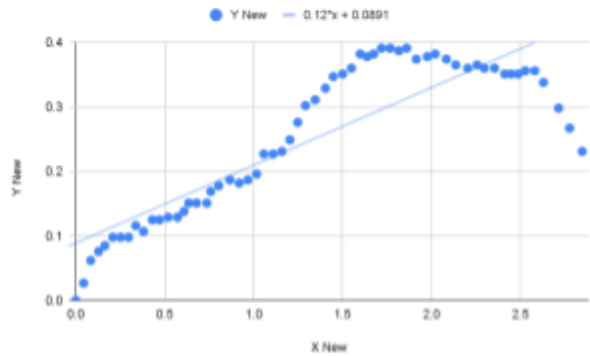

Figure 18: Cut of soybeans with a higher RMSE value (hand cut)

i. *Efficiency*

Another goal of this project was to cut down the time it took to cut multiple beans in half. This comparison was made by timing how long it takes to cut five beans by hand versus the time it took to cut five beans via the machine. The machine can cut five beans at once due to the case holding capacity while the hand cut beans had to be cut one at a time. Through testing, it was found that to cut five beans by hand it would take two minutes and ten seconds. Meanwhile, it took a total of fifty-five seconds to load the beans into the machine, cut the beans, and unload the beans from the machine. A reduction of over half the time it takes to cut the same amount of beans demonstrates an improvement in methodology in at least one area of the measurable objectives that were given.

Figure 19: Soybeans cut with the machine

Figure 20: Soybeans cut by hand

Even without quantitative analysis by just visualizing the cut surface there are obvious differences. On the beans that were cut by hand (Figure 20), there are ridges about halfway through the bean that could create shadowing when image analysis is applied. Also the soybeans experienced significantly more fracturing where little pieces would break off. For the beans cut by the machine (Figure 19), the cut surfaces are visually smoother with less ridges and almost no fracturing.

j. Discussion

The results that were obtained revealed that the machine does increase the efficiency of the cut. Overall, the cuts made by the machine had a smoother cut surface. This is shown by the smaller root mean square error value. The smaller values indicate that the values were closer to the values predicted by the line of best fit that was determined from the given points. This is also evident with qualitative analysis. Through just visualizing the beans it can be seen that cutting them using a handheld blade results in the bean breaking off into multiple pieces. This makes image analysis difficult since there is not a clear picture of the cut surface as a whole. There could be some damage that cannot be seen since the whole half cannot be analyzed. Meanwhile, the cuts made by the machine resulted in whole halves of the beans with little to no fracturing and limited ridges. This increases the accuracy of image analysis when it is used to grade the bean. These cuts were also completed faster with the machine than by hand. Overall, the device appears to be a beneficial tool in the agricultural community.

Conclusion

The goal of this project was to create a semi-automated soybean cutting device that can cut the beans in a consistent manner. It was found that the machine consistently cut five beans at once, which surpassed the goal of just cutting one bean consistently. By using threaded rods, linear actuators, stepper motors, a power supply, and some coding, a guillotine like device was created that cuts multiple beans at once in an semi-automatic manner. The scope of this project was to successfully cut one soybean consistently; however, to ensure success in that manner, the cut soybeans were analyzed through ImageJ image analysis. Image J was used to create a scatter plot out of the outline and points determined from the side, perpendicular to the surface cut. The smoothness of the cut was then evaluated and compared to the line of best fit by using the root square mean error. The root mean square error showed that when the beans were cut by the machine the cut surface was smoother overall. This also could be obtained by qualitative analysis since the beans cut by hand split into multiple pieces that could not all be imaged. They also had ridges down the middle which would impact imaging since it could hide any impurities. Overall, the team believes that this project shows effective utilization of engineering design and execution. This project also shows promise in standardizing and streamlining the soybean grading process.

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Appendix I - Labeled Machine Layout

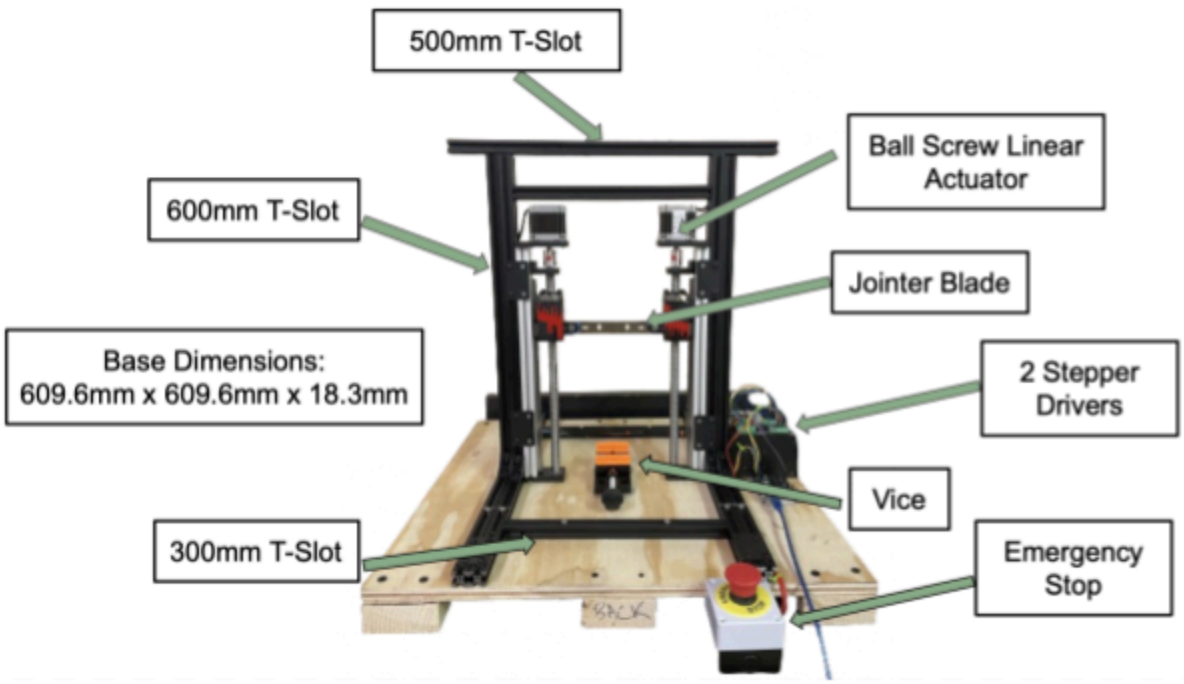

Figure 21: Final machine design and fabrication with labeled parts. Not seen or labeled are the arduino uno and the power supply

Appendix II - Soybean Elasticity

Table 4. Strain energy and modulus of elasticity of soybean seeds of different moisture content

Cultivar	Moisture content %				
	7	10	13	16	19
			Energy mJ		
Aligator	17.3 a (6.4)	40.5 ab (13.0)	80.7 b (26.9)	132.6 c (39.8)	233.8 c (54.7)
Amandine	25.2 a (10.7)	56.6 c (15.5)	111.9 d (67.2)	179.0 e (111.1)	341.1 e (164.7)
Augusta	19.6 a (7.0)	43.1 ab (11.2)	82.5 b (65.8)	134.7 c (96.8)	231.7 c (129.4)
Herta PZO	16.4 a (7.9)	32.5 a (14.7)	60.6 a (40.0)	98.6 a (58.6)	174.4 b (80.6)
KS-40	12.6 a (9.1)	34.5 a (21.5)	85.4 bc (45.7)	154.5 d (74.4)	342.3 e (128.3)
Mavka	22.7 a (8.3)	41.3 a (13.3)	65.9 a (26.8)	96.1 a (35.2)	131.7 a (37.5)
Petrina	18.1 a (5.8)	42.4 ab (20.3)	79.7 b (48.9)	117.7 b (64.9)	239.9 cd (102.9)
SP-16	23.9 a (9.5)	51.0 bc (8.0)	93.1 c (61.1)	123.4 bc (72.8)	247.9 d (113.8)
SP-29	18.0 a (8.9)	37.0 a (18.9)	69.8 ab (50.3)	100.3 ab (65.1)	193.3 b (97.6)
Aligator	21.9 a (10.3)	52.7 bc (14.1)	107.0 cd (77.9)	174.4 e (103.7)	339.0 e (217.3)
Average	19.6[1] (9.0)	43.2[2] (19.0)	83.6[3] (51.2)	131.1[4] (86.4)	247.5[5] (126.8)
			Modulus MPa		
Aldana	4396 c (784)	1593 cd (203)	601 ab (62)	341 ab (42)	190 a (21)
Aligator	3409 a (574)	1261 ab (307)	508 ab (92)	242 ab (53)	177 a (35)
Amandine	6072 e (421)	1193 a (265)	422 a (58)	184 a (30)	95 a (14)
Augusta	3857 b (606)	1302 ab (310)	622 ab (104)	346 ab (69)	213 a (38)
Herta PZO	4018 b (675)	1125 a (402)	458 a (154)	305 ab (93)	125 a (45)
KS-40	4771 d (512)	1851 d (432)	951 c (96)	381 ab (46)	269 a (29)
Mavka	4338 c (312)	1571 cd (318)	598 ab (84)	230 ab (39)	200 a (30)
Petrina	3906 b (278)	1471 bc (246)	847 bc (83)	387 b (45)	268 a (28)
SP-16	5329 de (527)	1779 d (295)	749 bc (69)	496 b (55)	253 a (25)
SP-29	4934 d (820)	1521 bc (323)	417 a (58)	346 ab (57)	173 a (26)
Average	4503[4] (734)	1467[3] (353)	617[2] (111)	326[1] (60)	196[1] (38)

Note. Mean values in columns marked with the same letter, and in rows marked with the same numerals do not differ significantly at α = 0.05. Standard deviation values in parentheses.

Figure 22: Moisture content affect on modulus of elasticity for different soybeans (Kuzniar, 2016).

When the seed modulus of elasticity (Figure 22) is lower, its viscosity parameter tends to be higher, leading to reduced resistance to mechanical damage and increased susceptibility to fractures caused by external forces (Kuzniar, 2016).

Appendix III - Force Calculations

- Both motors running in tandem
  - Max thrust = 188 N x 2 = 376 N
- Calculations based on soybean seed hardness
  - Force needed to shear 1 soybean = 1.8 N to 4.3 N
  - Force needed to shear 5 soybeans = 9.0 N to 21.5 N

Figure 23: NEMA 23 motor dimension and performance

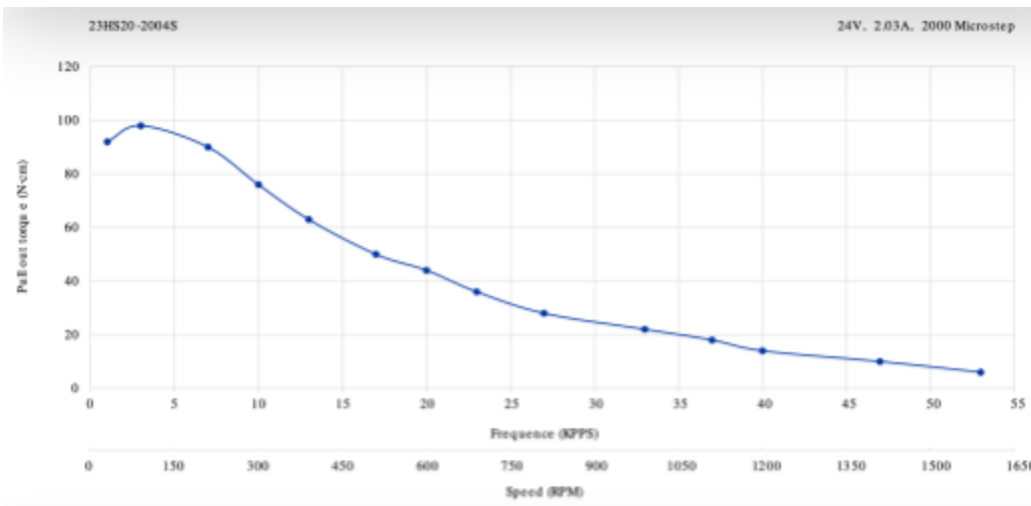

Figure 24: NEMA 23 Torque Curve

Position Accuracy[mm]	±0.03		
Ball Screw Diameter[mm]	φ12	φ16	φ16
Lead[mm]	4	5	10
Max Horizontal Loadings[kg]	25	25	20
Max Vertical Loading[kg]	15	15	10
Without Loading Speed[mm/s]	100	180	255
Max Horizontal Full Speed[mm/s]	80	150	230
Max Vertical Full Speed[mm/s]	40	90	50
Max side mounted payload[kg]	5		
max side mounted speed[mm/s]	60	75	150
Rated Acceleration[mm/s²]	500		
Maximum thrust[N]	471	376	188
Storage temperature[°C]	-15°C—+60°C		

Figure 25: FUYU motion guide for linear actuators performance

Appendix IV - Instructional Video for the Device

As part of the requirements for the final departmental presentation, the team was tasked with creating a video that is a walkthrough of the device.

The video can be found here for your viewing: https://youtu.be/e91GKq0eLSU