

Food Insecurity Design Report

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Executive Summary

It is our purpose to create a device that allows plant breeders to accurately measure stalk strength in an economically feasible and high throughput manner so they may breed for stronger stalks to prevent lodging. Our device will create a way to do non-destructive testing to obtain a strength value of corn stalks that is light, quick, and easy to use. By using a needle to measure the diameter and rind thickness of a cornstalk, our device is able to find the strength of a cornstalk using engineering principles quickly and accurately. From the testing we have done, our device is able to calculate the diameter and rind thickness using the force displacement curve generated shown in the Appendices.

Background

Stalk lodging is a phenomenon where a plant stalk breaks and falls over before it is able to be harvested causing loss of production and increased costs. While it is possible to harvest lodged corn, it is inefficient requires more work costing more money and can lead to volunteer corn growing the next year. Every year farmers in the U.S lose 5% - 25% of their harvest due to stalk lodging; and since the agricultural market is so competitive, any reduction in costs could be the difference between a profit and a loss. So any way to use fewer resources to create larger gains is important.

Currently, there are very few ways to accurately measure the stalk strength of a plant and none of those are cost effective, non-destructive, and easy to use in the field. Currently the best way to measure stalk strength is through the use of a bender that bends the stalk until it breaks. The problem with this method is that once the stalk is broken the plant is no longer usable. While our device will not immediately solve the issue of stalk lodging, it will give plant breeders an easy quantifiable number for each stalk which can be used to create new varieties of corn that will have stronger stalks. Another benefit of our device is that, because it measures stalk diameter and rind thickness, it could be used by researchers who are doing different studies on corn.

Problem Definition

In order for our device to be competitive over existing technology, we wanted to create a device that would be able to be taken out into a corn field and used for an entire day of analyzing and storing the stalk strength for corn stalks quickly and accurately. So by the end of the project we wanted a handheld device that would be able to analyze at least one hundred stalks per hour for an eight hour work day and would not destroy the stalks it was analyzing. After deliberation with our client, we came up with more specific specifications and constraints in the table below as well as an explanation for it.

Specifications/Constraints	Reason
Device must use non-destructive testing methods	The purpose of the device is to measure stalk strength in such a way that it will not harm the corn stalk. So we must collect data in such a way that will not break the corn stalk.
Handheld and operable by one person	It would be inconvenient and impractical if the stalks had to be brought to the device from the field or if it required more than one person to operate the device in the close confines of a row of corn.
portable, lightweight, & low force required for operation	The purpose of the device is to measure data all day, so if the device is too heavy or awkward to use it will greatly hinder its ability to be useful.
Device must be durable & impervious to environmental conditions	Because the device is meant to be used in the field, it must be able to stand up being dropped, soaked, and covered in dust on a regular basis.
Device must measure distance with accuracy of +/- 0.01 mm	In order to accurately calculate the stalk strength we need an accurate force vs distance graph, and so it is important that the device is able to record very small changes in the location of the needle to create a good graph.
Device must have a stroke length of 3"	Because corn stalks come in a variety of sizes, it is important that the device be able to puncture all the way through the largest stalks.
Device must collect data at least a rate of 60 Hz	To create an accurate graph, there must be a lot of data points collected. By collecting the data at a rate of at least 60 Hz then there should be enough points to make a nice curve that will make it easy to calculate the stalk strength.

Device must use existing User Interface	It is the purpose of this device to replace the existing device that uses destructive testing that was created by previous design teams. Since many of the same people in the field will be using it, it is important leave the familiar layout of the interface to make the device easier to use.
Device must include data logging	By including data logging it will allow for comparison analysis at a later date of the different stalks tested.
Design must have a back support for the corn stalk	The back support of the corn stalk is intended to keep any deflection from occurring in the corn stalk while the test is occurring. If there is any deflection it could impact the testing and throw off the results.
Device must be able to generate enough force to puncture a corn stalk	The rind of a corn stalk can be fairly tough and however it is decided to puncture the corn stalk, there must be enough force behind it to puncture the stalk in a timely manner with a minimum of effort.
Design must be primarily made from existing components and parts	Parts on the device must be easily replaceable if something breaks, and the device must be inexpensive to create in mass quantities.

Project Plan

Within the project team, activities and assignments were broken up by each member's specialty. The electronic components and design of the device was handled by the electrical engineering major, while the biological engineering major worked on design, testing, and building of the physical prototypes. However, most of prototyping was done by the two mechanical engineering majors.

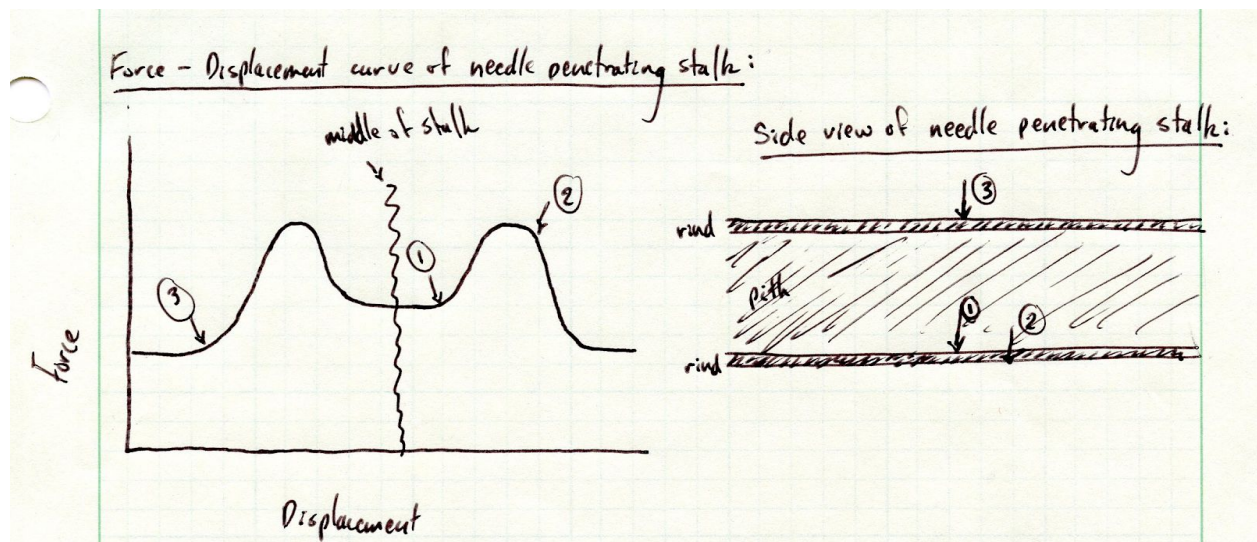
It was the team's goal to have a completely finished, tested, and marketable product by the end of the class. The plan was to spend about 3 months learning about different components and design ideas. Then build different prototypes and start testing accuracy and ease of use for the different designs, and deciding upon a final design by the end of the first semester. The team would then take that design and, with the start of the new semester,

continue to improve it and build a final product. The last couple months would then be used for final product testing and streamlining the design.

In actuality, things did not turn out the way we had planned in the Gantt chart as seen in the Appendices. It took the team much longer than expected to find components that would meet our criteria and constraints and design a working prototype. It took the team until December to create models for the different prototypes and until the start of the new semester to have a final design picked and built. However there were complications with the electronics and it took until March to get the electronics to the point where data could be logged and analyzed from the load cell and linear potentiometer using the Arduino and Raspberry Pi. So the team was unable to start testing until half way through April, at which point, the only testing that could be accomplished was to prove that the data gathered followed the trend line of what was expected.

Concepts Considered

There was a base concept that all of our team's designs stemmed from and revolved. It was derived from research done by our lead instructor and client Dr. Robertson. The idea is by using a force sensor like a load cell and an actuator or a linear potentiometer to measure displacement, the force and at every distance as a needle punctures a corn stalk can be found. From these measurements a force vs displacement curve can be generated. The figure below illustrates the concept and the general shape of the curve. Force is on the y axis and displacement on the x axis. The curve will start out at zero force and curve up and peak as it begins to puncture the stalk and goes through the outer material known as the rind. Then it will decrease and plateau as it enters and goes through the middle section of softer material known as pith. It will increase and peak again as it goes out the rind on the other side.



Since each force is associated with a distance the inner and outer diameter of the rind can be found from points on the curve. With this information the resistance to bending can be

found by approximating the stalk as an ellipse and calculating the moment of inertia of the stalk. The higher the moment of inertia the more resistant to bending the stalk is. This is the most important concept behind all the concepts we considered. It fulfills our goal of being non-destructive and can be significantly smaller than devices that use other methods like bending a stalk until failure.

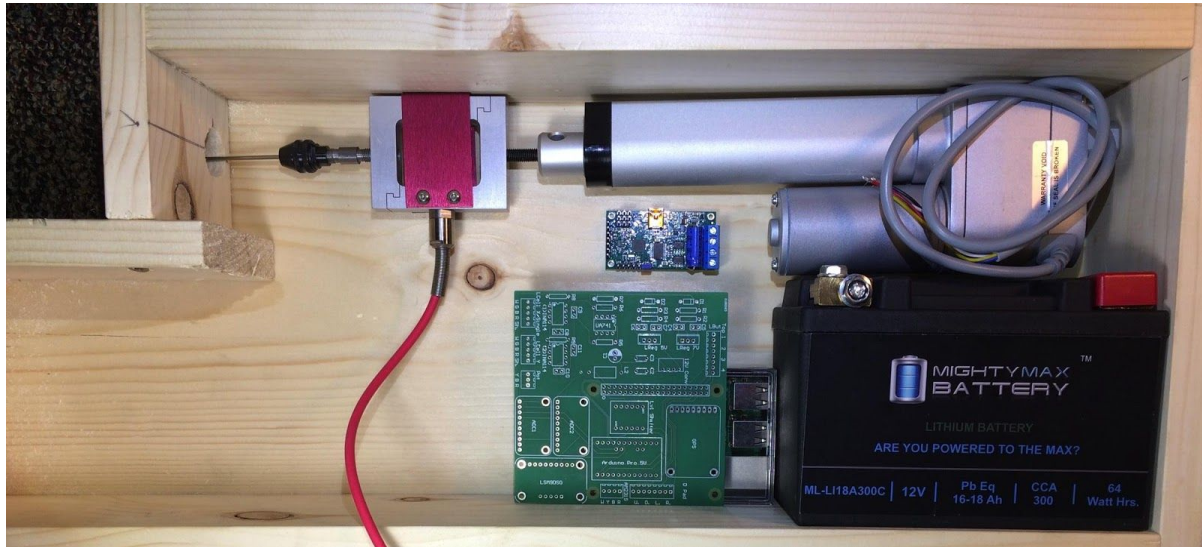
Another major concept we explored was the difference between applying or driving the needle through the stalk by human power with a mechanical advantage or using an electric device to power the device. This was considered early and revisited throughout the project. Our initial consideration led us to pursue a design powered by a mechanical or electrical device. This was chosen because it provided a more ideal solution. It requires less effort by the operator and provides more accurate and consistent data. The operator will not have to manually generate the force to puncture the stalk with the needle. Repeatedly doing this for eight hours could be strenuous at least and prohibitive at worst. A hand-powered device will generate different data every test because the operator will not apply the needle through the stalk at the exact same rate every time. Since the force is applied at a different rate this will cause the force to be higher if one run is faster and lower if one is slower. If multiple tests are run on the same stalk they will vary because of the change in rate the force is applied. It may be possible to overcome this change in analysis of the data, however it would not be ideal and we chose to pursue the design that gave us the best data. A third reason we chose to pursue the using a device is that there were already electric devices required to be able to make measurements and display the results, adding one to provide the force was reasonable. The minimum required components were: a force sensor to measure the force through the stock, a displacement sensor to measure distance, an arduino to interface with the sensors, a raspberry pi to run interface with the screen and display the graphical interface and data, and a battery to power them.

We looked at various devices to drive the needle and we chose a linear actuator because it accomplished two functions: driving the needle at a constant rate and measuring displacement. It also met all our constraints.

We explored many ideas of how to create a device that operates on the foundational principle while meeting the other design specifications and constraints. We considered six different designs and went through five iterations of basic prototypes for the device. They can be broken into three different categories: In-line devices, and offset devices.

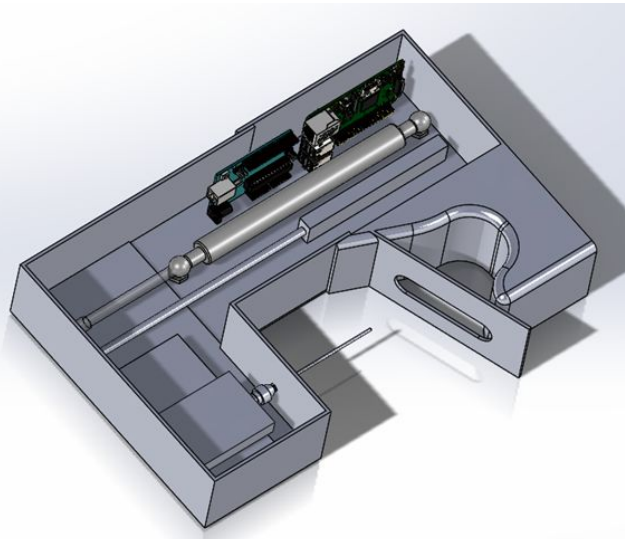
The first concepts we pursued were the in-line designs. We called them in-line designs because the critical components to measure the data (the actuator, load cell, chuck and

needle) were placed in a straight line to each other



Our first prototype is shown above. We designed it to have the actuator and load cell to be perpendicular the the user and be held in front of them. There is a cutout of one side that allows a corn stalk to be slid in and the needle to be driven into it from the side. This first design had all the components fully enclosed in a box for protection. Because the load cell, actuator, chuck and needle were in line and their physical size was our constraint the box was very wide (approximately 22”). The case had empty space because of this. We decided it was not ideal because of size, which would make it awkward to use and caused it to be uncomfortably heavy.

Our next idea was to offset the actuator and the load cell, chuck and needle. A model of the design is shown to the right. This significantly reduced the width of the design. And made it much more manageable to hold. Our design still had all the components covered in a case for protection, this created a different issue. Because the load cell didn't move back and forth by being directly attached to the actuator the case that they both were attached to needed to be made of two different pieces and compress and retract with the actuator. This created a box that would be prohibitively complicated to manufacture.



After this design we changed our approach to having a case and pursued more “bare bones” designs. We reimagined our first prototypes simultaneously.



Our reimagined first prototype, exchanged the case with a bent sheet metal frame. This design is shown above. This reduced the wasted space, manufacturing time and weight. However the required length, because the components were in line, was still very long and determined to impractical to be used in between corn rows. We also made a hand powered version of this design. Which let the operator move the needle by a lever arm connected to a rack and pinion gear. We used a linear potentiometer to measure displacement.



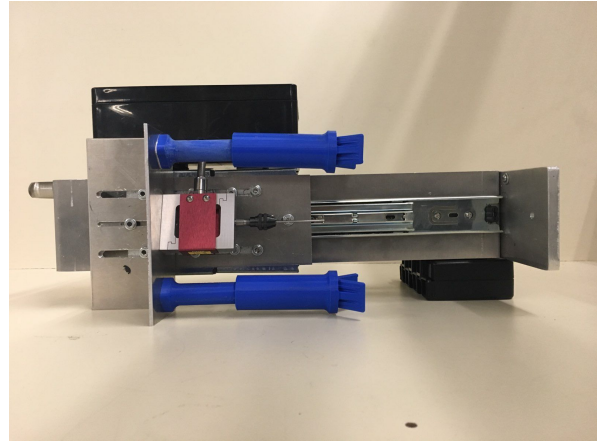
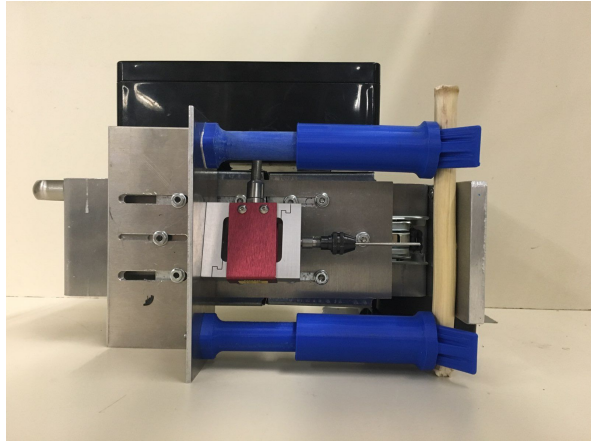
Our reimagined second prototype is shown above. Not pictured is an L bracket mounted to the top side of the actuator facing left with the load cell, chuck, and needle mounted on it. This prototype also exchanged the two piece case for a frame made of bent sheet metal pieces. It was designed with L brackets for ease of manufacturing and assembly. It reduces size and weight. This proved to be the best design yet. The main concern was deflection by the far side because there was no middle support in between brackets over the actuator, this led into our final design. We rearranged the offset barebones design to be two U shaped brackets with a drawer slide on each side of the actuator. This made the structure much more rigid. It increased manufacturing complexity and meant we needed to outsource two parts. The price for this work is low and the lead time is only a few days, so the drawback of a slight increase in manufacturing complexity in outweighed by benefits it provides for the design. The final design is shown and discussed more in the next section

Concept Selection

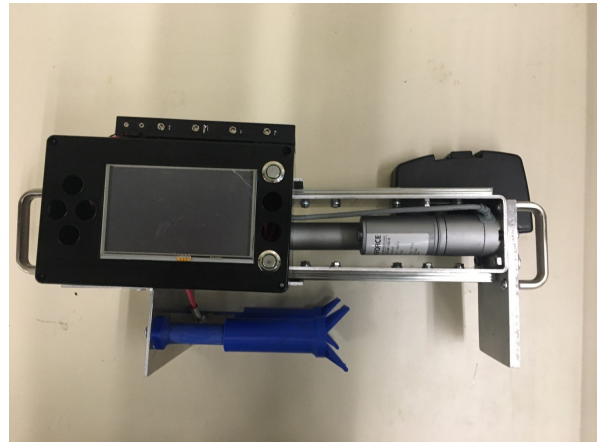
When we were considering designs and deciding to the on the design to fully develop we had three types of designs. They have been described in the concepts considered section. In summary we had an actuator design which was in line hand powered device which was in line and an a design where the actuator was offset from the load cell, chuck and needle. Along with considerations mentioned in concepts considered we made a decision matrix.

Design Criteria	Actuator	Hand Powered Device	Offset Actuator
Lightweight	1	2	1
Fast	2	2	2
Ease of Operation	2	1	3
Compact	1	2	1
Accuracy	2	1	2
Durability	1	1	2
Cost (\$100)	2	2	2
Machining	1	2	1
Sum	12	13	14

This is the decision matrix we used to decide on which design to develop completely. The designs were very close in score, however the offset design scored the highest in our analysis. A few of its main benefits were that it is easy to operate, fast, accurate and durable. The hand powered device scored second, its main advantages being it was lightweight, fast, cheaper to make and easier to machine. We also considered that the U shaped bracket design could be turned into a hand powered design easily, if the actuator was replaced by a linear potentiometer. This would make it significantly lighter. It could also be scaled down for hand powered use. These considerations with the fact it scored the highest in are decision matrix led us to develop the offset actuator design.



This shows the front view of the U shaped offset design, closed (left) and open (right)



This shows the top view of the U shaped offset design, close (left) and open (right)

This is the final design we decided to develop and the pictures are the result. The components and their function will be discussed in the system architecture section.

System Architecture

The device consists of the following components: the box made out of two U-shaped pieces of bent sheet metal, the backplate made of thicker sheet metal than the rest of the box, drawer slides, a plastic box containing the PCB, motor controller, arduino, raspberry pi, buttons, and screen. The device also contains a set of batteries, a linear actuator, a load cell, a dremel chuck, a specially machined needle, two 3D printed assemblies containing springs. In the following section, I will describe how the features are integrated together, what function each feature provides, and what value each feature adds.

Two U-shaped pieces of bent sheet aluminum were used to create a box. On one side of the box is a backplate, made of a much thicker piece of sheet aluminum than the rest of the box. The box is designed to house all of the electronics, sensors, and other components of the device. The backplate is made thicker than the rest of the box because the needle will be used to pierce corn stalks against the backplate. This means there will be a large number of cycles of

force against the backplate. The measurement system must also be very precise. For these reasons, the device needs a rigid backplate that is unlikely to flex, given the forces being used (under 35 lbs). The metal used in the project is aluminum, a sturdy but light metal. A light metal is needed because the device requirements dictate the device be handheld, and able to be carried for at least 8 hours per day without causing fatigue. The original design of the device consisted of having the linear actuator in line with the load cell and needle. This makes the prototype very long and difficult to hold. The device needs to be easy to hold for long periods of time, so the linear actuator is now used to move the two parts of the U-shaped box apart and together, with the load cell and needle pushing corn stalks against the backplate. Thus, space saving is the primary reason for the shape of the box, and its construction. Using this design, the box must be able to move back and forth easily. This problem was addressed by placing linear drawer slides in between each of the U-shaped pieces of the box. Drawer slides were used on the top and bottom of the device where the U-shaped pieces mate, so as to prevent the device from wiggling when expanding or contracting, since very precise measurements are crucial.

A specially designed PCB is used in order to integrate the many electronic parts of the device. A motor controller is a device that acts as intermediary between the microcontroller (Arduino), batteries and motors. A motor controller is necessary because a microcontroller can usually only provide roughly 0.1 amps of current whereas most actuators require several amps. A microcontroller is an integrated circuit chip that executes programs for controlling other devices or machines. The arduino executes programs that use the power from the batteries and communicates with the actuator through the motor controller to control the actuator. The raspberry pi is a microprocessor (a small computer, less powerful than your average computer, but still able to perform all of the same functions). The raspberry pi interfaces with the arduino, and collects the data that is read from the load cell, as well as powering the graphical user interface (GUI) that appears on the screen. The raspberry pi also communicates instructions to the arduino based off of operations being performed in the GUI by the user. The buttons on the plastic box next to the screen correspond with the buttons that can be seen on the screen's GUI. These buttons are used to control the many functions of the device. The screen is simply used to present the GUI and options available to the user.

As stated previously, the batteries are used to power all of the electronic components of the device, including the actuator, which has a large amperage draw. The batteries are AAs, connected together in a long slim case, so as to minimize the amount of space they take up. The linear actuator is a worm gear motor that moves a shaft in and out of its casing, in a linear direction. This linear actuator has a 4 inch stroke length, which meets the project requirements of being able to puncture a corn stalk up to 4 inches in diameter. The linear actuator is attached to the box case in such a manner that when it actuates, the box opens out, and retracts inward (becoming longer and shorter). The linear actuator contains a potentiometer, which we are using to measure the exact distance the needle has moved from its original position. The linear actuator also provides a consistent velocity, and force as the needle is being pushed through the corn stalk. Both of these things are crucial to obtaining accurate results. The load cell is attached to the box, and the dremel chuck, which holds the needle. The load cell is simply used to measure the force being exerted on the corn stalk by the needle. The needle is machined

specially to have a 1mm flat base, then a 45 degree chamfer up to a 2mm shaft of the needle. This design was given to us by our sponsor, and determined to provide the most useful data when testing. The force data is used as the y-axis on a graph. The x-axis of this graph is the distance the needle is at. Using this force-displacement graph interpreted and stored by the raspberry pi and displayed to the user with the screen and GUI, we can determine the wall thickness of the rind of the corn stalk. Corn stalk varieties with a greater wall thickness will be more resistant to bending. The load cell, needle, and actuator are thus very crucial in meeting the end goal of the project. Lastly, the two 3D printed assemblies containing springs. There are 2 parts to this assembly. The bottom part of the assembly has a round base, with a cylinder rising out of the base. This cylinder is filled inside nearly to the top of the bottom part of the assembly. The parts not filled in accomodate a lengthy screw (to hold the base to the box of the device) and to contain a spring inside the cylinder. On the outside of the cylinder are 2 sets of 4 cylindrical, short nubs normal to the outer surface of the cylinder, and place 90 degrees apart along the circumference of the cylinder. The top part of the assembly is a hollow, thick cylinder designed to contain the bottom portion of the assembly. The cylinder is attached to a round top, and on this round top is a V-shape. This V-shape is designed with a size and angle meant to help align a corn stalk of any size into the middle of the V. On the inside walls of the cylinder on the top part of the assembly are grooves meant to contain the nubs on the outer surface of the cylinder on the bottom part of the assembly. These grooves run along the length of the cylinder, and allow the two cylinders to expand and contract. The spring provides a minimal force so that the two parts of the assembly stay expanded, until they are pushed against. There are two V-shaped 3D printed assemblies on the device, on either side of the load cell. These are positioned in a way that when then device closes on a corn stalk these 3D printed assemblies hold the corn stalk against the back plate (used as a dimensional reference), and hold the corn stalk centered over the needle, so the needle is piercing the largest diameter of the corn stalk (in order to get an accurate result).

Design Evaluation

Each component examined on the design failure mode evaluation and analysis conducted for our device is rated on a scale of one to five. These meaning of each rating is defined in the table below.

Risk Level	Meaning
5	Severe bodily harm caused to operator
4	Minor bodily harm caused to operator (bandage-able)
3	Device rendered inoperable and in need of extensive repairs
2	Device rendered inoperable and in need of replacement parts
1	Simple fix—no harm to user or device

The table on the following page uses the ratings defined above to identify the level of risk associated with each design risk and potential remediations.

Component	Design Risk	Remediation	Risk Level (1-5)
Needle	Impale operator	Additional shielding added around needle	5
Frame	Pinch/crush operator's hands	Adjust design to remove any pinch points	5
Handles	Fingers Scraped on screw heads	Countersink screws used to mount backplate	4
USB Battery & AA Batteries	Shorting during rainfall or if dropped in water	Wrap batteries in shrink tube or water-tight tape	3
Electronics Case	Not waterproof	Electronics destroyed by rain, dust, etc.	3
External Wires (Actuator, Load Cell)	Pinched in device, caught on environment	Route in a manner that keeps wires away from pinch points	2
Load Cell	Easily damaged if dropped	Move to smaller load cell, additional shielding	2
Actuator	Device rendered inoperable	Confirm feasibility of operating device by hand	2
Needle	Easily broken	Prevent stalk from rotating, don't puncture at node, drill wider hole in backplate (perhaps 1/4")	2
AA Battery Pack	Battery cell pops out of pack	Tape or velcro strap across open face of battery pack	1
Drawer Slides	Bind or lose bearings	Keep well-greased and don't overextend	1

Testing for our product occurred throughout the life of the project. Long before having a completely-assembled system, individual components were tested and refined. For example, the first battery purchased for powering the actuator went through rigorous testing by using it to power the actuator running at a rate of 100 cycles an hour (in accordance with product specifications). Since the actuator without a load pulls a steady level of current, we were able to ascertain what a typical lifetime of the battery would look like. We were surprised by how quickly

the battery was drained and realized we had misunderstood the meaning of some of its specifications. Consequently, we moved to a drastically different battery platform, which we tested first in the same manner and then with an additional load on the actuator. This time, the results were more than satisfactory. Because of this testing, we were able to reduce the size and weight of the battery system dramatically and simultaneously improve its performance and longevity.

Throughout the process of testing the batteries, mechanical components were also being tested and refined, especially the spring holders used to keep the stalks aligned. These went through numerous iterations as each design was tested, refined, and improved. Testing was usually performed by simply observing the performance of the system, comprised of a spring and the inner and outer shafts, when pressed against a table or between a team member's hands. Design inadequacies identified by testing include the spring being too stiff and too long, the inner and outer shaft binding when being compressed, and the edges on the base of the shafts being too sharp and too thin. By the end of the design process, the system was refined and operating much more smoothly and effectively than at first, necessitating only minute adjustments to be optimally effective.

With the basic functionality of the device electronics fully operational, we ran several tests at various positions along the stalk. Plotting the results, we saw a force-displacement curve of the form we were anticipating. This result validated our expectations and confirmed our device is capable of operating as expected. However, the plot also made it abundantly clear that the device is still under-sampling, as there was a clear deficit of data points in the critical regions of the peaks. This data rate bottleneck will need to be identified and addressed before the device is able to produce data accurate enough to yield legitimate results. The plot can be viewed in the Appendices.

Future Work

What features still need to be implemented into the project? One very large challenge that the next Electrical Engineer must overcome is finding and removing the data bottleneck that exists within the devices electronics. Our current device sample at a rate of 20 Hz. The ideal sampling rate would be 60 Hz. Anything lower than this will not provide accurate enough results to meet requirements. The next team must try to find a way to combine the arduino and raspberry pi into one device, if possible. This will potentially minimize the data bottleneck that currently exists. The code used for running the device, as well as the code used for the GUI, and the code used to process the data collected by the device all need to be improved, and cleaned up. The load cell that we are currently using needs to be replaced, likely with a load cell that is smaller in size. The load cell currently being used is not designed for the maximum force required for this project. The load cell the next team will use must be able to withstand a maximum of 35 lbs of force. Our team has done some research into pancake load cells. The linear actuator must also be replaced. We began the project with a requirement of a 4 inch stroke length, and later decided on a 2-3 inch stroke length. Our current actuator is designed for 4 inches, and thus is larger than it needs to be. The length of the box holding the actuator can be reduced, if a smaller actuator is purchased. The next team may be able to reduce the size of

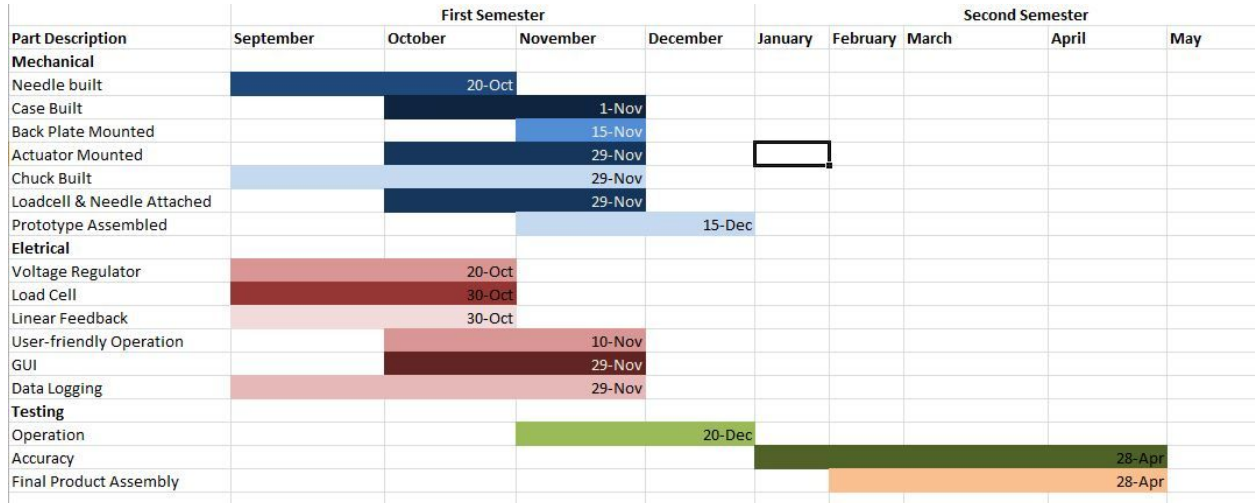
box even further if they change the design to be manually powered; this however faces the challenge of needing a consistent velocity and force throughout the entire stroke. The next team needs to look into adding humidity, temperature, gps, and other sensors to the device, if possible. The next team also needs to address the GUI, which is somewhat confusing. It could be made simpler, and easier to understand for those who will be testing the device, or using it with minimal instruction.

The overall aesthetics and functionality of the device need to be taken into consideration as well. Although our prototype has come a long way in making the device smaller and less unwieldy, the device is still somewhat bulky, and difficult to hold. Selecting a smaller actuator and load cell should help reduce the size. A more well designed and compact PCB (and thus smaller electronics box) would also help. It must be carefully considered where the handles are placed; currently, when holding the two handles of the device, it is rather difficult to press the button to start the test. The start button for the test would ideally be redesigned so that it operates as a “dead-man’s switch” in the sense that when it is being pressed down, the actuator opens, and when the button is released, the actuator retracts. Other safety features need to be taken into account as well. Removal of any potential spots where the user could pinch themselves, or get poked by the needle.

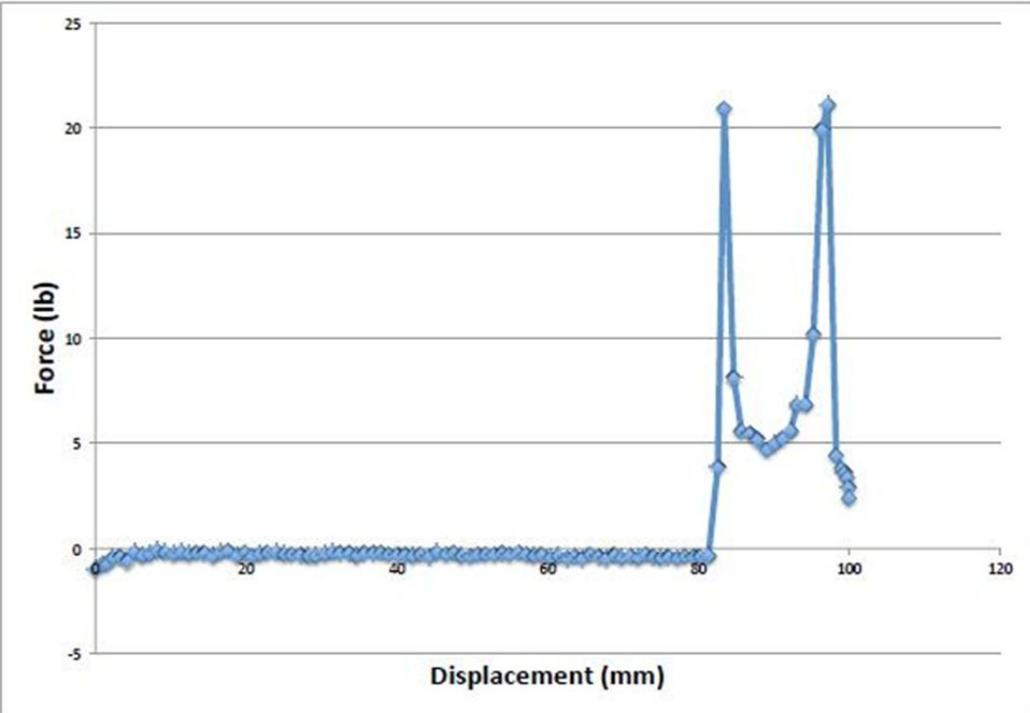
The next team must find a way to easily manufacture the 3D printed device designed to align the corn stalks as they are being punctured. It is not ideal to 3D print on the final design. The corn stalk holders are a complex design, so this may prove to be a difficult challenge with the tools available at the University of Idaho. The device needs to be tested and redesigned for drop resistance. Currently, the needle, load cell, and corn holders are exposed in the event the device would be dropped. All of these are fragile elements of the device, and cannot be damaged. The next team should investigate changing the needle design. More testing is required to decide whether or not this is necessary. The current device design grips the needle using a dremel chuck. Dremel is proprietary, so a different means for gripping the needle needs to be found.

Appendices

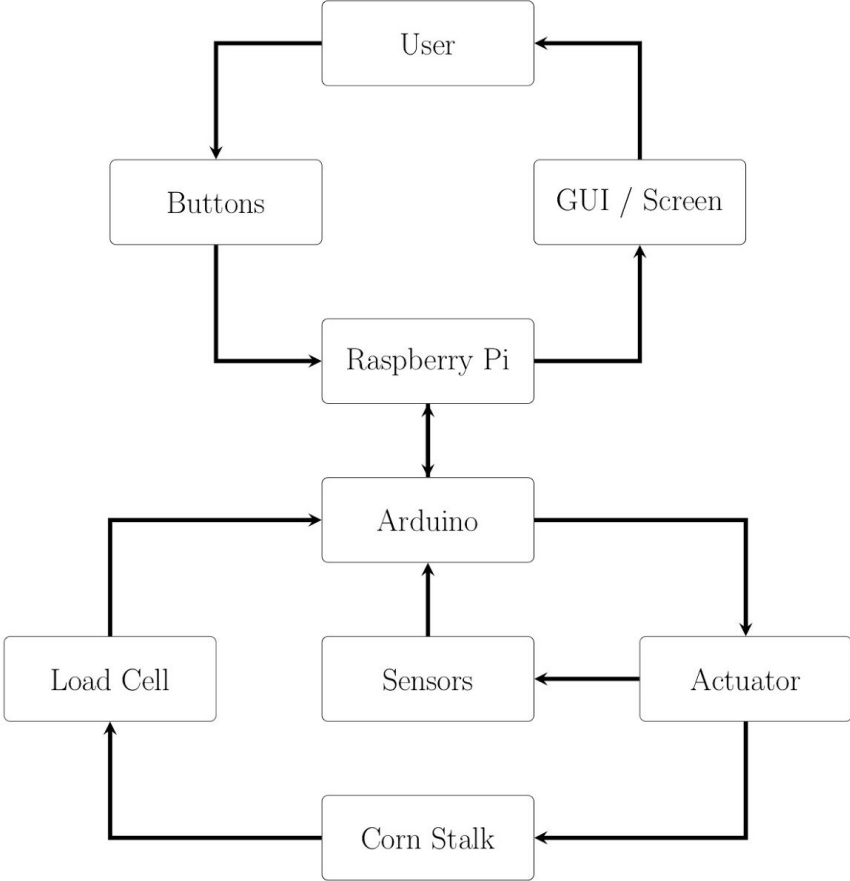
Project Plan



Test Results



Electronics System Diagram

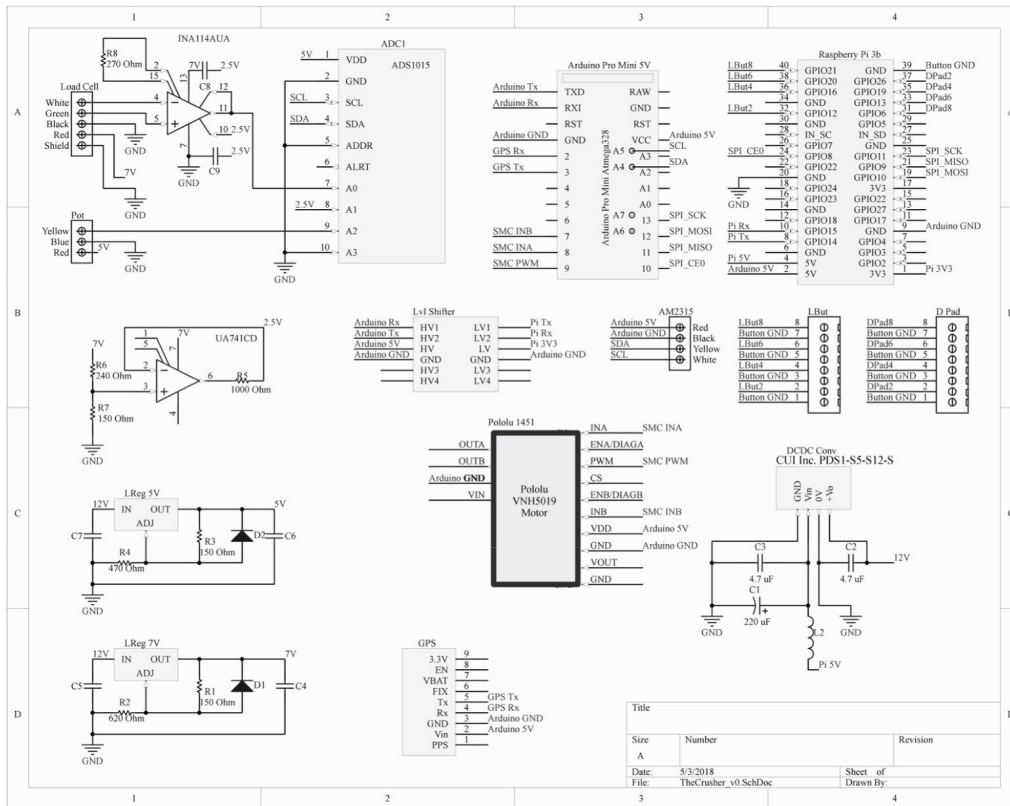


Recommendations for Improvement - Electronics

Recommendations for Improvement - Electronics

Idea for Improvement
Consider changing from the current motor controller (Pololu 1378) to a smaller, simpler, cheaper one that I believe will serve the same purpose (Pololu 1451); The 1378 has a number of features that aren't utilized by our project (e.g. controlling the motor via serial communication)
Touchscreen?
Change Pi GUI buttons in the following manner: 1 button on the left is 'Select'; two buttons on the right are 'Up' and 'Down' and are used to scroll through options on left-hand side of screen and in the main area in each view
It may be beneficial to design the geometry of the PCB to overhang the edge of the Pi a bit to 'reserve' space in the box/case for the HDMI and micro-USB cables to plug into the Pi. Alternatively, it may save valuable (vertical) space to have the PCB not mounted on the Pi (the trick will be finding a reliable, secure way to connect the Pi's GPIO pins to the PCB). This could reduce the depth of the electronics box and make it easier to reach the buttons on the lid with thumbs while holding the device's handles.
Add mounting holes on the corners of the PCB to mount the electronics to the box/case via the PCB instead of the Pi
Use 2" actuator instead of 4" (same brand should work)
Change sides on which buttons are for operation (physically especially, but also in the GUI) so that the button to run the test (currently the top button in the vertical row (i.e. top button of the LBut group)) is accessible when the device is extended.

Re-Designed Schematics (not quite complete)



Raspberry Pi 3b

