Prototype Device for the Detection of Subsurface Peach Pit Fragments

A Senior Project
presented to
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California Polytechnic State University, San Luis Obispo

In Partial Fulfillment
of the Requirements for the Degree
Bachelor of Science

by

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Peach Pit Fragment Detection: Final Project Report

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Peach Pit Detection

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Abstract

Peach pits can break during processing into several small fragments and are difficult to see and remove from the peach. Wawona Frozen Foods is asking for a fully designed, built and tested prototype that can detect these pit fragments with ease and speed. Our design uses an array of needles that puncture into a peach half. A pressure sensor measures the force on the needles and determines whether or not each needle hit the peach flesh or a pit fragment. The array of needles consists of 313 needles each with a diameter of 0.6 mm with a total array diameter of 1.5 inches. The needle array puts a maximum force of 12 lbs compression on the peach half when the needles are puncturing into peach flesh. Our device works for peaches that range from 2-3 inches in diameter. Testing has shown that the needles do not change the integrity or taste of the peach. Our design was built and tested over 3 months and improved as necessary. All feedback from Wawona during the Critical Design Review was be incorporated into the final prototype.

Chapter 1: Introduction

Problem Statement

The Atlas Pacific Clean Pitters used by Wawona at their Clovis facility efficiently halve up to 91 peaches/minute. They can detect and remove split pits from the peaches, however, they are unable to sense pits which have broken and left fragments embedded in the peach. Additionally, the pitters do not reliably detect all split pits. Any pit fragments remaining in product are considered “foreign material” by Wawona’s customers.

To combat this, Wawona employs a significant workforce dedicated to finding and removing these pit fragments. Inspectors are stationed at all stages of the processing line. Their sole responsibility is to spot and remove pits. Split pits and large pit fragments are easy to find and remove. However, small pit fragments less than ⅛”(3mm) in major diameter may pass visual inspection. The high number of workers employed, coupled with the redundancy of their positions, has led Wawona to seek a solution which *automates part or all of the pit fragment detection and removal process*.

To date, Wawona has applied several industrial solutions to the pit problem. Typically, these machines rely on optical detection. However, none of these machines have met the high standards Wawona and its customers have set. Manual detection and removal has remained the only method to ensure little to no fragments are packaged.

Our team aims to develop and test an automated pit detection system which meets Wawona’s high standards , and reduces the number of inspectors Wawona requires.

Project Goal

Our team developed and tested a system which can detect these straggling pit fragments. It is reliable at high volume (2200 peaches/min) and able to integrate with the existing production line Wawona has set up at its Clovis facility. It is be able to detect pit fragments down to ⅛” (3mm) in major diameter. The prototype created in this project represents one module that can then be replicated as many times as needed in order to scale with the volume of peaches that are processed.

Report Overview

We have fully designed a system that will detect peach pit fragments. This report expands on the Conceptual Design Report, providing analysis and descriptions of how the design will work. This report begins by retaining the information presented in the Conceptual Design Report. It then introduces our final design drawings, supporting analysis, and assembly and maintenance instructions. Finally, it provides a bill of materials and a cost analysis of the design, along with an updated schedule and management plan.

Customer Requirements

There are three customers our system will affect: Bill Smittcamp (President/CEO Wawona Frozen Foods), the Wawona Frozen Foods' Employees, and the end customer, the Peach Consumer. For each customer, the following requirements must be satisfied.

Wawona Stock Holders

- High Speed Detection
- Highly Precise Detection
- High Speed Sorting
- Highly Precise Sorting
- High Longevity
- Low Design, Prototype, and Build Costs
- Environmentally Friendly
- Smallest Device Size for Successful Operation
- Low Operating Cost

Wawona Food's Employees

- Safe to Operate
- Easy to Operate
- Easy to Maintain and Clean
- Highly Reliable Operation
- Easy to Install and Assimilate into Existing Line

Wawona's Customers

- Highly Precise Detection
- No Damage/Alterations to Fruit as a Result of Process

End Consumer

- Fruit is Processed Safely
- Fruit is not damaged
- No Foreign Materials or Contaminants Left (Including Pits)

Design Specifications

The design specifications are developed directly from the Customer Requirements. These Design Specifications are the criteria we will use to evaluate our designs. For additional discussion of how these were developed, see the QFD discussion immediately following this section. A QFD (Quality Function Deployment) table shows the engineering specifications and their corresponding rank of importance.

The legend for the compliance category indicates how we will evaluate whether we are meeting that specification. Analysis indicates a mathematical or theoretical model will be used. Test indicates the specification must be tested to assure compliance. Similarity to existing design is a comparative approach, and inspection indicates the specification can be evaluated without any testing.

The risk column indicates how difficult, relatively, meeting that specification will be. H indicates a high risk. This will be harder to meet than a M (medium) risk, which in turn is more difficult to meet than an L (low) risk.

Table 1. on the next page lists the design specifications developed for this project.

Legend

- Analysis (A)
- Test (T)
- Similarity to Existing Designs (S)
- Inspection (I)

Table 1. Quantifiable Design Specifications. These specifications will be used to evaluate how well our team is meeting the customers' requirements at all stages of the project.

Spec. #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	% of Fragments Detected	99 %	Min		A, T
2	Fruit per Minute Throughput	2160 peaches/min	Min		A, T
3	% Fruit Damaged By Detector	<1 %	Max		A, T
4	Operating Temperature Range	-10 to 50 °C	Range		A, T
5	Pit Size Range	1 to < ⅛ in	Range		A, T, I
6	Power Consumption	1.5Kw	Max		A, T
7	Material Cost	$10,000	Max		A
8	System Learning Time	1 Hr	Nominal		I
9	Warm Up Time	15 Min	Nominal		A, T, I
10	Dangerous Mechanisms Exposed	None	Max		I
11	Unsafe Chemicals or processes	None	Max		A, T, S, I
12	Size	10x6x8 ft	Max		A, I
13	Operating Time	21 hours/day	Nominal		A, T, I

14	Assembly Time	14 Days	Max		A, T, I

Chapter 2: Background

Current Processes at the Clovis Facility

Peach Grading

When peaches are brought from the farm to Wawona's storage warehouse, each grower is graded on their fruits' sizes and ripeness, as well as the number of peaches which have worms or rot. Grading is used primarily to determine prices paid to the growers, although, it is also used as the first step in tracking split pits. Once peaches are moved from storage to the production facility, each grower's peaches are quality checked for split pits. This information is used to adjust production during the day as needed.

Atlas Pacific Clean Pitter II

Wawona employs 24 Atlas Pacific Pitters fed by three separate production lines, typically for small, medium, and large peaches. Each machine uses a cup with slot on the bottom under which a spindle rotates. A peach is deposited in the cup, which rocks back and forth as the spindle turns the peach end over end. This process aligns the peach upside down, with the stem facing downwards and the peach's suture facing outwards. This is the best orientation for the pitter to cleanly halve and pit the peach.

Once the peach is correctly oriented, the pitters separate the peach flesh from the pit. Two arms grab the peach from its cup and hold it in position for the blades to cut. Two ridged surfaces in the center of the blades grab the pit from either side. Each side of the peach is rotated opposite each other, finishing the halving step and separating the pit from the flesh.

Split pits occur when the blade arms make contact with the pit along the suture line and it separates into two halves, which remain embedded in the fruit. Pit fragments occur when the pit is broken inside of the peach, and is described as "looking like the pit has exploded inside the fruit."

Freezing Process

Wawona Foods Inc. uses the individually quick-frozen (IQF) process. This process rapidly freezes individual peach slices and diced squares in an air tunnel at negative 35°C (2). This freezing method stops the activities of the microorganisms that can decay and deteriorate the peach flesh. It also preserves the same color, flavor and texture of the peach so that is tastes "farm fresh." This process reduces the freezing time from 3 hours down to 10 minutes.

Existing Solutions to the Pit Problem

Raytec, Odenberg, and Best Optical Sorters

Figure 1. Odenberg Titan Sorter

Raytec(5) products use a combination of optical detectors which work in the visual wavelength and near infrared in its sorting process. Near infrared analysis is an improvement in detecting defects and foreign material, and can even be used to classify the sweetness of a peach based on its soluble solid content(1).

The optical sorter developed by Odenberg operates solely on the visible wavelength. It can detect fruit blemishes, defects, pits, pit fragments, foreign material and size of each (3). Peach halves are fed into the device and get separated into 3 grades. Grade 1 is acceptable peach quality. Grade 2 is for peaches that require re-work, trim, or repit. Grade 3 is the reject . The largest model of this machine can do 25,000 kg of peaches per hour.

The Genius optical sorter by Best uses cameras, lasers, LED and ultraviolet light to detect peach pit fragments after the peach has been cut into sections (sliced or diced). All the peach sections are moving along a conveyer belt with the previously mentioned technologies positioned over them. When a pit fragment is discovered, a jet of air is released from above that pushes the entire peach section of both flesh and pit out of the main flow of peach sections (4).These defected peach sections can be processed further down line.

In general, optical sorters use Charge Coupled Devices to capture light reflected off a surface. In the visible light spectrum, this only works if the peach flesh is a different color than the pit. In Wawona's product, the red interior of the peach is near identical to the pit. This reduces the reliability of optical sorters to detect pit fragments. Wawona has sent test samples to various companies which produce optical sorters. However, these machines'

performances have not impressed Wawona.

Ixus X-Ray Sorter

Figure 2. Best Ixux sorter

The Ixus X-Ray Sorter uses X-Rays which rely on the difference in density of the peach and pit (6). However, the machine only works on diced peaches. In Wawona's experience, this technology has similar problems to the optical sorters. It cannot detect small fragments. Further still, it will often reject good product.

Laser Sorters

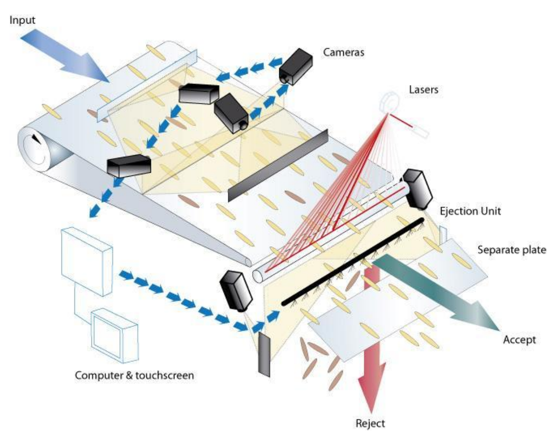


Figure 3. Schematic Diagram of Laser Sorters

Finally, Laser Sorters can detect differences in reflectivity between a pit fragment and a peach's flesh. These sorters are reasonably accurate but only work on frozen peaches. If the peach is unfrozen, the water in or on the surface of the fruit interferes with the reading. Wawona does not freeze its product until after it has been packaged. Integrating a laser sorter into the existing production would require reorganizing the production line, which is not cost beneficial for Wawona to perform.

Wawona's Experience with Existing Technologies

Wawona has sent test samples to several companies to be sorted using their respective solutions. The test samples had a known quantity of small peach pits included in a package of peach dices. Neither the Optical nor the X-Ray sorters tested were able to satisfactorily detect the pit fragments known to have been packaged. The Laser sorters were able to detect the small pit fragments, however, it is not cost effective for Wawona to introduce a laser sorter into their production line.

Table 2. Existing sorting solutions are listed with why each were rejected by Wawona.

Device Classification	Advantages	Disadvantages
Optical Sorter	Detect blemishes and defects	Testing proves unreliable for Wawona's purposes
X-Ray Sorter	More accurate than Optical Sorters	Testing proves unreliable for Wawona's purposes
Laser Sorter	Most accurate sorting	incompatible with current production line

Chapter 3: Design Development

Testing Procedure

The following is a general outline we are following to record the results of all the tests we perform. It may be revised in the future as we come to understand the pit problem and its complexities better, but we believe it provides a suitable framework for the tests we have performed and have planned.

To determine if each concept met our requirements, we came up with criteria that can determine whether a concept is worth pursuing. We cover everything, even if it may seem obvious, in order to take out the bias in the decision making process.

Peach Standards

All concepts are tested using, at a minimum, peach halves, slices, and diced pieces both with and without pits. The peach halves are tested using both a split pit and pit fragments, ranging from ½” to ⅛”. The slices and diced cubes are tested using just pit fragments.

Subjective Evaluation Criteria

Our testing procedure allows room for subjective evaluation of concepts. We use them to quickly compare ideas on a shallow level. Each procedure is evaluated using the following critical questions as guidelines

1. Does it detect the pit halves? What about the pit fragments?
2. What were the effects on the peach? Was the test nondestructive?
3. Could the concept be used to sort, detect, or both?
4. Is the process reliable? Does it produce the same results on multiple trials?
5. Is it reasonable to automate this process?
6. What specialized equipment is required.

Objective Evaluation Criteria

Each procedure’s quantifiable data is different, so general data recording guidelines will be followed. However, the goals of each test are the same. Each test is designed to obtain a distribution representing the accuracy of the method (% of pits found) for each size pit fragment the method was tested with.

Reporting

Finally, each test is summarized and saved in a shared repository.

Everything discussed above is included. Additionally, a summary or abstract of the testing methods and results are included.

Concept Models

The following list is a brief representation of the ideas we have developed and tested.

Sketches for each of these concepts are shown in Appendix D.

Electrical Resistance Detection

An electrical current is passed through the peach, using a thin gauge wire or needle. Peach flesh easily conducts a current, whereas the pits have a large amount of resistance. From our tests, pits have an electrical resistance around 10x the peach flesh. An embedded computer can analyze the current passing through the peach, and determine if the wire or needle is in contact with a pit.

Needle Hardness Tester

Multiple needles are inserted into the peach using a fixed applied force on each needle. The force on each needle will be sufficient such that the needle may penetrate the peach flesh, but only barely. Any needle which hits a pit or fragment is prevented from penetrating further. The motion range will be limited so that they do not penetrate through the peach fully, but only breach the surface of the peach.

Combination of Electrical Resistance and Needle Hardness Tester

An array of thin needles will act as both electrical probes and as hardness testers. A positive voltage is applied to each needle, while the peaches are each electrically grounded. A computer will be able to tell if one of the needles has come in contact with a pit because the pits have a much higher electrical resistance than the peach flesh. Additionally, a needle will not be able to penetrate as far as its neighbors if it is resisted by hitting a pit.

Painting and Washing

Testing shows that the peach pits tend to retain paint films applied to them, whereas it is easily removed from the flesh under running water. A brightly colored food safe paint is sprayed onto the face of peach halves and then air dried. Water is used to wash the paint off of the peach flesh, but the paint will remain on the pit. Either an optical sorter or workers can then easily spot and remove the peaches with fragments. A liquid embedded with UV-light sensitive material can be used to illuminate the pits under an ultraviolet light.

Buoyancy Separation

Diced peaches are put into a solution whose density is identical to the peaches. While the peaches will float along the surface of the fluid, the pits, which are slightly denser than the peaches, will sink. While this method would viably only work with peach dices, it has the advantage that embedded fragments will be detectable. The free fragments and diced product with embedded fragments are then collected from the bottom of the tank, while the product without fragments are collected from the top.

Thermal Resistivity and Detection

Peaches are heated via radiation (microwave), convection (hot air), or conduction (hot plate). Testing has shown that the peach flesh and pits vary in thermal conductivity. Differences in temperature in the peach flesh vs. the peach pit are measured using a thermal imaging camera. The peaches which retain fragments will show cold spots where the pit is located.

Decision Matrix

To quantify and objectively compare our test results, we made the following decision matrix. Our decision matrix weighs the results of each of the concepts described against the design requirements for the project. Using the weighted total, shown along the bottom row, we are to rank our current list of concepts from highest to lowest.

Table 3. Concept Decision Matrix. This shows each of our concepts weighed against the design requirements generated from the QFD analysis.

Specification	Description	Weight	Resistance	Hardness	UV Light	Buoyancy	Thermal	Painting
1	Fragments Detected	10	5	9	1	1	1	5
2	Speed	5	6	4	10	5	10	3
3	Fruit Undamaged	3	5	5	10	5	7	2
4	Operating Temperature	3	2	10	3	5	4	7
5	Pit Size Range	8	5	9	1	1	1	5
6	Power Efficiency	1	8	4	6	4	1	9
7	Material Cost	1	8	4	2	5	1	8
9	Warm Up Time	1	10	10	2	1	2	9
10	Safety	4	8	8	10	8	5	2
11	Device Size	4	5	7	4	1	3	5
13	Assembly Time	2	5	5	8	1	4	8
		Total	229	315	189	121	145	202

As you can see, the top rated concept is the needle hardness tester. This is the concept we choose to proceed with. The next two highest in ranking, painting and resistance, could be integrated into our final design in order to provide more detection methods and to increase accuracy of the machine.

Top Concept Design: Needle Hardness Tester

Our team's current top design is the Needle Hardness Method. It has proven the most effective at detecting pits based on the testing performed thus far. This method relies on very thin needles being inserted to just below the surface of a peach half. When the needle comes in contact with a pit, the entire array of needles is stopped from penetrating further. We can then detect whether a pit fragment has been found by recording the force on each needle. Utilizing high gauge (thin) needles, this test leaves no visible damage to the fruit.

We have developed two machine designs for this detection method. The crux of this detection method is that every needle in the design must be inserted with the same force. Our first design uses a pressurized cylinder to apply an equivalent force to each of around 700 needles arranged in a circular pattern. The second uses an array of rectangular spaced needles each mounted on the ends of rotating arms. In this design, each arm will be torqued the same amount, ensuring the penetration force on each needle is the same. Detailed descriptions and sketches below explain each design in detail.

Design Idea 1: Pressure Cylinder

A pressure vessel is pressurized to apply an even force of 1.5lbs to each needle in the diagram below. This force is sufficient for fully puncturing the flesh, but not the pit. Therefore needles that hit pits or pit fragments will not be able to puncture the peach, and will be offset in height from its neighbors. An optical or laser-interference device could then be used to detect when a needle is stopped before the fully submerged position. Another possibility is that a force gauge could be used on each needle to detect which has hit a pit fragment.

A delrin block will be drilled to house each of the needles. The stopper for the needles will also be made from delrin. The outer container will be made from steel or aluminum, with a sized thickness to contain the internal pressure safely. The needles can be made from stainless steel or titanium. The advantage of this design is that it only requires one puncture test to determine if there is a fragment in the peach. The disadvantage is that with 700 needles, the design is complex and will be difficult to assemble and maintain. We also suspect that the needles may need to be washed after each cycle, in order to clear any debris that could give false readings.

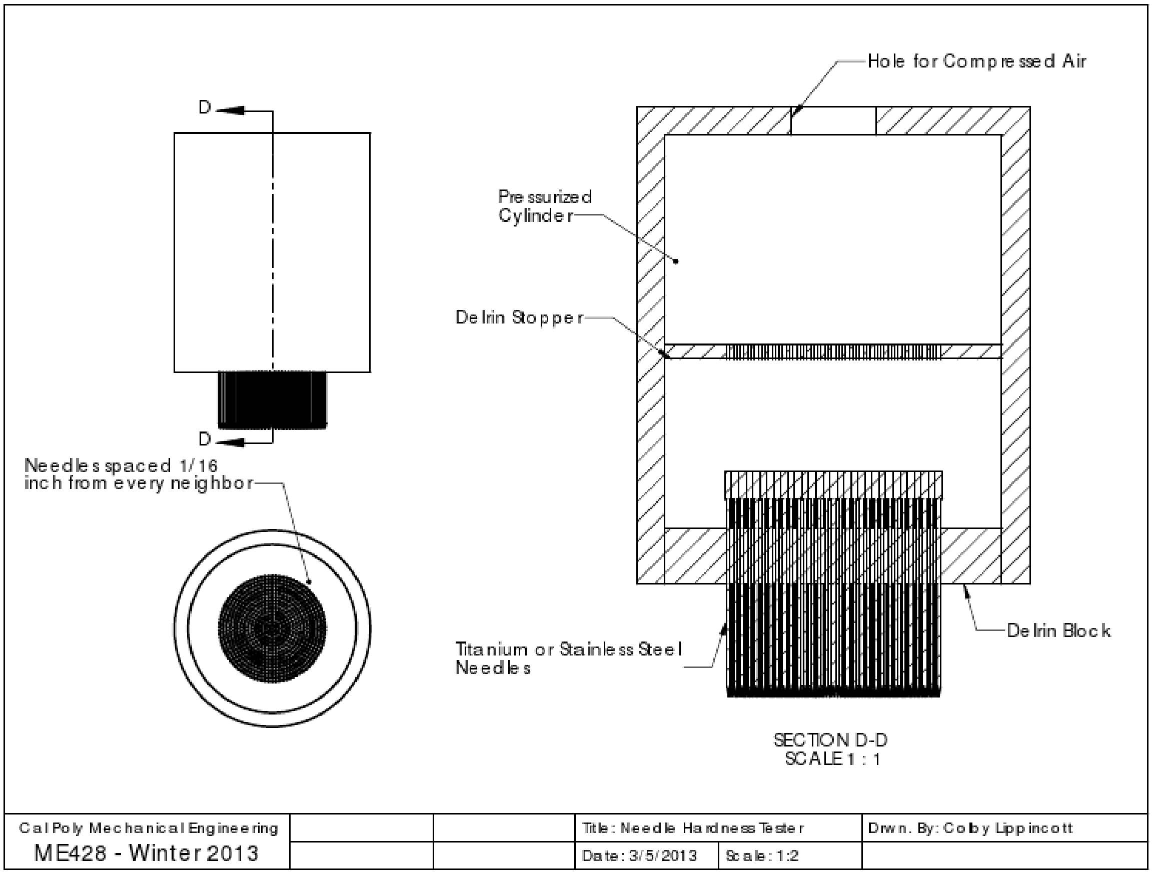


Figure 4. A pressure container is used to apply the same force to each needle. Upper and lower travel limits are imposed by an internal stopper and the lower casing, respectively.

Design Idea 2: Typewriter or Loom-Style Array

In this design, a set of arms is attached to a common pivot point. Multiple sets of arms can be positioned vertically above each other, and offset by the thickness of each arm, to allow tighter spacing between each needle. A force sensor is used to determine the resistance to puncture from each needle. If any of the needles reach 1.5lbs, The force maximum force necessary to penetrate the peach flesh, it will have detected a pit. In this case, all arms will retract, and the peach is removed from the line.

An advantage of this design is that it can detect the exact location of the pit fragment, and possibly even mark the fragment for removal. Also, it is a less complex design than the previous because there are less needles used, and the needles are fixed in position relative to their housing. However, because this design uses less needles, it will need to test the peach in several locations, and may take longer than using 700 needles at once, or be required to operate at a higher speed. Both of these ideas are simply concepts to show functionality of the basic needle design, and most likely will not represent the final product.

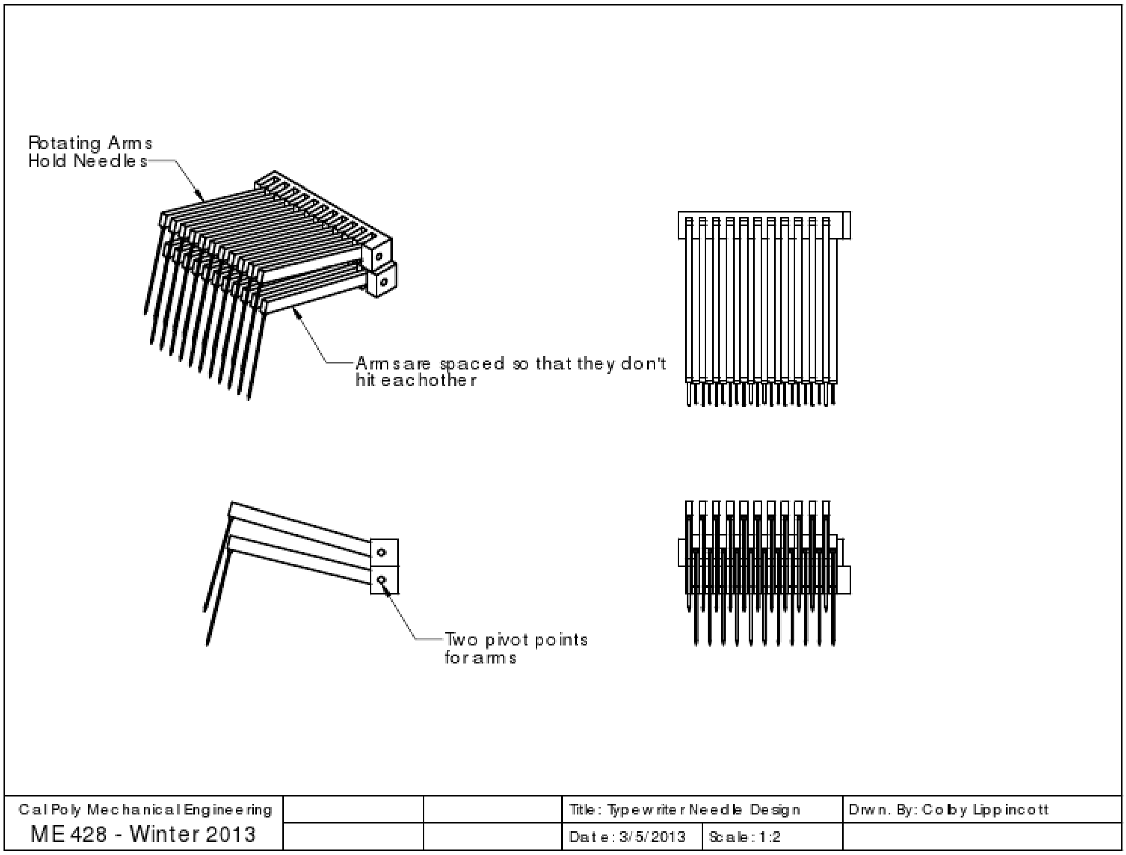


Figure 5. This drawing shows a configuration with two sets of arms. Each set is made of multiple arm-needle assemblies. By rotating each set about its pivot point, the needles are swept in a vertical arc.

Chapter 4: Description of the Final Design

Overall Description

Our final design is shown in the picture below:

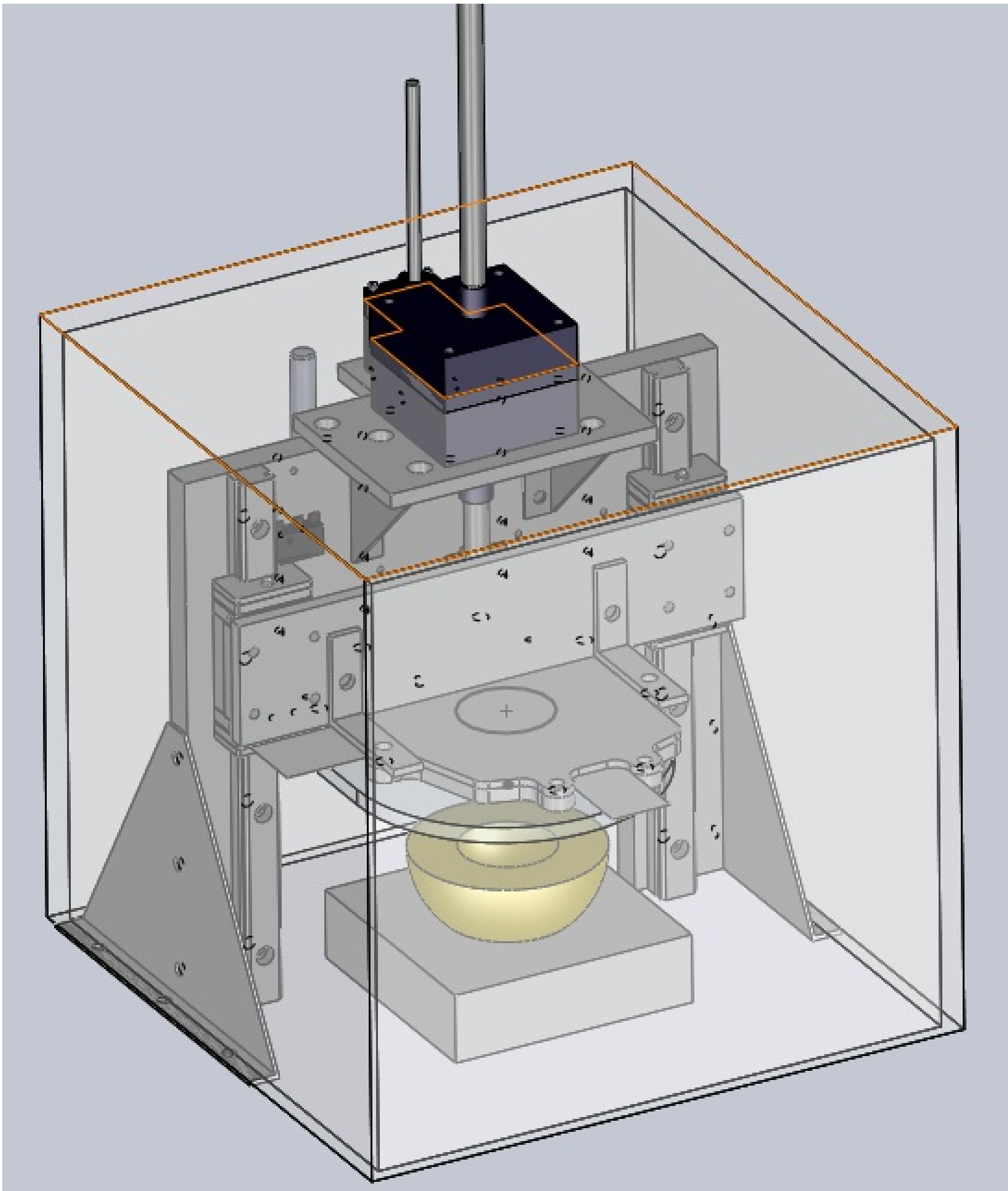


Figure 6. 3D view of assembled prototype.

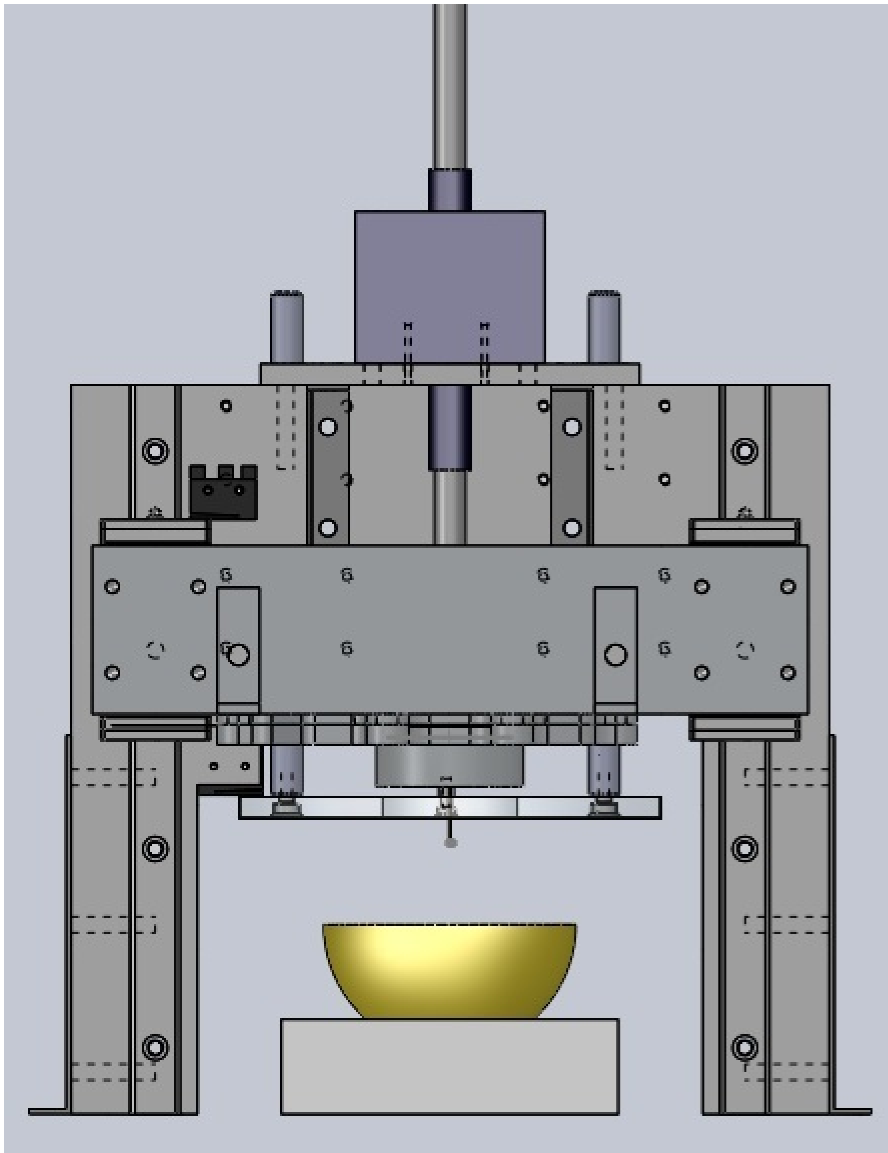


Figure 7. Front view of our assembled prototype with the cover removed.

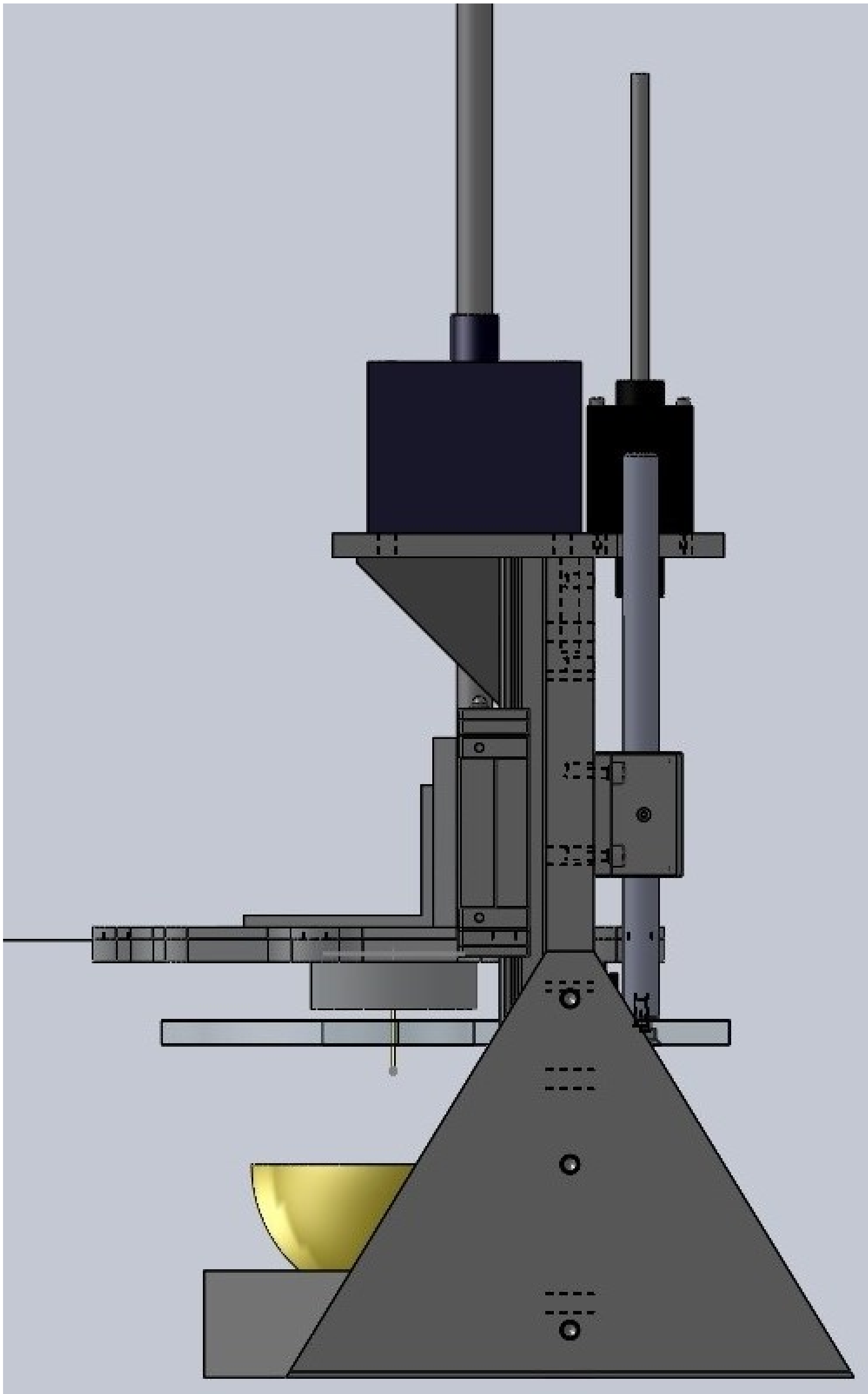


Figure 8. Right side view of our assembled prototype with the cover removed.

After significant testing that showed us that multiple needle punctures over a small area had a very similar effect to single needles, we decided to use a single needle array sensor (2). This allows us to check the peach for pits very efficiently, as we are able to cover the entire surface of the potential area in one pass. However, this also brought up the additional problem that, due to the large number of needles, the peach was often lifted up or stuck to the needles after testing. This required the development of the retaining ring (3), which holds the peach still as the needles are inserted and also provides a downward force so that the needles can be removed without difficulty. The retaining ring has its own motorized system (4), in order to allow it to provide the necessary force to do its job while doing the least amount of damage possible to the peach. It also has a simple contact sensing system that allows it to halt its movement when it reaches the peach surface. Each of these components is attached to a set of linear rails supported by a frame (1), which constrains both moving systems to vertical motion. The motorized systems and sensor are in turn supported by an electrical system (not currently shown in the mode). Most of the electrical systems will be enclosed in a large electrical box, but leads will extend to the two motors, the pressure sensor, and the contact sensors in the retaining ring. All cables will be properly sheathed to avoid contact with water, and the prototype will be enclosed in a plastic case for safety purposes. The prototype will only operate when the safety case is in place.

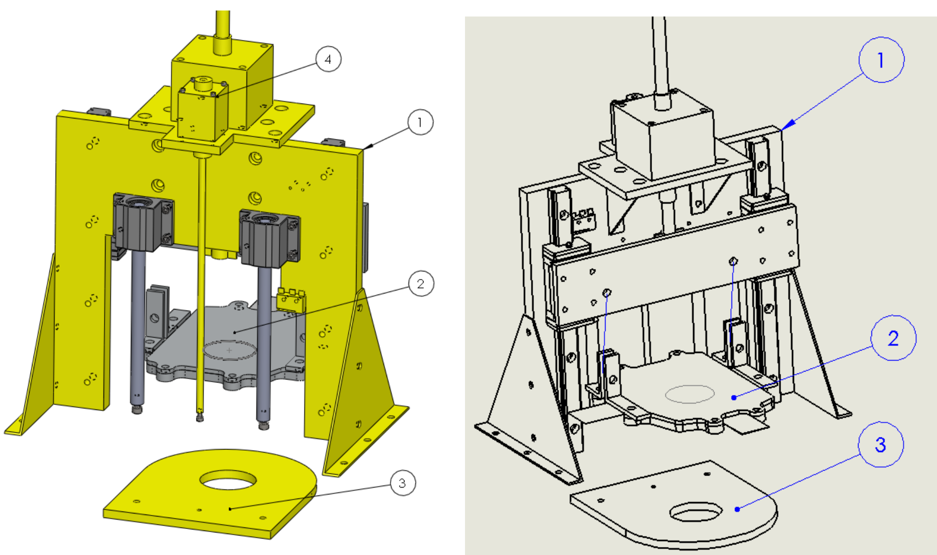


Figure 9. Front and Back view of Sub Assembly

It should also be noted that this system is designed to fit over a conveyor system like those that exist in current repitting devices, which use a long segregated belt (similar to a tank tread), where each section is a large piece of plastic or metal containing depressions designed to hold peaches. Our system is scalable so that multiple units could be installed over such a conveyor in order to check multiple peaches at once.

Detailed Design Description

Mechanical

Frame

The mechanical system of the assembly are described in this section. These carry out the physical actions of the prototype and are comprised of the Frame, Retaining Ring, and Sensor Array.

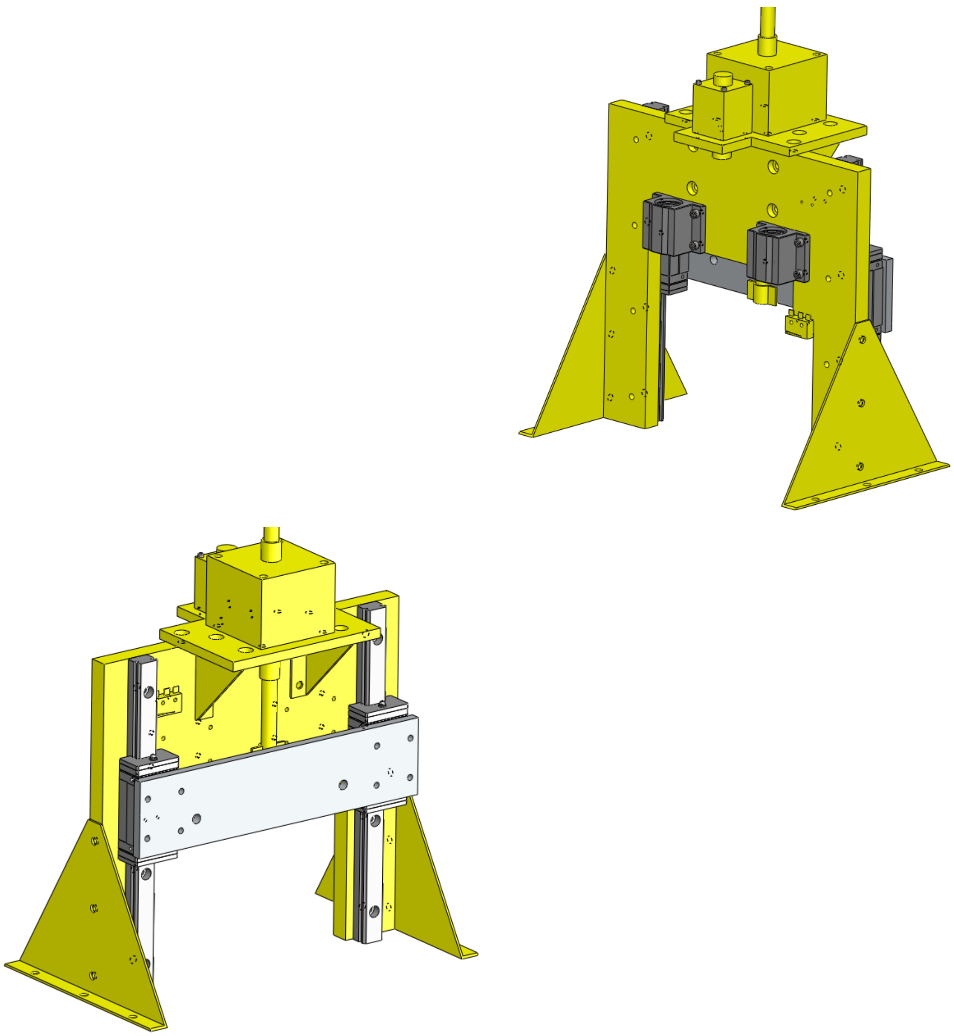


Figure 10. Front and Back views without needle carriage and retaining ring

The first major component of the system is the frame, which provides support for all of the other components. This includes the linear rails that constrain each motor system, allowing them to move only in the vertical direction. For the purposes of this prototype, the frame was designed from aluminum, which is structurally sound but also easy to machine

and work with. If multiple units were to be incorporated into the structure, it is likely that the major structural systems would be combined and changed to stainless steel to support the increased load without deflection, as well as reducing the overall metal usage.

The actuating motor for the needle array is also included in the fame, and sits on top of a set of brackets at the top of the assembly. It is a linear actuating system, and drives a vertical shaft, which moves the needle carriage. The needle carriage is the aluminum bar that the sensor array attaches to.

Retaining Ring

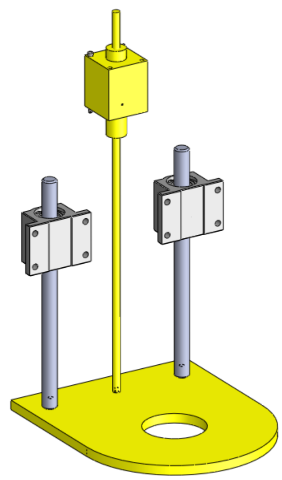
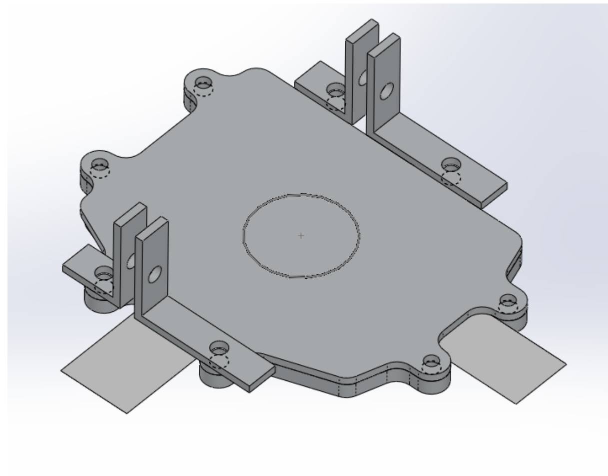


Figure 11. Retaining Ring Assembly

The second major component of the system is the retaining ring, which holds the peach steady as the needles are inserted and withdrawn. The retaining ring has its own motor system, which lowers it when the peach comes into position. It recognizes that it has touched the peach through a simple set of sensors on its contact plate. Essentially, the sensors are two sides of a broken circuit. When in the air, there is too much resistance to allow the circuits to connect, but when both touch a peach, the water in the fruit conducts a weak electrical signal that tells the motor to stop. There are 4 sets of these sensors on the plate to account for different sized peaches and to ensure that the ring is level on the peaches surface. When the needles are inserted, the plate simply keeps the peach from slipping or turning, as well as leveling the surface. More importantly though, when the needles are removed, the retaining ring holds the peach down so that it does not become stuck to the needles. This keeps the process running without interruption.

Sensor Array



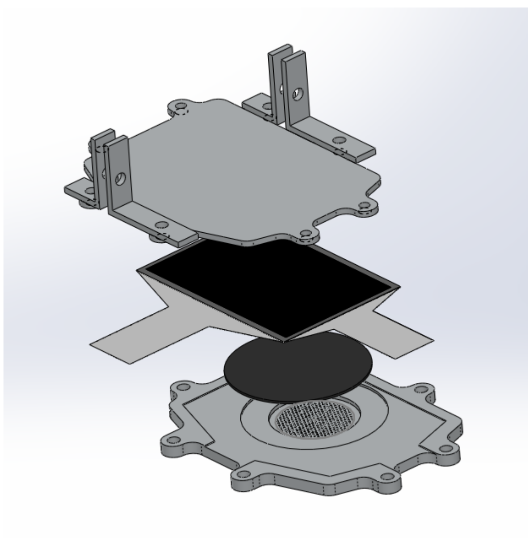


Figure 12. Sensor Assembly before the needle hole modification.

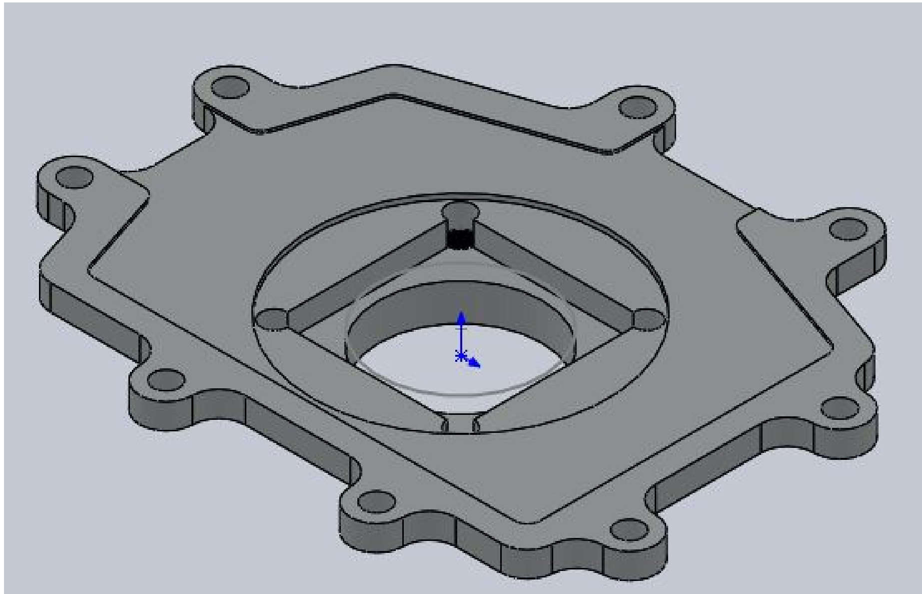


Figure 13. Needle holding plate final design. A sandwich of perforated aluminum square sheets were inserted into center cut out to hold the needles.

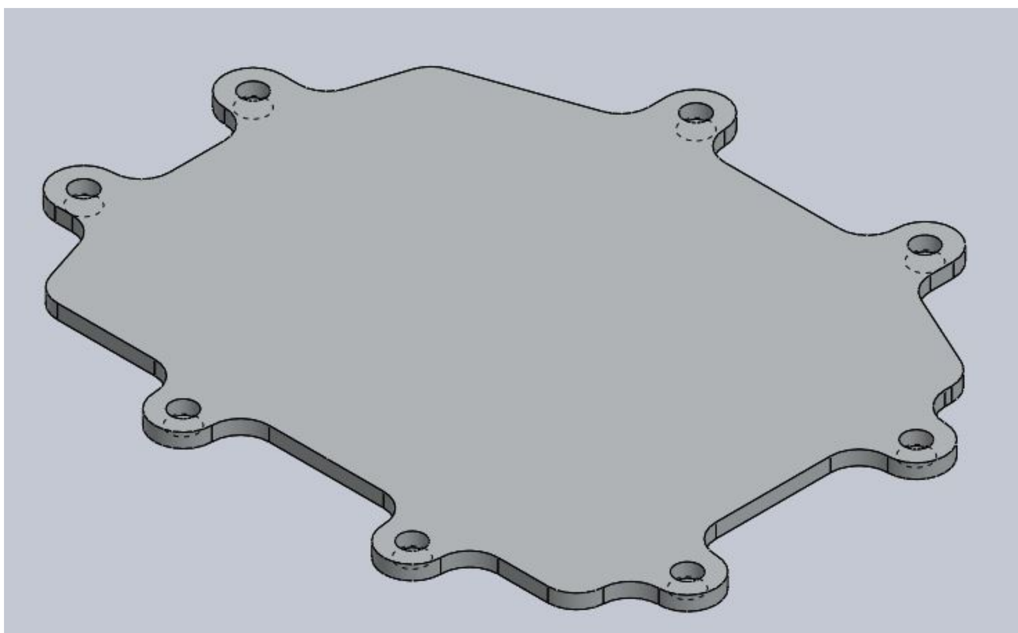


Figure 14. Needle holding top plate final design.

The sensor array is the combination of the array of needles and the pressure sensor that make up the primary pit detection device. The needle array is comprised of 313 needles of 0.0275in or 0.7mm in diameter, spaced 2mm apart in a hexagon pattern. These are encased in a specialized mount plate, with the flat tops of the needles keeping them from slipping out. Above the needles is a thin rubber sheet, which helps provide a layer of protection between the needle heads and the pressure sensor. The pressure sensor has a resolution of 3mm, which will allow us to find pits down to at least 0.125in in diameter. The needles and sensor are enclosed in an aluminum casing that protects them from water and

provides the structural support to allow the array to be moved up and down. When the peach is in position, the array is lowered until the needles pierce 0.25 inches below the lowest point of the peach pit depression, based on the average depth of a 3in peach pit. If the pressure sensor detects a spike in pressure at any point, indicating a pit, it immediately stops and reverses the motor.

It should be noted that the needle array is arranged within a 1.5in diameter. We found this to be the rough dimension of the pit center in a 3 inch pit. This design decision was made due to the fact that an array of 2in would be problematic for peaches 2in in diameter. With a 1.5in diameter array, the prototype will be able to check 2in to 4in peaches, but it will only check part of the potential affected area for peaches over 3 inches in diameter.

Electrical

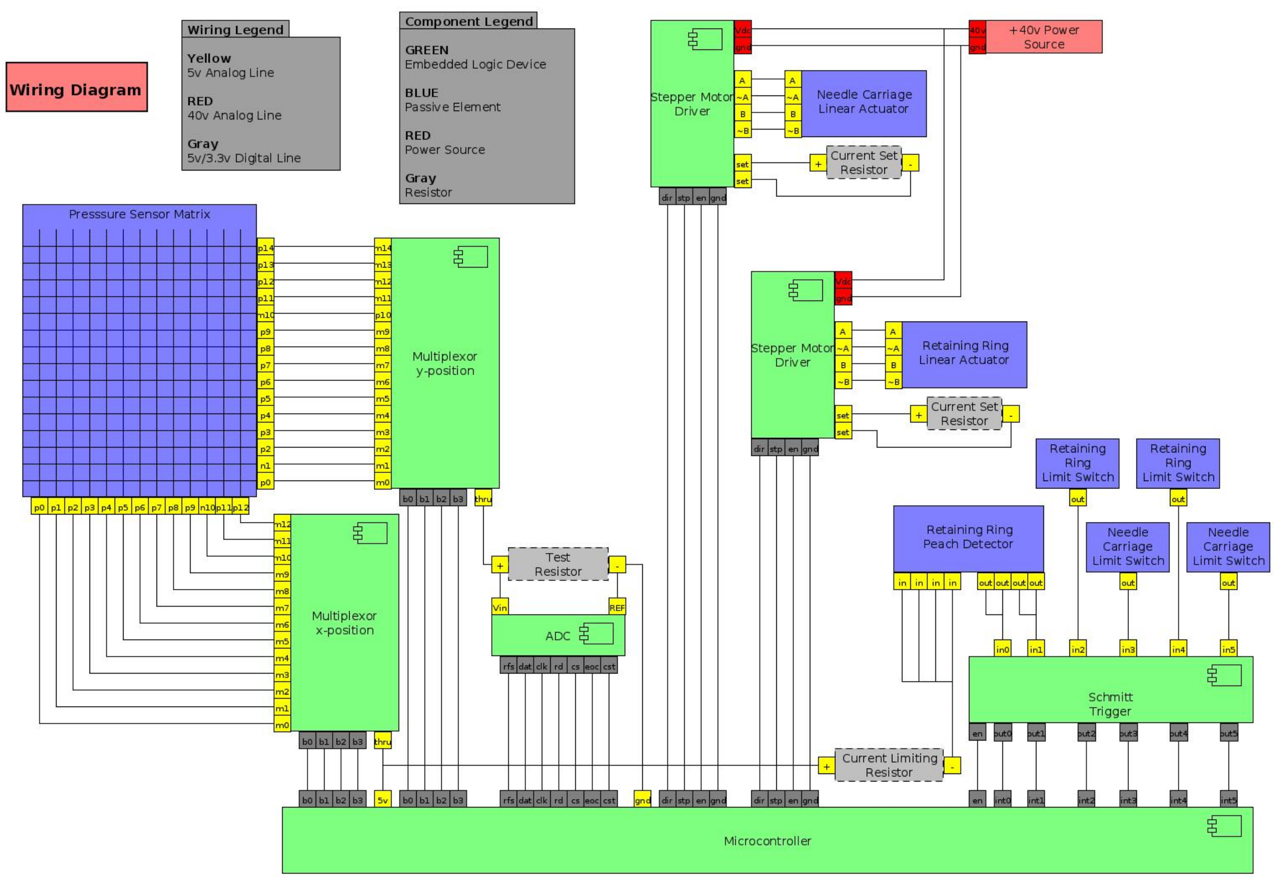


Figure 15. Electrical System Wiring Diagram - shows how the various electrical components are to be wired together.

The wiring diagram above shows how each of the electrical components, explained in detail below, will be wired together. The electrical system design is twofold: the hardware and software must interact in order to create an intelligent system which can detect pits. The following section describes in detail the electronic components required. The software design description follows this section, as the software design is primarily driven by the hardware design.

MicroController

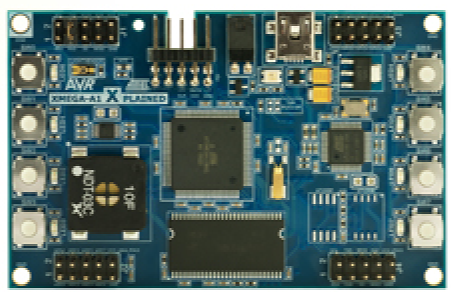


Figure 16. Atmel XMEGA-A1 Development Board - the development board chosen to control the system.

A microcontroller contains a CPU, memory, and peripheral interfaces all in a single package (a so called System-On-Chip, or SOC). It acts as the 'brains' of the system, controlling the various mechanical and electrical components therein. In the picture above, the microcontroller is the large black square in the center of the board. The development board pictured will be used in our design. It contains the microprocessor, a USB port, additional SDRAM memory, and a number of LEDS, button switches, and header pins, all of which simplify the prototyping process. The microcontroller will be programmed to follow the pit detection algorithm outlined in the Software Design Description, which is detailed later in this report.

Stepping Motors

A traditional electric motor employs a single stator winding which produces a constant torque on the rotor when energized. However, a stepping motor is designed with

multiple stator windings. When a winding is energized, the motor snaps forward one ‘step’. The linear actuators in the system use stepping motors to drive forwards and backwards as this simplifies actuator position control. A traditional electric motor requires a second order, closed loop model to achieve position control.

While it is simpler to control the position of a stepping motor, it is more complex to actuate than a traditional electric motor. The stepping motor’s windings must be pulsed in a specific order and at a high rate. To achieve a 6 inch per second travel speed of the retaining ring’s linear actuator, the motor pulse frequency is 9.6 KHz (one step every 0.1ms). Designs which employ stepping motors also require stepping motor drivers to actuate them.

Stepping Motor Drivers

Figure 17. Gecko 213V Stepping Motor Driver - the stepping motor driven selected for the stepping motors utilized by the linear actuators.

The stepping motor driver is used reduce the CPU burden on the microcontroller by providing a simple digital control interface to actuate the stepping motors. The stepping motor driver selected for the system additionally smoothes out the velocity profile of the motor by interpolating 10 microsteps between each full step.

The driver additionally shields the controller’s sensitive digital components from the high current, high voltage motor lines. This is especially important during motor deceleration, when it behaves like a generator and tries to source a current back to the controller. Without a stepping motor driver’s protection circuitry, this would absolutely fry the system’s electronic components.

Retaining Ring Peach Detector

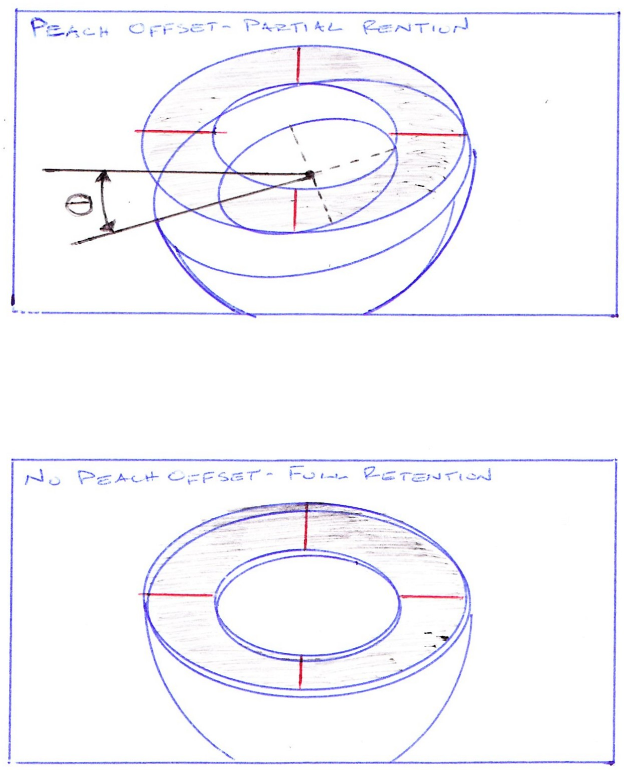


Figure 18. Peach Retaining Ring Detector sketches - Top panel shows peach offset from horizontal at angle θ, bottom picture shows peach properly retained in the horizontal position.

The retaining ring used to hold a peach firmly in position during pit detection must be able to detect when it is in contact with the peach. 4 electrical contacts are placed between the inner and outer diameter of the retaining ring. Two of them are positively charged, while the other 2 are grounded. The peach is used to complete the circuit through the wires. When the peach is fully retained in the horizontal position, a small current will be flowing through all 4 wires. If the peach is only partially retained, as in it is not horizontally aligned, current will not be flowing through all four wires.

The figure above shows this operation. In the top slide, the peach is offset by some angle θ. When the retaining ring descends on the peach, it will level the peach surface. Only once the peach is properly retained in the horizontal position will each contact patch register.

Matrix Pressure Sensor

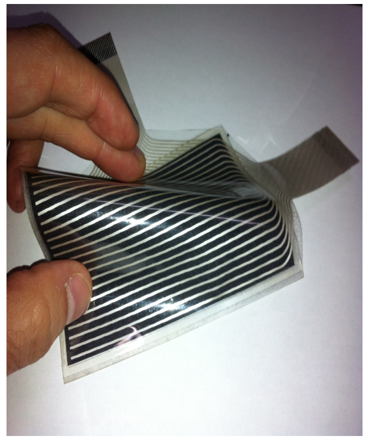


Figure 19. SensingTex 3x3.3mm resolution 28x24 sensing element matrix pressure sensor, the pressure sensor used to measure the force on each needle in the needle array.

The pressure sensor contains a matrix of pressure sensing elements spread out across its surface. The sensor contains wire traces printed on two pieces of plastic. These plastic sheets sandwich a proprietary material whose electrical resistance decreases as it is deformed. When pressure is applied at a point to the sensor, the electrical resistance of the material at that point is decreased. By orienting one plastic sheet with wire traces in the x-direction, and the opposing sheet in the y-direction, the pressure at each (x, y) position can be measured.

Multiplexers

A multiplexer is a digital selector. The multiplexers in this design have 16 inputs and a single output. The design utilizes multiplexers to select at what (x, y) position on the pressure sensor to obtain a reading. Therefore, for this system, a total of 256 (16 x 16) discrete points of pressure can be measured. However, only 200 are necessary to completely measure the pressure distribution of the needles used in the system.

Analog to Digital Converter (ADC)

The final component necessary to measure the pressure on each needle in the system is an ADC. It converts an analog voltage into a discrete digital value. The ADC measures the voltage drop across the ‘Test Resistor’. When the pressure point being measured is high, the pressure sensor’s electrical resistance at that point will be low. Therefore, the voltage drop across the test resistor will be high. The opposite is also true: when the pressure being measured is low, the voltage drop across the test resistor will be low. By using the ADC to measure the exact voltage drop across the test resistor, we can precisely calculate the force on each needle in the system and to detect if there is a pit.

Software

Pit Detection Algorithm

The pit detection algorithm diagram is in Appendix B. It is an overall view of the algorithm the prototype will follow in order to detect pits. The system advances to the next state when it receives the appropriate signal, shown in [square brackets] in the diagram. The software design will therefore include a Signal Daemon: a background process whose job it is to receive signals from the various system components, and issue commands the appropriate hardware based on the signal received and the current state of the system.

Idling

The default state for the system is idling. In this state, both the retaining ring and needle carriage are in the home position. In this position, they are raised to their maximum height, to allow the conveyor to bring a new peach into position underneath them. The system will remain in this state until the [run] signal is received, at which point the signal daemon will instruct the retaining ring to advance.

Retaining

When the system enters the retaining state, the peach retaining ring will lower. It will continue to lower until it has detected that the peach is fully retained, (see Retaining Ring Peach Detector, page 27). When the retaining ring has fully retained the peach, it will send the [retained] signal back to the signal daemon, which will tell the needle carriage to advance.

Engaging

The system is in the engaging state when the needle carriage is lowering but has not yet come into contact with the peach. In this state, the needle carriage will lower itself quickly until the needles are at the same height as the retaining ring. After this, the needles will advance slowly until the first needle comes in contact with the peach. At this point, the needle carriage sends the [engaged] signal to the signal daemon, which instructs the pressure sensor to begin taking measurements.

Detecting

In the detecting state, the needle carriage is advancing very slowly, and the pressure sensor is constantly being scanned to determine the force on each of the needles. The system will remain in this state until either a pit is detected, or the carriage reaches its lower travel limit.

A pit is detected when a pressure reading from the sensor reaches or exceeds a

threshold. From our preliminary tests, the threshold force on a needle is around 1.5 lb. However, the pressure this corresponds to will depend on the needle head diameter, and further tests are needed to determine an exact measurement threshold. When a pit is detected, the pressure sensor system sends the signal [pit] to the signal daemon, and the system cycles to the disengaging state.

As long as no pits have been detected, the carriage continues to lower until all of the needles have come into contact with the peach. When every needle has been inserted 0.25 in, and no pits have been detected, then the pressure sensor sends the signal [no pit]. When the signal daemon receives this signal, it responds by telling the needle carriage to retract, and for the pressure sensor to stop collecting data.

Disengaging

In the disengaging state, the needle carriage raises slowly until the needles are at the same height as the retaining ring. At this height, no needle is in contact with the peach, so it then quickly retracts the rest of the way until it is in the home position. The needle carriage knows it has reached home when the carriage hits the limit switch mounted on the prototype’s frame. When the carriage has reached home, it send the signal [disengaged]. The signal then tells the retaining ring to retract.

Releasing

In the releasing state, the retaining ring is being lifted off the peach. The retaining ring continues to rise until it reaches its home position. Like the needle carriage, the retaining ring has a limit switch it hits when it has reached its home. When it is fully raised, it sends the signal [released]. Based on the results from the detecting state, the signal daemon sets the state to either rejecting or passing.

Rejecting

In the rejecting state, the system is separating the peach from the production line or otherwise marking the peach for pit extraction. In this prototype design, there is no production line to separate it from, so this information will simply be relayed back to the user. Most likely, for this prototype, the system will send this information to an attached laptop or computer via USB.

Passing

In this state, the system is allowing the peach to continue down through the production line in the pass line. As there is no production line developed for this prototype, this information will simply be relayed back to the operator. Most likely, the system will send this information to an attached laptop or computer via USB.

Stopped

The stopped state is a special case. At any time, the entire system can be halted by sending the stop signal to the signal daemon. This is an emergency override for the system. It is in place to allow an operator to stop machine operation for any reason. For example, if an obstruction falls into the machine, an operator should be able to stop it in order to remove the obstruction, regardless of what state the machine is in. Upon the resume signal, the system will pick up immediately from where it was stopped. However, the signal daemon also accepts the reset command while in the stopped state. No matter where the system was, this will set the state to disengaging, and if there was a pit detected before the reset command was set, it will be ignored. Again, this is a safety feature. If an obstruction fell in, and the machine thought it was a peach with a pit, it allows the operator to override the default behavior of the machine.

Additionally, if any faulty behavior is detected by the system, the Signal Daemon will reset the machine. This could happen, for instance, if there was no peach loaded in the machine. Rather than continue to look for a peach which isn't there, the system will be smart enough to reset itself, and wait for a peach to be loaded.

Class Diagram

The software class diagram (see Appendix B) describes the various components of the software which must be written in order to implement the pit detection algorithm described above. A detailed description of this diagram is not be included in the report, the diagram is included just as an appendix reference. However, to understand a broad overview of the software class design, start by examining the titles of each of the classes. Each class represents a piece of electronic hardware discussed in this report. The Needle Carriage is the class which is in charge of raising and lowering the needles. The 'Has A' relationship indicates that the needle carriage has a linear actuator and a limit switch. The limit switch is what allows the needle carriage to know when it has reached the home position. The linear actuator class has a stepping motor, which is what is uses to drive forwards and backwards. The linear actuator, therefore, acts as a wrapper class for the stepper motor. Whereas a stepper motor rotates, a linear actuator translates, so the linear actuator class provides the interface to retrieve position information from the stepper motor.

The most important piece of information from this diagram is the distinction between the blue and green classes. A real time operating system, FreeRTOS, is used to schedule each of the green classes. These are the classes which have a hard real time constraint. For example, the user interface task should run at 20 Hz, so there is no perceivable delay between user input or output. The pressure sensor has the highest real time constraint at 350 KHz. This corresponds to the frequency at which the ADC is taking

readings. In order to detect pits as quickly as possible, when in the detecting state, the pressure sensor should be running at full speed.

Sequence Diagram

Based on the pit detection algorithm and the class diagram, a full system cycle sequence was developed (see Appendix B). This ties the previous two sections together: it shows what classes are active during each step of the detection algorithm, and shows who is responsible for sending and receiving signals at each step of the detection algorithm. The system is initiated by a start command, which can be seen as originating from the User Interface at the top of the diagram. The diagram proceeds chronologically from the top to the top to the bottom, until at the end we see the system has returned to the idle state, where it is ready to begin the cycle again.

Analysis Results - Mechanical

The supporting analysis for these discussions are included in Appendix E.

Needles

In order to choose the size of the needle we needed, we first conducted tests to determine how large the needle could be without affecting the texture of the peach. Peaches were tested with varying sizes of needles, and then the peaches were taste tested to determine if there were any effects on the peach. A needle diameter of 0.6mm was determined to be the optimal size for the needles.

Next, we tested how much force is required to puncture a peach. An array was created with 19 needles in a rectangular formation, 2 mm apart. The force required to puncture the peach per needle was measured to be 0.038 lb. Taking into account the acceleration of the assembly plus the force required to puncture the peach, the motor is required to provide a force of 21 lb. The retraction force was around one third of this force, or 7 lb. Additional data is given in Appendix E.

Using the force on each needle, we calculated the safety factor against buckling for the needle, and determined that the force was well below the critical load (Appendix E). Therefore, 0.6 mm diameter needles are sufficiently sized to handle the loads they will see.

Retaining Ring

The retaining ring (see figure 11.) is made out of ¼" thick acrylic sheet. A beam bending analysis was performed to determine the stress on the acrylic sheet. The lead screw and 2 support rails are located 2.5" from the 4 lb force of the needle array pulling out of the peach. This creates a 10.25 in-lb moment. The stress calculation gives 197 psi which is way below the 17,000 psi endurance limit of acrylic. This data is given in Appendix E with diagrams.

Motor Bracket

Using the 21 lb upwards force on the motor lead screw (see figure 6 of the full assembly), a beam bending analysis was performed to determine the size of the motor mounting plate. The analysis is shown in Appendix E. The stress in the beam was found to be only 313.6 psi, which is well below the strength of aluminum, and provides a life of greater than 10^9 cycles.

Motor Bracket Screws

From the above calculations for the bending moment, the force on each screw and on the reinforcing bracket was also found, and is shown in Appendix E. The force on the reinforcing bracket screws is 34.21 lb of shear on each bolt. The force on the mounting

plate screws is 23.7 lb of compression on each bolt. This a very high estimate of the force on the screws, because the actual reinforcing bracket acts all the way along the motor mount, rather than just at the wall. Both a fatigue and static loading analysis was performed, shown in Appendix E, and show that #10 bolts are sufficient for infinite fatigue life. The safety factor of 1.1 for the bolt in tension is due to the static preload, and can be reduced if necessary. Therefore the forces on the screws will not cause failure.

Stand Bolt Shear

The triangular stands that hold the machine to its base have 3 screws that hold it in place. As seen in Appendix E, these screws undergo 3.5 lb of shear each. From the calculations for the motor bracket screws, you can see that #10 bolts are also sufficient for the stand.

Analysis Results - Electrical

The supporting analysis for these discussions are included in Appendix E.

Microcontroller

The microcontroller has several design characteristics to consider for this prototype. From the wiring diagram, it must have the following IO ports: 6 external interrupt pins + 24 General purpose IO pins. The hardest real time constraint to meet is the ADC frequency, which must be initiated and read at 350 KHz. In order to achieve, this, the ADC I/O clock line must be toggled at 20 MHz, so the processor's internal clock must be at least this fast. Finally, there may be the desire to produced data logging output from this machine, so it should either have a large amount of memory (> 1MB), or allow for easy memory expansion. Finally, there should be built in USB adapter, to ease prototyping and debugging. This would not be necessary in a final product. The Atmel XMEGA-A1 development board satisfies all these requirements, by including an XMEGA128A1 microcontroller with 32MHz internal oscillator, 8MB RAM, and a USB adapter.

Stepping Motor Power Supply

Each linear actuator utilizes a stepping motor to provide actuation torque. Power supplies for stepping motors are typically selected to supply 10-25 times the motor's rated voltage. Using an increased voltage improves motor response time by reducing the motor's time constant (a first order approximation of the time delay between stator energization and rotor torque output). The stepping motor driver manufacturer suggests selecting a power supply based on the following equation:

$V_s = 32 \cdot \sqrt{L}$, where *L* is the inductance of the motor in milliHenrys

Conveniently, the measured inductance of the motors for both linear actuators in the system is 1.5 mH. Using the above equation, a 40v power supply was selected.

Additionally, the current rating of the supply must meet or exceed the current drawn by each of the motors it is powering. To simplify the design, a single power supply is used for both motors. The current draw ratings of the needle carriage and retaining ring actuators' motors are 3A and 1A, respectively. Therefore, the power supply must be rated for at least 4A. A suitable power supply providing 32-40v adjustable, 7A maximum current draw was selected for the system.

Stepping Motor Driver

The critical design considerations of a stepping motor driver are its voltage and current ratings. These ratings must meet or exceed the motor's levels . Using the analysis performed to select a power supply, these are set at 40v , 3A and 40v, 1A for the needle

carriage and retaining ring actuators. Additionally, the rotational speed of the motor must be within the limits of the driver. Our design requires the actuators to travel at a top speed of 6 inches per second. The corresponds to a step frequency of 2.4 KHz for the needle carriage actuator and 9.6 KHz for the retaining ring actuator. To simplify the design and improve serviceability, the same driver will be used to control the stepping motors on both linear actuators. An 18-80v, 0-7A , 350 KHz maximum input step frequency driver was selected.

Cost Analysis

The bill of materials is shown in Appendix B. The total cost for the system is $2368 including tax and shipping. Operating costs include electricity cost and water usage (to clean the needles after each cycle). The electricity used is approximately 4 KWh per day ($0.68), and the water used is approximately 72 gallons per day ($1.40), assuming that the machine is operated 20 hours a day. This results in a total operating cost of $2.08 per day.

Component Selection Notes

Mechanical Devices

- In order to provide the 21 lb of force calculated above, a linear actuator was chosen that could provide up to 70 lb of force. This linear actuator uses a stepper motor to drive a lead screw up and down, which provides the force on the needles. The linear actuator chosen is from Anaheim Automation.
- For the linear rails that guide the needles up and down, we chose McMasterCarr's Corrosion Resistant linear slides and rails, to make sure that the machine could operate in a moist environment.
- For the needles, we chose stainless steel for the material , which does not corrode.
- For the machine frame, we chose aluminum because it is food safe , and easy to machine.
- All of the screws in the machine are also stainless steel for the same reasons as above.
- The retaining ring material chosen is acrylic, because it is lightweight, food safe, and exceeds stiffness requirements.

Electrical

- The software design of the system was developed to be highly portable, in case the microcontroller or other electronic hardware changes during a design revision.
- The ADC selected for the design was chosen because it is a high speed converter. Because we are sampling voltage readings at 195 points along the pressure sensor, a fast ADC is necessary to keep the system running quickly.
- The power supply and stepping motors drivers are specified to handle much larger loads than what the design calls for, as in a final product, the weight being lifted by the linear actuators may increase if parts are added.

Maintenance and Repair Considerations

The primary concern for maintenance and repair is the possibility of needle breakage. If a needle was to break, the sensor array must be easy to disassemble so that the needle can be replaced in a short time and without any difficulty. Hence, the sensor assembly is designed to be easy to remove from the carriage and then opened. Likewise, the sensor and sensor protector pad are held in place only by their containing shell, so they can be easily removed from the housing to get to the needles.

Another concern is the leakage of water into the electronic systems. It would be important to provide gaskets at all entry and exit points to sensitive electronics, as well as coating wires in protective sheathing or tubing. These should be watertight but also easily removable in case a wire or system needs to be replaced.

While we have deliberately chosen materials to be resistant to corrosion, the buildup of minerals or peach material could be an issue for the mechanical and electrical systems if not regularly maintained. It is recommended that the users check the unit for such buildups during the daily cleaning hours.

Manufacturing Plan

Materials needed:
-12X 12 X 1/2” Aluminum Plate
-Two 8 X 8 X ¼” Aluminum Plates
-12 X 12 X 16 ga. Aluminum Sheet
-12 X 0.375 DIA Aluminum Rod
-8 ft X 2 X 1 ½ Aluminum Angle
-6X6X1 Aluminum Plate
-Urethane Rubber
-1/4” thick Acrylic

Manufacturing Schedule:
All manufacturing was done in house
Motor Mounting plate- 10/23/13
    -uses ¼” thick Aluminum plate
    -requires mill/ drill press/band saw
    -time 4 hr
Frame - 10/27/13
    -uses ½” thick Aluminum plate
    -requires mill/ drill press/band saw
    -time 8 hr

Carriage - 10/30/13
-uses ¼” thick aluminum plate
-requires mill/ drill press
-time 2 hr
2X Stand - 10/14/13
-uses 16 gauge Aluminum sheet
-requires shear and drill press
- time 2 hr
Retaining Ring- 10/23/13
-uses ¼” thick Acrylic
-requires drill press//band saw
-time 2 hr
Sensor Cap plate- 10/12/13
-uses ¼” thick Aluminum
-requires CNC mill
-time 8 hr
4 Sensor Brackets- 10/16/13
-uses Aluminum Angle
-requires drill press/band saw
-time 2 hr
2X Guide rods - 10/19/13
-uses aluminum rod
-requires lathe
-time 2 hr
Lead screw tapping - 11/4/13
-uses actuator leadscrew
-requires lathe
-time 1 hr

Mass Manufacturing Plan

The Wawona peach plant would decide how many of our machines would be needed to account for the large peach volumes of 2.7 million peaches per day. Our prototype would need to be modified to fit Wawona’s system of conveyor belts and current machine spacing. Our device is a proof of concept prototype, and more direct work with Wawona is required before mass manufacturing our machine.

Safety Considerations

A safety consideration of ours was the needles injurying a member of the audience during the senior project design expo. We implemented a clear acrylic safety box to protect us and the audience from the needles. This safety box had foil tape on one edge that completed a circuit which allowed power to flow to the rest of our device. If this safety box is not in place, then no power will be delivered to our motors and the needles will not move up or down.

Chapter 5: Product Realization

Manufacturing Processes

We manufactured the majority of our parts in the Cal Poly machine shop. We decided to design as many of our parts as possible to be easily machined on campus using the tools and machines readily accessible, as knew outsourcing our parts would be expensive and time consuming.

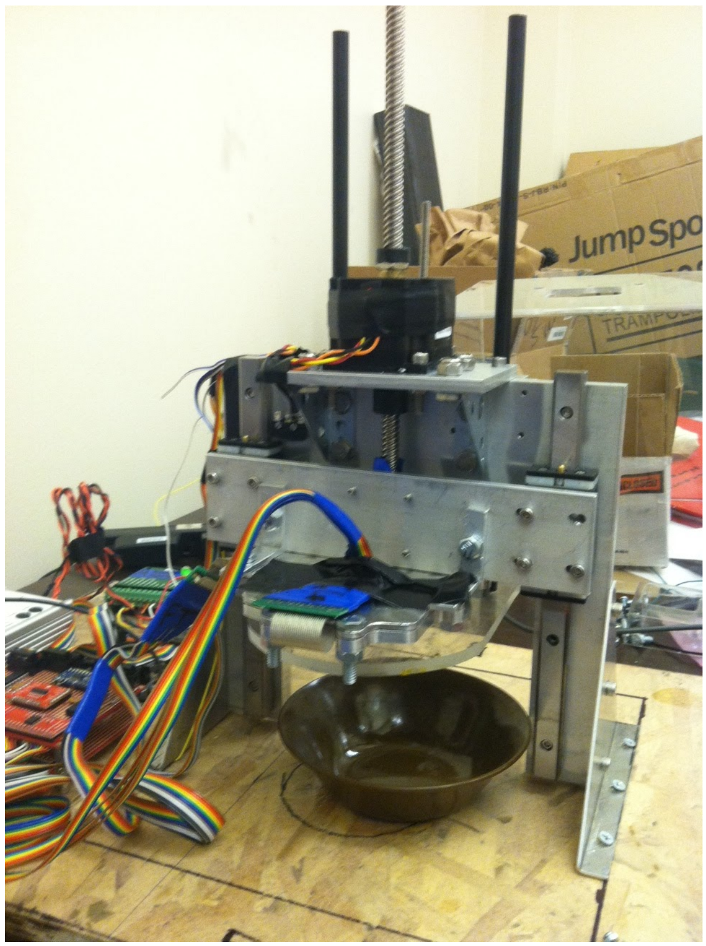


Figure 20. Shows the finished prototype we presented at the senior project expo. All of the plates and brackets shown were built on Cal Poly campus.

Prototype

As planned, the majority of our prototype was built on campus using hand operated machines. The one part intended to be outsourced was the sensor mount plate, which required the machining of over 300 very small, fine holes that the needles would slide through. The tolerance of the hole size itself as well as the spacing between the holes would need to be outsourced to be manufactured accurately. However, the cost of outsourcing this array of very small holes proved to be too great, and we decided to find

another option.

We decided as a team to change the needle holding plate design so it could be machined quickly and easily on campus. Rather than outsource for machining, we replaced the small holes with perforated aluminum sheet metal, which we could cut with a mill to the required size. We ordered perforated aluminum sheet metal with the specified hole size and spacing already present. The thickness of the sheet was too thin to provide enough stability with only one layer, so we cut and stacked several square sheets on top of each other in order to achieve our desired thickness. This plate "sandwich" was placed into a modified pocket we designed into the needle holding plate. We had to properly align each of the plates precisely when inserting the needles into the plate sandwich. After the first few needles were inserted, the rest of the needles easily slid into the perforated sheet holes. Our final design consists of 3 perforated plates, each separated by a spacer, in order to provide as much constrained length along the needles as possible.

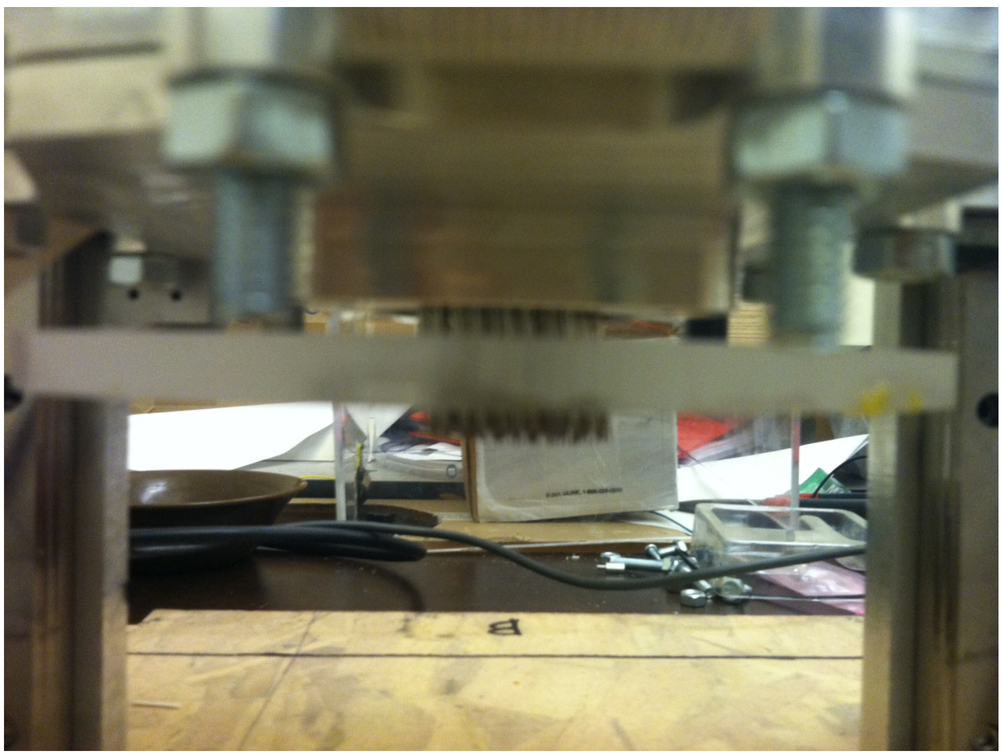


Figure 21. Shows the needle tips protruding out of the bottom of the sensor mount plate with the perforated sheet sandwich inside. The clear acrylic retaining ring is shown in the foreground of this photo.

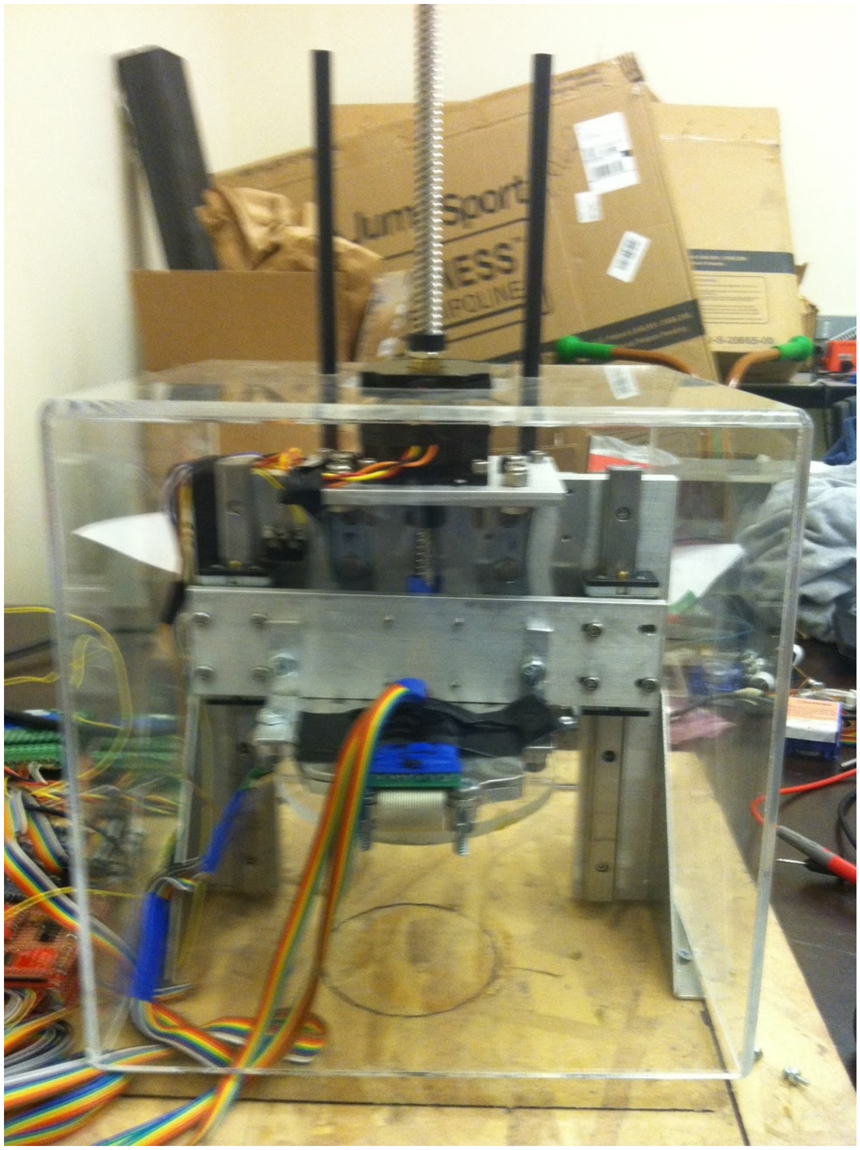


Figure 22. Shows the clear acrylic safety box that was used during testing and at the senior project expo to protect us and the audience from the needles.

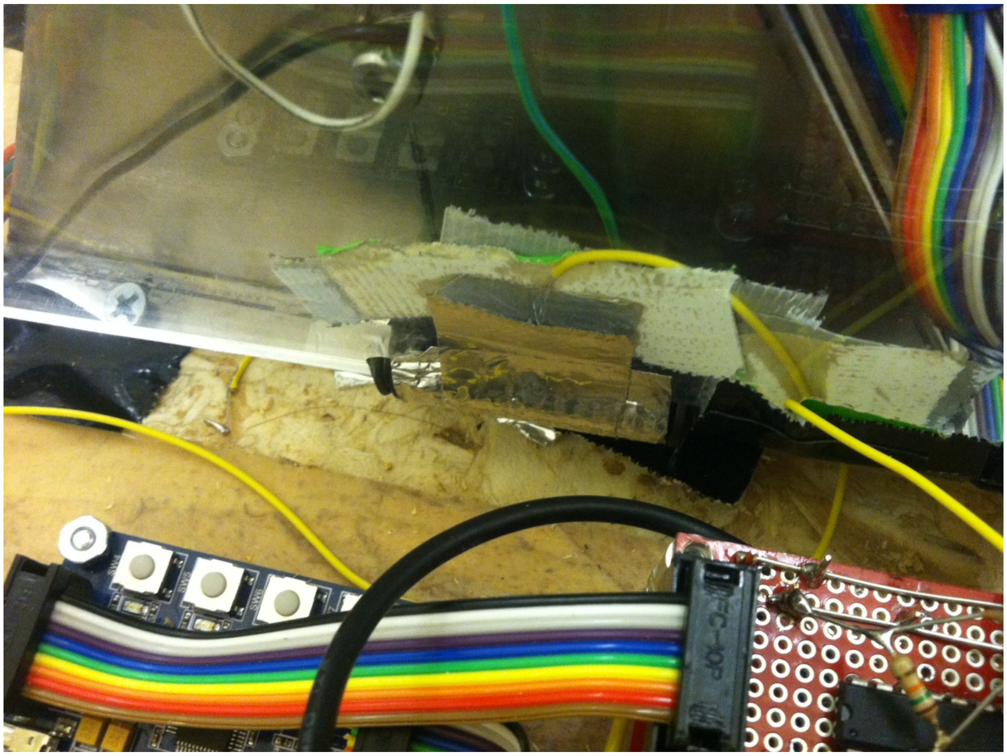


Figure 23. Shows the edge of clear acrylic safety box with foil tape that completes the circuit which allows our device to operate. If this safety box is not in place, then no power will be delivered to our machine and the needles will not move up or down.

Future manufacturing of our design

When manufacturing several of these pit fragment detectors in the future, we recommend more advanced fabrication techniques, such as CNC, for the job. While using more hand operated or simpler machines was convenient for our prototype, processes like CNC are also much more accurate and repeatable, and better able to manufacture multiple parts to the same tolerance. Some of our plates had drilled holes that later needed to be made into slots in order to fit the required hardware or mate with its neighboring piece, which is undesirable, and which CNC would avoid.

In addition, our change to perforated plates from a solid metal piece with machined holes may have been a direct cause of some of the problems our prototype had in fulfilling its purpose, particularly because the sheets do not provide as much stability as the original solid part would have. While it would cost more money, a design closer to our original design for the sensor mount plate would likely be better able to function.

More conclusions on manufacturing may be found in the Recommendations section of the report.

Electronics and Software

There are four major systems to the electronics side of this project: The micro-controller, the pressure sensor, the linear actuators, and the retaining ring. How each of these subsystems interact to give the machine its “intelligence” will be described below.

Microcontroller

For the final design, the XMEGAA1 XPLAINED development board from Atmel was used. It features an XMEGA128A1 microcontroller, along with some useful peripherals and broken out pins. The USB-UART gateway chip built into the development board is used to show system status to and receive commands from a computer running a Virtual COM Port interpreter, such as hyperterm. However, as mentioned in the system design, a real time operating system was not used in software to accomplish the peach detection algorithm. Instead, the system is modeled as a finite state machine, with each state of the machine corresponding to a step in the pit detection algorithm described earlier.

The software developed for this project totals around 7,500 lines of code. While the main peach pit detection state machine is only a few hundred lines of this, most of the software development effort went into writing flexible libraries for the various peripheral devices the microcontroller must communicate with. These devices are explained in detail in the next sections.

Documentation for the source code was created using Doxygen, a comment parsing program which neatly formats the source code and documentation into both HTML and PDF formats. However, the pdf version of the documentation is over 300 pages long, so it will not be included in this report. Instead, it will be handed over to the sponsor as a separate attachment along with this report.

In order to interface with the system, a Virtual COM Port interpreter, such as HyperTerm (a free program for Windows) can be used. The interpreter should be set up with a 9600 baud rate, no parity bit, no flow control, and 1 stop bit. On initialization or reset, the help menu is displayed. To display the menu at any time, type the ‘?’ command. The full list of commands available, and a more in depth tutorial on how to operate the system, is included in the introduction to the software documentation.

Pressure Sensor

The SensingTex matrix pressure sensor is the most complex portion of the electronics implementation. The sensor is a 24x28 position matrix sensor, capable of sensing discrete pressures at each point. In order to interface with the sensor, multiplexers

were used to select each x-y position on the sensor one at a time. A 5v line is driven by the y-position multiplexer, and is routed through a series resistor when the x-position is selected. The voltage drop across this test resistor is used to extrapolate the pressure at each point along the sensor.

In order to enable scanning the full sensor, two 16-channel multiplexers are used in parallel. However, each multiplexer requires a minimum of 4 pins each to select the desired channel. At four multiplexers, this equates to 16 pins, which is half of the useable pins on the microcontroller break out board. In order to reduce this number, two 8-bit shift registers are used. Each shift register requires only 3 pins to interface with. Data is shifted into the shift register serially, and is then clocked out in parallel. In this way, the 8-bit output from the shift register is used to control one of the pairs of multiplexers (either the x-position pair or the y-position pair).

The third component necessary to interface with the pressure sensor are the Analog to Digital Converters. These are the devices which take a voltage reading across the test resistor described above. The voltage levels read are directly proportional to the pressure reading at the given x-y position selected by the multiplexers. In order to increase the speed at which the system can scan the entire 672 elements of the sensor, two ADCs are used in the final design. Each ADC requires 5 pins to interface with, 3 of which are used for the SPI bus used to transfer conversion results from the ADC to the microcontroller. In order to reduce this, the shift registers and ADCs share the SPI bus. As conversion results are clocked out from the ADC, the next channel to select is clocked into the shift registers.

All of these digital electronic components, along with a bidirectional 3.3v to 5v logic level converter were soldered into a perfboard to permanently connect them all together. 5x2 pin female header were also soldered onto the board, and 10-wire ribbon cable was used to jump the necessary pins from the microcontroller to these boards (see figures 24 and 25, the microcontroller development board is the blue component in the center, and the developed perfboards are red). However, these components did not fit onto one board, so two perfboards were developed. The wiring diagram for each are shown in Appendix B.

During the manufacture phase of this project, an overlooked issue arose. When the pressure sensor was tested in the open air, its readings were typically as expected: a spike in pressure was detected wherever that pressure was applied to the sensor. However, in the final design, the sensor is clamped inside of the needle carriage housing. This puts a static strain on the sensor, effectively increasing the zero-pressure reading to a non-zero number. Additionally, the enclosure designed for the sensor is slightly too small for the sensor. Additionally, due to the inability of the sensor to freely flex in its housing, when a pressure is applied at a given point, a band of pressure readings along the x-axis and y-axis about the point of applied pressure can be observed. Two techniques

were implemented to combat this undesired noise sources in the sensor.

First, a zero-threshold value is used to eliminate the static loading in the sensor. Any reading which falls below this threshold is set to 0. This effectively raises the “floor” reading of the sensor. Secondly, oversampling at each point was implemented to reduce the noise that results from the inability of the sensor to freely stretch and flex at it is deformed. Oversampling takes multiple samples at the same point, and compares each of the values obtained. In our system, the maximum and minimum value are compared, and if they exceed a given threshold, the reading at that point is rejected and set to 0. We noticed that readings far away from where a pressure was applied would often fluctuate while the pressure was held, and disappear once the pressure source was removed. Oversampling reduces this source of noise by removing any sensor readings which are not constant to within a certain range. Once the oversampled point is found to be a valid reading, the average of the readings at that point are used as the final, accepted reading.

Finally, when interpreting readings from the pressure sensor, there are two methods used to determine if the pressure reading obtained is sufficiently high to indicate a pit. The first method is straightforward: if the reading from the sensor exceeds an absolute threshold, we can confidently say that it has detected a pit. The second method uses the change in the value at that point from the last time the sensor was scanned to detect pits. If the value increases by more than a delta threshold, this signals a pit detection as well. This second method helps to find pits which are located in a particularly soft part of the peach, and therefore, the absolute threshold is never exceeded. Both of these parameters are configurable from the user interface, described in the introduction section of the source code documentation.

Linear Actuators

The linear actuators were fairly straight forward to implement. Each linear actuator uses a stepping motor, for which stepping motor drivers are used, which takes most of the design work out of the equation. These stepping motor drivers simply require a step, direction, and enable pin from the microcontroller. There are two linear actuators in our design: one for the retaining ring, and a second for the needle carriage.

Atmel has produced a library for smoothly controlling the velocity profiles of a stepping motor. It uses an iterative method to determine the time interval to the next motor step based on the current acceleration, deceleration, max speed, and distance being traveled. Each of these parameters can be individually set, and define a “speed profile”. However, this library was written for an older chipset from the manufacturer, so the code was ported to the XMEGA platform. In testing, it has very satisfactory results.

Integral to the linear actuator subsystem are two limit switches mounted to the machine, one for each linear actuator. These limit switches are used to determine when the machine is in the “home” position. Because there are no encoders on the stepping

motors, if they miss a step, either because of mechanical interference or otherwise, the system will not be able to adapt accordingly. These limit switches ensure that the machine starts and stops each cycle from the same position, ensuring that any missed steps during a cycle do not accumulate into large drifts from the desired position of the actuators at each stage of a cycle.

Retaining Ring

The only electronic component of the retaining ring is the sensor which allows the machine to know when it has properly retained a peach. There are four contact pads on the bottom surface of the retaining ring. One of the pads is driven high by a 5v line. The other three pads have wires attached to them which are inputs to the microcontroller. When all three of the pads read high, we know that the peach has been properly retained, and the needles can be engaged. If no peach is detected by the retaining ring, the cycle is aborted. In testing, it was shown that the water content of peaches is sufficient to conduct enough electricity that our microcontroller can detect when a peach is being retained.

Chapter 6: Design Verification and Testing

Design Verification Plan (DVP)

The design verification plan is laid out in appendix A. The DVP chart outlines the tests we will perform in order to confirm that the prototype meets or exceeds the design requirements developed for the project. Due to time constraints on the project, tests 3 and 6 were not performed. The results of our testing are as follows.

Number of fragments detected

This test was performed with various sized pit fragments, using mangos as a substitute for peach flesh, but still using peach pits. The dimensions of each pit fragment are given in terms of the smallest dimension (ie. the smallest of the pit's length, width, and height). The fragment was randomly placed within the working area of the fruit, and cycles were run to determine if the pit was detected or not. Additionally, the pit was frequently removed and a cycle run to ensure that the machine correctly understood there was no pit to detect. It should be noted that the fruit had to be switched in between test runs, as repeated cycles on a single peach softens the flesh, altering the appropriate threshold values necessary to correctly distinguish clean from dirty peaches.

Table 4. Final Prototype Detection Capabilities

Pit Size (in)	Cyces Run	Accuracy (%)
⅛	20	50
¼	20	90
1	10	100

The goal of the project is to detect pits as small as ⅛" in the smallest dimension. Based on our testing, the machine is able to detect these pits, but not at a high accuracy rate. At ¼" and above, the machine performs satisfactorily. The suspected reason the machine does not reliably find ⅛" pits is due to slop in the needle retaining plates. The needles are not rigidly fixed in position, they can swing in their position a few degrees in each direction. When testing with the smallest pits, unless the needle directly contacts the pit, it would often glance off of the pit, effectively diverting around it. A better retention system for the needles would be the first step towards increasing the reliability of the machine when detecting these small pits.

Fruit per minute

As the prototype developed for this project is a proof of concept, and not a final design, the operating speed of the machine is scaled down from its maximum potential. Currently, the machine operates at an 8 second cycle time, however, based on the current hardware, this could be theoretically improved to less than 2 seconds per cycle. However, in order to prevent unintentional damage, the prototype has not been scaled to operate at this high a speed.

Electronics temperature range

To ensure that the prototype could function over a reasonable temperature band, it was subjected to a hot air and cold air test. Using a hairdryer, we heated the ambient air around the electronic systems to 120 degrees F for five minutes while the prototype was operating continuously. During this time, the prototype suffered no ill effects, and we concluded that the prototype was usable at higher ambient temperatures.

We also performed a test using cold packs set around and on top of the electronics to simulate cold air. However, we found that, due to the heat produced by the electronics themselves, it was difficult to use a thermocouple to find an accurate reading of the ambient air around the electronics. We left the ice packs in place for 5 minutes while the machine was running, and saw no ill effects. We concluded that the electronics, as they produced a large amount of heat on their own, would have little trouble operating at lower temperatures.

Power consumption and operating time

In order to determine power consumption, the machine was operated for 9 hours straight, and the power drawn was measured using a killowatt meter plugged into the wall. This had the added benefit of stress testing the endurance of the system. The machine was found to halt operation sporadically 4 times during this period. There are several possible sources this error could be due to, but there is a simple solution to them all. In software, what is known as a watch dog timer can be used to allow the system to recover from unexpected halts.

At the conclusion of this endurance test, the total energy used by the system was calculated to find the power consumption of the machine. We found that the system uses an average of 0.03KW during typical operation.

Water Loss

Due to concerns over the potential for fruit tested with this mechanism to lose water more rapidly, we devised a test to check for potential water loss over time with the tested fruit. First we split one of our test fruits in half, and weighed both sides, then proceeded to

use our testing prototype on one side multiple time. Then, both the tested fruit and the untested fruit were turned over to let them “leak,” for five minutes. After the five minutes, we weighed both sides again. There was a slight change in the weight of the untested fruit, from 291 grams to 290 grams, but no detectable change in the tested fruit. From this, we concluded that, there was no significant difference in water loss between tested and untested fruits.

Foreign object safety

This test validates that if a foreign object is inserted into the working area of the machine instead of a peach, the machine will behave appropriately. The first line of defense is the retaining ring. The material that comes into contact with the retaining ring must be conductive in order for the machine to think there is a peach in position to be checked. If the foreign material is not conductive, the machine will never engage the needles to check for a pit.

If the material is conductive, the needles will be engaged. So long as the foreign material is hard, the machine will interpret it as a pit and flag it as dirty. If the foreign material is soft, the machine may pass it as a clean peach. For this reason, we recommend visual inspection of all fruit which passes through the machine.

User safety

In order to prevent an operator or onlooker from being injured by the moving parts of the system, an acrylic box is provided that must be placed on top of the machine while it is in motion. In software, if this safety cover is removed, the current operation of the machine is halted, and the machine will not move nor respond to a new command until the cover is returned. This is accomplished by attaching a contact pad to the bottom edge of the cover. This pad rests on the leg of the machine’s frame, and the microcontroller checks that there is electrical connection between these two points while it is operating. While in place, it is impossible to handle any moving portion of the machine.

In addition all electrical connections are shielded from being touched by multiple layers of duct and electrical tape.

We concluded that the prototype is safe enough to hand off to an untrained user.

Failure Modes and Effects Analysis (FMEA)

The Failure Modes and Effects Analysis (FMEA) is laid out in appendix A. The FMEA outlines the potential failure modes of each performance requirement. The effects of each failure modes has a list of potential causes. Each of the failures has a given severity and probability of occurring. When the severity and probability of occurrence are multiplied together Risk Priority Number (RPN) . The higher the Risk Priority Number the worse the

potential risk.

The results of our FMEA showed that an exposed wire getting water damage had the highest Risk Priority Number. The second highest risk priority number occurred when there was an absence of a peach, and the needles would hit the conveyor and puncture or tear the conveyor material. After all of the Risk Priority Numbers were assessed, we understood what failure modes would have the most catastrophic impacts. This helps us in understanding what areas to concentrate in to prevent such failures. In response to our results from the FMEA we changed our design by adding a clear plastic case around our entire machine. We wanted to protect the operator from having the needle array poke into his or her hand. We also changed our design from any needles hitting the conveyor by adding limit switches to reduce the total travel distance of the needle array.

Test Description

For testing of our prototype, we needed to calibrate the sensitivity of the needle heads on the pressure sensor. We started testing with a thin rubber pad located between the needle heads and the pressure sensor. This rubber pad turned out to desensitize the needle forces so much that it would not register on the sensor. We removed this rubber pad and the pressure sensor was able to register the needle forces on the computer. Our computer system was programmed to register pressure sensor readings from 0 (no force) to 300 (highest force). We were regularly reporting values from 0 to 300 with a few random values above 1000. The needles that registered over 1000 were not consistent, but were bouncing all over the array. We changed the code to convert all negative values into 0 which solved the problem. It turned out that these extremely high numbers in the 1000's were actually negative voltage readings.

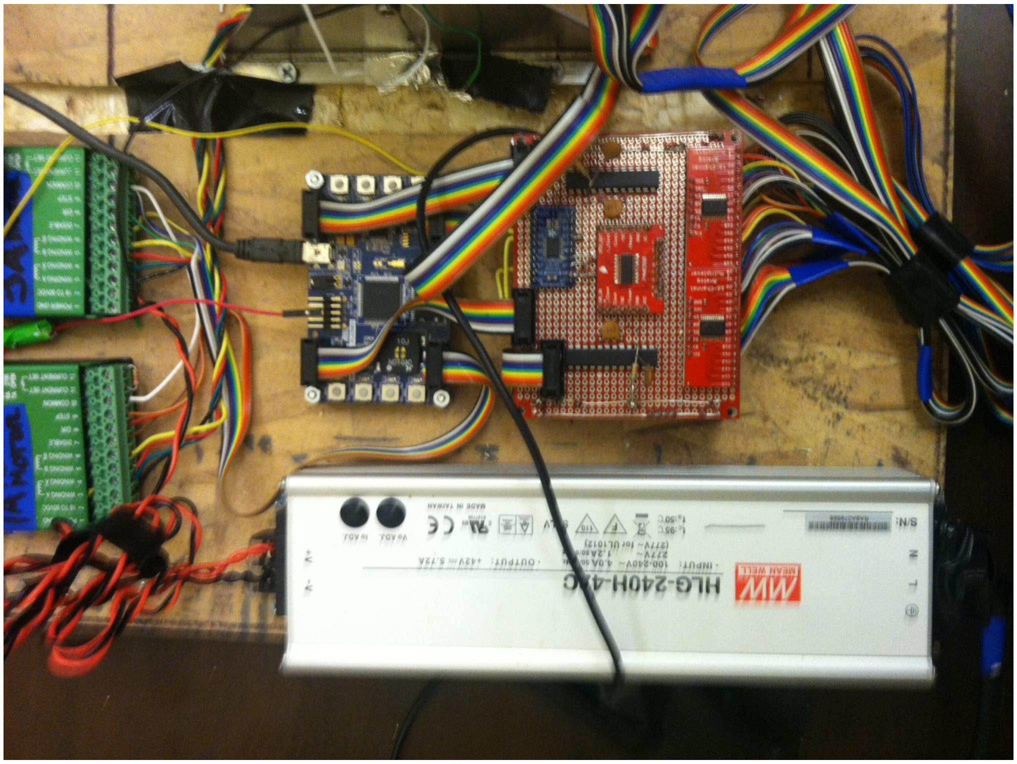


Figure 24. Shows the electrical layout with the circuit boards, power source and the motor drivers (in green).

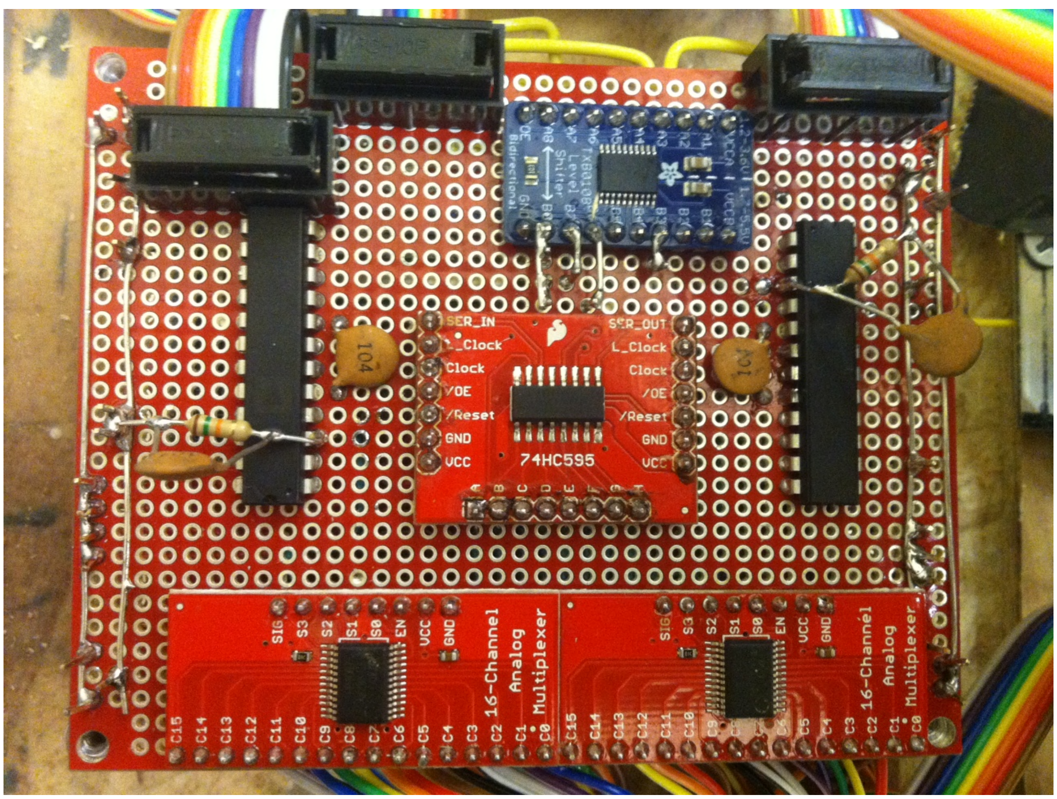


Figure 25. Shows the printed circuit board with the resistors and capacitors we used.

Chapter 7: Conclusions and Recommendations

Recommendations

The prototype will be a proof of concept that will be a basis for the final, integrated machine. For the final integrated machine, we suggest a few added components. First of all, a conveyor system is needed to feed the peaches into the testing area. An existing rotary turntable that is currently used before the Atlas Pitter will work for this purpose. Second, we suggest that a stream of water be used to clean the needles after every cycle. This will prevent buildup of debris. Last, we suggest that a metal detector be placed after the machine in order to detect broken needles. The design could be adapted to detect broken needles using the pressure sensor by measuring a force of zero where that needle is located, but we suggest adding a metal detector after our device.

Because this project used limited funds, many things could be changed to be more reliable, faster, and easier to interface with. And obviously the design will change drastically depending on how many machines need to be controlled at one time, and how it will integrate into the plant.

First of all, the parts of the machine could be made by CNC instead of by hand, ensuring that parts fit together well and hold tolerances. For instance, the carrier for the needles turned out to be very difficult to manufacture, and so we changed to a stacked plate design instead. This turned out to be less stable than a rigid piece of metal with drilled holes, which affected our results in detecting small fragments. Also, a greater density of smaller needles would allow for detection of even smaller fragments, and a more accurate map of the hardness of the peach.

Second, the machine would need to be water-proofed before using it in a factory setting. All the electronics would need to be enclosed, both on the machine and on the control board. Because everything would be sealed, it would also need either ventilation for cooling or a heat sink of some kind.

Third, a pressure sensor with both a higher resolution and a larger range of forces should be used to measure the needle forces. In the current design, each needle only contributes a small amount to the pressure on one pressure element. The best design would use multiple sensor elements for each needle, so that the results are continuous and trends can be identified easily.

Fourth, the machine should be programmed to communicate with other machines in order to calibrate itself, depending on the hardness of peaches. The hardness of the peach greatly affects the readings, and could be much more easily accounted for with multiple machines, or other machines that specifically test the hardness.

Finally, a better user interface is necessary. Most likely, a Programmable Logic Controller, as used in many other parts of the factory, would be appropriate. This would allow a familiar interface to adjust all parameters of the system, such as operating speed

and threshold values. Additionally, a custom PCB board should be manufactured to house the electronics necessary to run the machine. While the perfboard designed for this system works reliably, it is bulky and irreplaceable. A PCB board would reduce size constraints, and be easily interchangeable into the system should a board fail.

Conclusion

The goal of this project was to detect peach pit fragments that are a minimum of ⅛” in length. Our design did not meet these goals, due to inaccuracies in manufacturing, as well as unforeseen effects of using a lower resolution pressure sensor. However, we feel that this design has proven that this kind of detection method is viable for detecting small fragments, given a more accurate manufacturing method, and a higher resolution sensor. A complete design would be more reliable, and more accurate than other fragment detection options due to the mechanical nature of the design, as well as the scalability or resolution. We hope that we have provided valuable information that can be used as a jumping off point for fully integrated machines.

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