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MEMS 411: Improved Greens Harvester

Matthew Celentano  
*Washington University in St. Louis*

Nicholas Watts  
*Washington University in St. Louis*

Sam Friedrich  
*Washington University in St. Louis*

Ava Mennin  
*Washington University in St. Louis*

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Improved Greens Harvester

Earth Dance Organic Farm School has asked that we design an improved version of their “Quick-Cut” greens harvester. The redesign should be capable of cutting a 36 inch wide bed of greens, should roll on wheels, and should be able to operate for long periods without interruption.

This report details the concept generation and selection phases of the project, wherein we elect to design the system with a aluminum extrusion frame, four-wheeled custom band saw system, and rope sweepers, among other key features. In the concept embodiment phase we explore the features of our initial prototype and areas for improvement as we develop the final prototype.

Design goals for the prototype system include cutting 90% of harvestable greens, operating for a minimum of 10 minutes with minimal wear to the entire band saw, and for 90% of the cut greens to be harvested into the removable basket. We were successful in achieving the latter two of the three goals, with a qualified success on the first.

Discussion of our final prototype includes the engineering models used in design decisions as well as unexpected issues that emerged. We briefly touch on finite element analysis of structural components and design for manufacture analysis. Project discussion includes analysis of team dynamics, performance, and improvements for future development.

Celentano, Matthew
Watts, Nicholas
Mennin, Ava
Friedrich, Sam
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Improved Greens Harvester
Assignment: Concept Embodiment

Group J
Watts, Nicholas
Celentano, Matthew
Mennin, Ava
Friedrich, Sam
1 Introduction

Earth Dance Organic Farms has tasked us with designing an improved greens harvester. A greens harvester is a device that cuts and collects leafy greens that are approximately three to six inches tall. Our contact at Earth Dance Organic farms, Ray Leining, has expressed some concerns about the current design that is operating on the farm. She wants a harvester that is more efficient, more ergonomic, and easier to use than the current “Quick-Cut” greens harvester model. Our research has indicated that there are a variety of equipment used to harvest greens. These devices range from wheeled operation to fully manual cut and collection. Furthermore, the new device must be capable of evenly cutting a 36 inch wide bed of leafy greens. The following report outlines our procedure, design, and implementation of an improved greens harvester.

2 Problem Understanding

2.1 Existing Devices

2.1.1 Existing Device #1: Greens Harvester

![Figure 1: Johnny’s Selected Seeds Green Harvester (Source: Johnny’s Selected Seeds)](https://www.johnnyseeds.com/tools-supplies/harvesting-tools/greens-harvester/greens-harvester-30%22-9301.html?cgid=greens-harvester)

Description: The Greens Harvester is a handheld manual greens harvester, which uses the same technology as large bandsaw harvesters. It uses a blade to cut the greens, which is then collected into a cloth basket. The device is shaken back and forth to allow the stationary blade to cut through the leaves. It is able to cut an entire bed at once and is available in three different sizes. A sharp blade is very critical for the device, since a dull blade will not cut through the greens efficiently; therefore the blade is to be replaced after a certain extent of time.
2.1.2 Existing Device #2: Quick-Cut Greens Harvester

Figure 2: Quick-Cut Greens Harvester (Source: Farmer’s Friend)

Link: https://farmersfriendllc.com/products/harvest/quick-cut-greens-harvester

Description: The Quick-Cut Greens Harvester is a handheld baby greens harvester that uses a razor blade and macramé brush that brushes the greens into the blade and then into the cloth basket. The macramé brush is connected to a power drill that allows you to easily power the brush while holding the device with your other hand. A simple pin allows the blade to pivot which makes cutting, cleaning, and sharpening all that much easier. This device is able to collect up to about 175 lbs. per hour. To use this harvester, you are required to physically lift your arms up or down for different size crops and maintain a hunched over posture.
2.1.3 Existing Device #3: HarvestStar

![Figure 3: HarvestStar* Mini-Harvester (Source: Sutton Ag Enterprises)](image_url)

**Link:** [http://www.suttonag.com/harvest_star.html](http://www.suttonag.com/harvest_star.html)

**Description:** The HarvestStar* Mini-Harvester is a single operator system that allows you to harvest up to 300lbs of greens per hour. It uses a band blade system that is adjustable for the required height and powered by a 12V motor. The harvester is on the larger size of machinery, but is pushed like a lawnmower with a lever to change the height of the blade as you cross the green beds. The greens are cut and brought up a moving slanted surface, where they will fall off into a bin for collection. This harvester is made for greens that are to be cut at or below 2 inches from the soil.

2.2 Patents

2.2.1 HARVESTER FOR LEAFY VEGETABLES

(US 9,021,775 B2)

This patent is for the device currently being implemented at Earth Dance Organic Farms. This device uses an off-the-shelf cordless drill to power an oscillatory blade and rotating brush. This device is hand carried and operated by depressing the trigger on the cordless drill. The drill transmits power to a shaft that rotates the oscillatory blade. Power is transmitted to the rotating brush through a belt. This device holds leafy greens in its rear fabric pouch.
Figure 4: Patent Images for Quick Cut Greens Harvester
2.2.2 BABY GREENS HARVESTER  
(US 5,799,474)

This patent combines the use of known components in basic agricultural harvesting machinery. The device is made with a preset automated cycle that allows the harvester to harvest the required crops and then transport the cargo to a certain destination. The harvester uses a series of brushes to guide the greens to a blade, where the crops continue up a belt to the required storage system. The device is powered by an internal combustion engine with approximately twenty horsepower.

Figure 5: Patent Images for Quick Cut Greens Harvester
2.3 Codes & Standards

2.3.1 OMRI - Generic Materials List
(ISO 17065)

The Organic Materials Review Institute (OMRI) evaluates products and materials to determine their suitability for producing, processing, and handling organic food and fiber. Specifically, for our device, the OMRI standards requires that the harvester is using allowed vegetable lubricants, which are not synthetic as well as substances that don’t affect the crops in any harmful way.

2.3.2 FDA - Standards for Growing, Harvesting, Packing, and Holding of Produce for Human Consumption
(HFS-317)

The Food and Drug Administration evaluates products to see if they follow their guidelines to make sure that the produce harvested is not harmful in any way to the consumer. This specific FDA standard provides guidance for small entity compliance. The FDA has many standards we need to follow on the appropriate type of measures needed to be taken for cleaning and maintenance of our device and to prevent contamination of covered produce and food contact surfaces.

2.4 User Needs

We performed an on site interview with the target customer.

2.4.1 Customer Interview

Interviewee: Rae Liening
Location: Earth Dance Organic Farm School Ferguson, MO
Date: September 6th, 2019
Setting: Our team drove out to Earth Dance Organic Farm School in Ferguson, MO and met with Rae Liening. She showed us the current model of the Quick Cut greens harvester and how it is supposed to operate. We then discussed shortcomings and necessary improvements of the product with her and made note of everything she wanted to see in the new model.

Interview Notes:
What are typical terrain conditions for the harvester?
- Beds are typically ~30 inches wide and 4-6 inches higher than the surrounding footpaths.
- Footpaths are ~20 inches wide.

How do you expect the improved harvester to interact with the environment and user?
- The current model is handheld, which can be uncomfortable for the operator. The ideal model will be on wheels and pushed by hand. The wheels may roll on the footpaths but should not roll on the greens.

What are the shortcomings of the current model?
- The current model has trouble collecting the larger greens.
- The current model is too narrow to sweep the entire bed in one pass.
The band used around the pulley is prone to slippage and is not water resistant enough.

**What standards do the materials in the current model comply with?**

- All materials are food safe as determined by the FDA and be certified by the Organic Materials Review Institute (OMRI).
- The Synthetic rope material is antimicrobial and does not retain water in order to avoid bacterial contamination.

**What features of the current model should be maintained?**

- The new model should also make use of the same Milwaukee Tool drill that uses a rechargeable 18V battery.

**What new features would you like to see in the redesign?**

- A removable and replaceable blade could allow for easier servicing with less downtime.
- The machine should be more adjustable to accommodate greens and beds of various heights.

### 2.4.2 Interpreted User Needs

We interpreted the user needs described by the team’s client and compiled the information below in Table 1.

<table>
<thead>
<tr>
<th>Need Number</th>
<th>Need</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>The rope used (if any) is bacteria resistant or easy to sanitize</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>The new model spans the width of the entire bed</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>The new model puts less physical strain on the user</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>The new model doesn’t damage the greens when used</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>The new model can easily collect greens of varying sizes</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Any materials used are food safe</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>Parts should be replaced as infrequently as possible with as low of a cost as possible</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>The new model uses a Milwaukee Tool drill with 18v battery</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>The new model should use a pulley system that is water resistant and non-slip</td>
<td>3</td>
</tr>
</tbody>
</table>

### 2.5 Design Metrics

We applied the interpreted user needs from Table 1 in order to construct a variety of target specifications, as presented in Table 2.
Table 2: Target Specifications

<table>
<thead>
<tr>
<th>Metric Number</th>
<th>Associated Needs</th>
<th>Metric</th>
<th>Units</th>
<th>Acceptable</th>
<th>Ideal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8</td>
<td>Daily Operating Span</td>
<td>hrs</td>
<td>10-12</td>
<td>Indefinite</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(with swappable battery)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Total Weight</td>
<td>lbm</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>7,8,9</td>
<td>Frequency of Part Replacement</td>
<td>Instances/month</td>
<td>3</td>
<td>1-2</td>
</tr>
<tr>
<td>4</td>
<td>2,4</td>
<td>Maximum mechanism width</td>
<td>in</td>
<td>45</td>
<td>37</td>
</tr>
<tr>
<td>5</td>
<td>1,6</td>
<td>Necessary Frequency of Sanitizing</td>
<td>Instances/month</td>
<td>3</td>
<td>1-2</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>FDA and OMRI Compliance</td>
<td>binary</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>7</td>
<td>4,5</td>
<td>Ride height adjustability range</td>
<td>in</td>
<td>&gt; 2</td>
<td>&gt; 3</td>
</tr>
<tr>
<td>8</td>
<td>4,5</td>
<td>Collector window adjustability range</td>
<td>in</td>
<td>&gt; 2</td>
<td>&gt; 4</td>
</tr>
</tbody>
</table>

2.6 Project Management

The Gantt chart in 6 gives an overview of the project schedule.
<table>
<thead>
<tr>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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</thead>
<tbody>
<tr>
<td>26</td>
<td>2</td>
<td>9</td>
<td>16</td>
<td>23</td>
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<tr>
<td>30</td>
<td>7</td>
<td>14</td>
<td>21</td>
<td>28</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>18</td>
<td>25</td>
<td>2</td>
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**Design Report**

Problem Understanding

Concept Generation

Concept Selection

Concept Embodiment

Design Refinement

Peer Report Grading

**Prototypes**

Mockup

Proofs of Concept

Initial Prototype

Initial Prototype Demo

Final Prototype

Final Prototype Demo

Prototype Expo

**Presentations**

Critical Design Review

Final Presentation

Figure 6: Gantt chart for design project
3 Concept Generation

3.1 Mockup Prototype

During the lab section on Monday afternoon we created a physically mocked up prototype out of foam-board, hot glue and PVC, among other materials. Photos of the mockup can be seen in Figs. 7, 8, and 9. We allowed this prototype to inform our concept of the scale of the final product along with potential roadblocks related to packaging and user operability. In particular, we recognized that a two wheeled design would require handle placement towards the rear of the machine in order to gain enough leverage to both push the device and maintain the desired angle of cut. We also saw the benefit of having individual motors to drive each component instead of a single, pulley linked mechanism, as this allowed us to separate the moving components quite substantially in order to improve the adjustability of the cutter height.

![Figure 7: Front view of Improved Greens Harvester (IGH) prototype.](image_url)
Figure 8: Front view of IGH prototype with mock up rope fan.

Figure 9: Profile view of IGH prototype.
3.2 Functional Decomposition

We analyzed the target user’s needs in order to generate a function chart that captured the major functional elements of a successful design, as shown in Fig. 10.

Harvest greens cleanly and consistently
  ▪ Interface with operator
  ▪ Interface with surrounding environment
  ▪ Greens cutter
  ▪ Greens holder
  ▪ Move cut greens into holding bay
  ▪ Operates for 12 hours without significant pauses

Figure 10: Function tree for improved greens harvester.
## 3.3 Morphological Chart

Figure 11 below shows the morphological chart composed from the function tree shown in Figure 4 and used to make several rough and final sketches for the team’s design.

![Morphological Chart](image)

**Figure 11: Morphological Chart for Improved Greens Harvester**
3.4 Alternative Design Concepts

3.4.1 Vacuum Greens Harvester

Figure 12: Preliminary and Final sketches of Vacuum Greens Harvester

Solutions from morph chart:
1. Handheld Drill to operate saw
2. Front Wheels
3. Oscillating Saw
4. Removable Bucket
5. Vacuum
6. Drill with Rechargeable Battery

Description: A oscillating saw is powered through a power drill to move the bottom blade back and forth while a fixed blade is above it to cut the greens. A vacuum is then ran with the saw to suck in any greens that are cut and stored in the removable storage system of the vacuum. The harvester is able to adjust its height at the wheels where there is a pin system to lock and unlock the wheels at different heights.
3.4.2 Battery Powered Bandsaw Greeens Harvester

Figure 13: Preliminary sketches of Battery Powered Bandsaw Greeens Harvester Concept
Figure 14: Final sketches of Battery Powered Bandsaw Greens Harvester Concept
Solutions from morph chart:

1. Handlebar
2. Adjustable side wheels
3. Bandsaw
4. Canvas Pouch
5. Synthetic Rubber Feeder
6. Quick Disconnect Battery

Description: A removable battery powers two DC motors, one to rotate the bandsaw, and the other to rotate the rubber feeder. The bandsaw cuts the greens and the rubber feeder forces the greens into the canvas pouch. The device rides on adjustable height wheels. The device is controlled by a handlebar with a safety and trigger. Aluminum extrusion provides the structure for the device because it is low weight and high strength.
3.4.3 A Third Concept

Figure 15: Preliminary sketches of Improved Greens Harvester Concept with two motors and removable greens storage.
Figure 16: Final sketch of Improved Greens Harvester Concept with two motors and removable greens storage.
Solutions from morph chart:

1. Handlebar
2. Front wheels and side wheels as support
3. High frequency oscillating saw
4. Removable bucket
5. Synthetic rope sweepers
6. Drill-type rechargeable battery

Description: This concept, seen in Fig. 15 and Fig. 16 sits with four wheels on the ground and is pushed forwards with a push-bar located on the left side of the machine. As the machine is pushed an oscillating blade swiftly cuts the greens, which are promptly swept into the removable bucket used as storage. The blade and sweepers are powered by individual motors which are connected to a hot-swappable battery system similar to those found in cordless drills. The removable bucket allows the user to quickly clear the bay without worrying about cross mixing of vegetables between subsequent harvests.

3.4.4 Improved Greens Harvester with Vertical Sweepers
Solutions from morph chart:

1. Pushbar
2. Front wheels
3. Band saw
4. Removable bucket
5. Synthetic rope sweepers
6. Drill-type rechargeable battery

Description:

This design has a rectangular frame that can hold a removable crate to hold the greens. It has a pushbar in the back to move the device, with two wheels on the front and two stopping posts in the back for stability. In the front there is a band saw that runs around 4 wheels with a protective casing. Two vertical spinning posts with synthetic ropes spin to collect the greens cut.
4 Concept Selection

4.1 Selection Criteria

In order to effectively compare the designs presented in the "Concept Generation" section we found it necessary to create a hierarchy of selection criteria against which to compare. We followed an "Analytic Hierarchy Process" and compared criteria as seen in Fig. 19.

<table>
<thead>
<tr>
<th>Selection Criterion</th>
<th>Weight (%)</th>
<th>Rating</th>
<th>Weighted</th>
<th>Rating</th>
<th>Weighted</th>
<th>Rating</th>
<th>Weighted</th>
<th>Rating</th>
<th>Weighted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of Manufacture</td>
<td>25.3</td>
<td>4</td>
<td>1.01</td>
<td>4</td>
<td>1.01</td>
<td>3</td>
<td>0.76</td>
<td>3</td>
<td>0.76</td>
</tr>
<tr>
<td>Total Cost</td>
<td>12.45</td>
<td>3</td>
<td>0.37</td>
<td>3</td>
<td>0.37</td>
<td>3</td>
<td>0.37</td>
<td>3</td>
<td>0.37</td>
</tr>
<tr>
<td>Ease of Use</td>
<td>12.45</td>
<td>2</td>
<td>0.25</td>
<td>5</td>
<td>0.62</td>
<td>3</td>
<td>0.37</td>
<td>5</td>
<td>0.62</td>
</tr>
<tr>
<td>Aesthetic Character</td>
<td>3.29</td>
<td>3</td>
<td>0.10</td>
<td>3</td>
<td>0.10</td>
<td>3</td>
<td>0.10</td>
<td>3</td>
<td>0.10</td>
</tr>
<tr>
<td>Safety</td>
<td>37.94</td>
<td>3</td>
<td>1.14</td>
<td>3</td>
<td>1.14</td>
<td>3</td>
<td>1.14</td>
<td>2</td>
<td>0.76</td>
</tr>
<tr>
<td>Portability</td>
<td>8.56</td>
<td>4</td>
<td>0.34</td>
<td>4</td>
<td>0.34</td>
<td>4</td>
<td>0.34</td>
<td>3</td>
<td>0.26</td>
</tr>
</tbody>
</table>

| Total score          | 3.214     | 3.587  | 3.085    | 2.869  |
| Rank                 | 2         | 1      | 3        | 4      |

Figure 19: Analytic Hierarchy Process (AHP) to determine scoring matrix weights

4.2 Concept Evaluation

Using the Criteria above, we rated each design concept. The weights from the AHP were added to the Weighted Scoring Matrix (WSM). Design concept three was used as the baseline and all of the other design concepts were compared to it. A higher rating indicates better performance in the criteria of interest.

Figure 20: Weighted Scoring Matrix (WSM) for choosing between alternative concepts
4.3 Evaluation Results

As shown above in Figure 19, safety was the most necessary criteria to fulfill at 37.94 percent. This is of the most importance because all four of the considered designs make use of a large saw of some form. The next most important criteria was the ease of manufacture at 25.30 percent, as it is essential for the group to be able to produce this somewhat easily and to make this machine somewhat simple to reproduce. These results along with the remaining weighted percentages were put into the Weighted Scoring Matrix shown above in Figure 20. All four designs showed similarities in that they all make use of a similar blade style and front wheels with some kind of handle to control the machine. Ultimately, the Weighted Scoring Matrix determined that the most desirable design was the one which made use of a large band saw for cutting greens, a rotating sweeping mechanism for collecting the cut greens, a removable basket, and a handle that allows the machine to be operated from the side as not to damage the greens’ already-cut stalks.

4.4 Engineering Models/Relationships

![Bandsaw Model](image)

Figure 21: Bandsaw Model to see the power needed to run a bandsaw on our given dimensions

Using the Bandsaw Model, we can calculate the power needed for the motor to supply to our wheel. The speed of the bandsaw is an important design aspect of our project because we need the
bandsaw to be able to run at a high enough speed to cut the greens in a precise fashion. The power of the motor we use will directly affect the bandsaw speed, since it will be spinning the wheels the bandsaw is going to be placed on [1].

\[ \text{Model 2 (Battery)} \]
\[ \text{Wh} = V \cdot I \cdot t \quad \text{(Wh = power (watt-hour))} \]
\[ V = \text{Voltage} \]
\[ I = \text{Current} \]
\[ t = \text{Time} \]
\[ C = I \cdot t \quad \text{C = power capability} \]

![Discharge capacity (Ah)](image)

Figure 22: Battery Model to help aid in decision of type of battery

The Battery Model, allows us to see how the power of a battery is depleted over time. The power capability (C) measures the amount of current a battery can draw without exhausting itself. This will be an important decision in when choosing the type of battery we are using, since we need a battery that is powerful enough to run the bandsaw and also run for at least around an hour [2].
The rope flow chart above aides in the decision making process of what type of rope is needed for our gathering system. The spinning brushing system is made from a rope woven within a rod and is what pulls the greens into the basket. Having a waterproof and synthetic rope will allow the rope to sustain its usage in a most likely wet environment, where the greens will be wet from watering.

5 Concept Embodiment

5.1 Initial Embodiment

Below in Figures 24, 25, and 26 are the projected three view drawing, the isometric view with a bill of materials, and the exploded view for the cutting and feeding section of the greens harvester.
Figure 24: Assembled projected three view drawings with overall dimensions
Figure 25: Assembled isometric view of greens harvester with bill of materials (BOM)

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>QTY.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>47065T602</td>
<td>3' Aluminum Extrusion</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>47065T144</td>
<td>2' Aluminum Extrusion</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>47065T241</td>
<td>Extrusion L Bracket</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>6235K64</td>
<td>Blade Guide Wheel</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>5912K3</td>
<td>Guide Wheel Bearing</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>92510A808</td>
<td>Guide Wheel Spacer</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>92620A659</td>
<td>Guide Bolt</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>591K64</td>
<td>Sweeper Shaft Bearing</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>9056K74</td>
<td>Sweeper Shaft w/ Rope</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>drive disc</td>
<td>Drive Disc</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>bigmotor</td>
<td>Blade Motor</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>47065T149</td>
<td>Big Motor Slot Bracket</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>bigmotor_facemount</td>
<td>Big Motor Face Mount</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>stepdownshaft</td>
<td>Big Motor Drive Shaft</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>cap</td>
<td>Sweeper Drive Endcap</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>smallmotormount</td>
<td>Small Motor Mount</td>
<td>1</td>
</tr>
<tr>
<td>17</td>
<td>smallMotor</td>
<td>Sweeper Shaft (Small Motor)</td>
<td>1</td>
</tr>
</tbody>
</table>
5.1.1 Parts List

For clarity, we have broken out the parts presented in the bill of materials from Fig. 25. These items are found below in Table 3.

<table>
<thead>
<tr>
<th>Item Number</th>
<th>Item Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3’ Aluminum Extruded Square Tubing</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>2’ Aluminum Extruded Square Tubing</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>L Brackets for Extruded Tubing</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>Blade Guide Wheel</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Bearing For Blade Guide Wheels</td>
<td>4</td>
</tr>
<tr>
<td>6</td>
<td>Spacer between Guide Wheel and Bearing</td>
<td>3</td>
</tr>
<tr>
<td>7</td>
<td>Bolt to Secure Guide Wheel</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>Sweeper Shaft Bearing</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Sweeper Shaft with Rope</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Drive Disc Attachment for Guide Wheel</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Motor for Blade (Big Motor)</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>Big Motor Slot Bracket to Attach to Tubing</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>Big Motor Mounting Plate</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>Big Motor Driving Shaft</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>Sweeper Driving Endcap</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>Mount for Smaller Motor</td>
<td>1</td>
</tr>
<tr>
<td>17</td>
<td>Motor for Sweeper Shaft (Small Motor)</td>
<td>1</td>
</tr>
</tbody>
</table>

5.1.2 Model-based design rationale

Band Saw Design:

From our research [3] we concluded that a blade speed of 2000 surface feet per minute was adequate for cutting greens. Furthermore, we decided to use a scalloped blade as this is the standard in food processing equipment. Scalloped blades are the most effective at cutting elastic materials such as vegetables and meat [4]. The idler pulleys we used have a 3 inch diameter. Using the equation from figure 21 we found the following motor speed.

\[
bs = \frac{bwd(\pi)(rpm)}{12}
\]

\[
rpm = \frac{12 \times 2000}{3 \times \pi} = 2546 \text{ RPM}
\]

Where \(bs\) is the blade speed (Surface Feet per minute), \(bwd\) is the pulley diameter (in), and \(RPM\) is the angular velocity (rotations per minute).

To find the proper power output of the motor, we researched the specifications for small portable bandsaws [5]. Many of these bandsaws operated with 2.5 amp AC motors. To convert this to watts, we multiplied by 120 V. This gave us an estimated motor power requirement of 300 W. With the motor speed and motor power in mind, we settled on the AmpFlow E30-150 DC motor [6]. This motor consumes a maximum 375 W at 12 V and rotates at 2800 RPM which fits the theoretical model described above.
**Brush Design:**

The type of brush that was picked for our design was selected by following our flowchart criteria of water resistant, durable, and synthetic from section 4.4. We were able to find the type of ropes that other green harvesters used and they fit all the criteria we were looking for. The rotational speed at which the brush had to spin was found by experimental tests. We used a Dewalt power drill at its speed setting of 1. We found that the brush would spin too fast and create air pressure that would possibly blow some greens out, which would lower our collection percentage. After various tests, we found that half the speed at setting 1 was around our optimal speed. According to the Dewalt website, the speed setting of 1 has a max of 600 rpm, therefore our optimal rotational speed was 300 rpm.

**Battery Life:**

For the battery of our design, we decided to use a harbor freight universal battery. This battery is a 12 Volt and 35 Amp-Hour battery, which is also our battery’s power capability. The Battery life is then calculated by dividing the Watt-hours by the two motor wattage. We wanted to have a battery life of at least half an hour. If the motor is only running while in use, then any time above half an hour should be more than sufficient.[2]

\[
Wh = V \cdot I \cdot t = 12 \cdot 35 = 420Wh
\]  
(3)

Where Wh is the Watt-Hours, V is the Voltage [V], I is the current [A], and t is the time [hr].

\[
BatteryLife = \frac{Wh}{W_{m1} + W_{m2}}
\]  
(4)

Simplifying to get

\[
BatteryLife = \frac{420}{373 + 30} = 1.04hrs
\]  
(5)

Where Wh is the Watt-hours, \(W_{m1}\) is motor 1’s wattage [W], and \(W_{m2}\) is motor 2’s wattage [W].

### 5.1.3 Performance Goals

Our group developed three testable performance goals with the help of our instructors. These goals are enumerated, below. An unqualified success would result in us achieving each of the design goals.

1. The harvester cuts 90% of any grass that the blade comes into contact with.

2. The harvester is able to operate with minimal wear to the band saw wheels (i.e. operate for 10 minutes).

3. The harvester collects 90% of cut material.

### 5.2 Proofs-of-Concept

Our group developed proofs of concept to flesh out design concepts under the real world constraints of packaging and manufacturing feasibility. Figure 27 shows a small scale proof of concept for the bandsaw guide system. Figure 28 gives a better view of this concept’s bandsaw tensioning mechanism, which allowed us to verify that a guide wheel in a moveable slot would allow for
sufficient tightening of the blade. This proof of concept also directed our attention to the issue of blade/wheel camber control, which we recognized would affect the wear of the blade on the guide wheels over time (Fig. 29. By cambering the wheels away from each other, we recognized that we could force the blade to ride on its non-cutting edge, improving blade and guide wheel life.

Figure 27: Proof of concept fabricated from 3-D printed parts and wood.
After developing the proof of concept presented above, we went on to develop a working initial prototype. This prototype is presented in Fig. 30; note that it is presented as being “under construction”. The prototype under development is quite similar to the concept selected in the
previous submission, and makes large use of off-the-shelf components, including the bandsaw blade, extruded aluminum frame, and drive motors.

One notable difference between the built prototype and the selected concept is that the prototype employs a four-wheeled bandsaw retention mechanism, similar to the one studied in the proof of concept, whereas the selected design concept was based on a two wheel system. This decision was made in order to decrease the required width of the device for the blade to fully pass over the “rope sweepers”, as we recognized it would be impossible to pass the blade through the sweeping shaft without incurring serious wear on the blade, shaft, or both. The rope sweepers can be seen in greater detail in Fig. 31.

Another major difference between the selected concept and the concept embodiment/prototype is that the selected concept relied on a single, offset pushbar to the left of the machine, whereas the embodied concept will employ a single rear pushbar. This decision was made with the understanding that the offset pushbar would require a large counter-torque to be applied by the user, which we deemed to be an unacceptably dangerous movement in the vicinity of a quickly rotating bandsaw blade.

Figure 30: First incarnation of working prototype.
6 Working Prototypes

6.1 Overview

Our initial and final prototypes are compared below. During the design process, many of the components from the initial prototype were carried over to the final prototype.

6.2 Initial Prototype

Our initial prototype consisted of only the front framing that was included in our final prototype. The overall goal for the design was to operate the brush and the band saw blade by two motors powered by one battery. This was not included in the initial prototype. Rather, we rigged those components to be operated individually by a drill. By doing this, the band saw was successful in cutting organic material tested outdoors, and the brush was successful in sweeping cut paper (used to imitate greens). Because of this, these components were incorporated into our final prototype.

6.3 Final Prototype

Our final prototype is shown below. Notice that a wheel system and basket have been added. The front two wheels have adjustable height while the back two wheels can swivel. The height adjustment mechanism is a easy quick-release handle that screws and unscrews through a nut to load and unload a force on the inner pipe. Friction force then holds the wheel mechanism in place as seen in Fig. 34. These two components allow for us to meet the goals of adjustable height and
easy maneuverability for the greens which can be at different heights and may not be on a straight narrow bed. A Handle juts out to the side allowing the user to push the greens harvester over the bed of greens without stepping on them. A removable basket made from cloth is placed inside the framing for easy collection and removal. The battery for the two motors is attached to the back of the frame and balances out the heavy bandsaw and feeding mechanism on the front of the frame.

Figure 32: Front view of final prototype.
Figure 33: Top view of final prototype.
Figure 34: Side view of final prototype.
Figure 35: Back view of final prototype.
Figure 36: View of final prototype handle.
7 Design Refinement

7.1 FEM Stress/Deflection Analysis

We elected to perform finite element analysis (FEA) on the bandsaw motor shaft coupling, which we expect to experience significant loading. We define two limiting design factors that the coupling must meet. First, it must not yield when experiencing maximum stress, which we anticipate to be under stall, where the motor is at max load while the bandsaw is completely stopped. Second, it must not deflect more than .003 inches across each tapped hole in order to retain the functionality of the set screw system [7].

Because we expect the stall condition to occur with the bandsaw stuck in material, we prepared the mesh with force and geometric boundary conditions as presented in Fig. 38. We approximated the thru holes on the flange to be fixed, as there will be bolts connected to the bandsaw drive wheel through three of the holes, constraining their position. Note that the fourth hole is not constrained because our final build does not include a bolt through the fourth hole, and this model attempts to analyse the physical build. The manufacturer of the bandsaw motor, an Ampflow E30-150, reports the stall torque to be 710 oz-in [6]. At a mean application radius of .6in, this gives an equivalent
force of 74 lbs, which was then distributed across the two set screw holes spaced along the shaft of the coupling. We think this is a reasonable, albeit highly simplified model of a stall condition. We recognize that we could improve the model by also incorporating the torque across the flange applied by the tension of the bandsaw, but because we do not have a method by which to reasonably estimate the tension in the blade we have focused on the torque from the motor, alone. The force applied through the set screws appears to be a reasonable simplification; while the physical model likely has some of the stress carried through friction from the not-quite-clearance fit, a worst case scenario would carry all of the load through the two set screw regions in an approximately uniform manner.

Figure 38: Finite element mesh in SolidWorks with force and geometric boundary conditions.

We performed the structural analysis for the material properties of Aluminum 6061-T6, which we ultimately used for manufacture. We chose to apply the von-Mises failure criterion, which is appropriate for complex load cases in ductile metals. The yield strength of the metal is 40 ksi and the maximum von-Mises stress in the part was 5.1 ksi, as seen in the analysis from Fig. 39 [8]. Applying the formula from Eq. 6, we find a factor of safety of 7.8 [9].

$$\text{Factor of Safety (FOS)} = \frac{\text{Yield Stress}}{\text{Working Stress}}$$  \hspace{1cm} (6)
Figure 39: Von-mises stress analysis in SolidWorks.

The deflection analysis depicted in Fig. 40 returned a maximum resultant deflection of .0004 inches at the end of the shaft. This maximum deflection is approximately one order of magnitude less than the maximum allowable deflection to retain the functional integrity of the tapped set screw holes. Deflection across each of the tapped holes is significantly smaller, so we are highly confident that the system will continue to operate normally under stall conditions.
7.2 Design for Safety

Safety was a large concern when designing this machine. The exposed band saw as well as the many rotating parts of the design pose several safety risks; however, our group has taken into considerations several modifications that would make this a safer machine while maintaining its efficiency.

7.2.1 Risk #1: Contact with Bandsaw Blade

**Description:** Our prototype has a fully exposed bandsaw blade. There is no blade guard to prevent the operator or another person from touching the bandsaw blade during operation.

**Severity:** Touching the bandsaw blade would result in serious bodily harm. The scalloped blade is used in industrial meat cutting applications, thus it would inflict severe damage if a person were to contact the blade accidentally.

**Probability:** We expect the machine to be operated alone. This would prevent someone besides the operator from contacting the blade. Furthermore, the operator is behind the machine during operation which lowers the probability of contacting the blade. We believe that contact with the blade would occur seldomly.

**Mitigating Steps:** In a future product, it is vital to have a blade guard to prevent the operator from contacting the blade. Furthermore, a two-hand safety switch would prevent the operator from contacting the blade because they would need two hands to operate the machine. If either hand was removed from the switch, the machine would turn off.
7.2.2 Risk #2: Bandsaw Blade Detaches

**Description:** The rotating bandsaw blade has the potential to fall off of one of the pulleys during operation. Oscillations in the motor or pulley mounts could cause the blade to wobble off the pulley.

**Severity:** If the bandsaw blade were to fall off of one of the pulleys during operation, it would most likely fly off due to the rotational inertia experience by the blade. This would cause serious bodily harm if a person were in the rotating plane of the blade.

**Probability:** The pulleys have flanges that prevent the band saw blade from falling off. Furthermore, a slight camber is applied to the pulleys to prevent the blade from cutting the front flange. These two mechanisms make the likelihood of detachment quite low.

**Mitigating Steps:** A blade guard would contain the blade and absorb the impact from the flying blade if the blade were to fall off.

7.2.3 Risk #3: Bandsaw Blade Snaps

**Description:** The bandsaw blade is made of thin steel, under high deflection or tension, the blade could snap.

**Severity:** If the blade were to snap during operation, the inertia of the rotating blade would make the blade fly out radially. If a person was in the plane of the blade, they would be cut severely by the flying blade.

**Probability:** Band saw blades are manufactured to withstand high deflecting and tension without failing. The probability of the blade snapping is very low.

**Mitigating Steps:** A blade guard would contain a flying blade and prevent injury to someone the blade plane.

7.2.4 Risk #4: Electrical Shock

**Description:** There are two parallel circuits that run from the battery to the two motors. If these circuits were to short, there is a chance that this could shock the operator.

**Severity:** At 12 volts, the battery would most likely not shock an operator. There is a higher chance that the short circuit could generate a lot of heat or a spark that would burn the operator. A shock or burn from this battery would be minor.

**Probability:** The probability of electric shock from a short circuit is very low.

**Mitigating Steps:** All electrical connections are wrapped to prevent exposed contacts from touching. Furthermore, a fuse could be added to the circuit to prevent damage from a short circuit.

7.2.5 Risk #5: Hair gets caught in Feeder or Blade

**Description:** Long hair could be caught in the rotating shafts of the band saw pulleys or feeding mechanism. This would tangle the hair and pull it in to the shaft.

**Severity:** If long hair was caught in one of the shafts, it could pull the operator into the machine. This could cause the operator to be cut by the blade. There is also a chance that the operator would be suffocated by being caught in the shaft. These two things would cause serious harm to the operator.

**Probability:** It is very unlikely that hair would get caught in these shafts. The harvester is operated from the back where there are no rotating parts.
Mitigating Steps: A blade guard surrounding the band saw pulleys would prevent the operator from getting their hair caught in a pulley shaft. A two-hand switch would prevent the operator from being at the front of the harvester while it is on.

7.2.6 Risk Heat Map

<table>
<thead>
<tr>
<th>Category</th>
<th>Probability that something will go wrong</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Frequent</td>
</tr>
<tr>
<td>Catastrophic</td>
<td></td>
</tr>
<tr>
<td>Critical</td>
<td></td>
</tr>
<tr>
<td>Marginal</td>
<td></td>
</tr>
<tr>
<td>Negligible</td>
<td></td>
</tr>
</tbody>
</table>

Figure 41: Risk Assessment Heat Map

Figure 41 shows there are two safety concerns that are both catastrophic and have the potential to occur seldomly. These two concerns are contact with the bandsaw and a detaching bandsaw blade. To mitigate the serious injury that could result from either of these events, a blade guard could be used to contain the band saw and prevent contact between the operator and the bandsaw blade. It is critical that we resolve these issues before creating a final product. Two other safety concerns with the bandsaw blade snapping or hair getting caught in the feeder or pulley shaft are equally severe but their probability of occurring is much lower. Finally, our lowest concern is with electrical shock. Although it is possible, an electrical shock from a 12 volt battery is highly unlikely. There is a greater concern with a short circuit burning the operator. This could be prevented by added a fuse to the circuit.
7.3 Design for Manufacturing

For our Draft Analysis, we looked at the mount for our battery. The original design was made with all walls perpendicular to the base. However, with this type of design, it would require draft and not be easily made by injection molding. The picture to the right has all the walls of the mounting box chamfered to a slight angle. The outer and inner side of the walls were chamfered with a 85 degree angle to allow the injection molding process to easily remove the part from the mold.
For the first DFM Analysis we looked at the basket mounting piece and ran an analysis of turning with a Mill and Drill. Most of the rules passed except for three. The three rules that failed were inaccessible features, Mill Sharp Internal Corners, and Fillets on Outside Edges. The Mill and Drill are not able to make fillet edges so the ends of the handles would not be manufacturable by using this process. The sharp 90 degree corners of inner bracket would also not be manufacturable due to drills would make rounded edges when they cut. To solve some of these problems, we should round the inner edges and to remove the fillets at the edge of the handles.
For the second DFM analysis we looked at the basket mounting piece again but with injection molding. One of the two rules for injection molding failed, which was the Maximum Wall Thickness. The total bracket frame is made for the purpose of being lightweight, however the framing has a considerable length therefore the wall thickness is large so there is minimal deflection when under load. Because of this design parameter the thickness of the framing is larger than what is allowed for injection molding. If we stayed within the limits of 1 mm to 4 mm thickness for the frame, it would either deflect a large amount or fracture under the weight of the greens that are meant to be carried.

7.4 Design for Usability

Our group sought to make a machine accessible to as many users as possible while maintaining efficiency and overall purpose of the design. There were several areas that influences this machine’s usability as well as several areas of improvement to make it more user friendly to all.

7.4.1 Vision

Color blindness does not influence the usability of this machine much, as the overall color is metallic and somewhat neutral. The only colored area of importance are the positive and negative wires for the motors, but the red and black should create a high enough contrast to be distinguishable to a color blind user. Regarding vision-related disabilities such as presbyopia, they influence the
usability of the design on a much larger scale. Because the exposed band saw of the machine poses some level of danger, it is necessary to be able to see any surrounding obstacles.

7.4.2 Hearing

Hearing-related disabilities do not drastically influence the usability of this machine. The most relevant instance of its influence is when a problem arises with the machine. One of the best indicators of an issue with a piece of machinery is when one of the moving parts does not sound like it normally does. For example, when the band saw rides at the front of the pulleys, the teeth eat away at the plastic. This could result in the band saw completely cutting through the plastic and flying off the machine. The first hint that this is happening is the sound the teeth make against the pulley. This particular issue can be somewhat easily corrected by the substitution of sturdier wheels or a sensor that automatically stops the motors when the sharp edge of the band saw comes in contact with the inside of the pulleys. Further more, any issue that’s prime indicator is sound can be redesigned to initiate an automatic or emergency stop as well.

7.4.3 Physical

The machine consists of many components attached to an aluminum frame. Some of those components include a large car battery and its mount as well as motors and their steel mounts. Overall, the machine is very heavy and requires some level of upper body strength to use for a continuous time period. However, the original model, though smaller and made of lighter weight materials, was low to the ground and not on wheels. This meant that somebody with back issues or muscle weakness would most likely not be able to use the original device. This was a fact taken under consideration in the design of our new version. This could possibly be further improved by the substitution of lighter weight materials wherever possible.

7.4.4 Control

This machine requires a somewhat high level of alertness due to the somewhat high risk involved with the band saw mechanism at the front of the machine. This may be impossible to have due to a control impairment. This design could become more accessible with the addition of an automatic or emergency stop in cases where the user is not at the level of alertness that this machine requires, as a lot of large machinery does.

8 Final Prototype

8.1 Project Development and Evolution

Does the final project result align with its initial project description?

- The final project result does align with its initial project description because we believe we were able to improve upon the current green harvester system. Our design is able to cut and harvest grass as effectively as the current design and it also allows the user not have to worry about physical injury as you do not have to support the machine by your own power.

Was the project more or less difficult than expected?
- The project was far more complex than we initially anticipated. This is due to the much larger scale of a full bed harvester. The final assembly had over 100 components. Furthermore, advanced manufacturing techniques such as CNC milling and welding were required to manufacture the final prototype.

On which part(s) of the design process should your group have spent more time? Which parts required less time?

- Our group should have spent more time on the bandsaw pulley mechanism and the wheel system. The bandsaw pulley mechanism could have a better way of attaching and detaching the bandsaw and the cambering of the pulleys should be done in a more efficient way. The wheel system isn’t the most stable system and having a cross extrusion that holds down the extrusion for the wheels would allow it to be more secure. The wheels also should be bigger so that it has better mobility on the type of terrain it is intended for.

Was there a component of the prototype that was significantly easier or harder to make/assemble than expected?

- We found our final blade system to be significantly more challenging to assemble than expected. We had made changes to the system from the initial prototype to allow for easier manufacture, but this had the unintended side effect of making certain bolts extremely difficult to tighten.

- The bandsaw direct drive system was surprisingly challenging to manufacture. One of the components required hours of CNC machining with the use of MDF jigging, which also added unexpected setup time.

In hindsight, was there another design concept that might have been more successful than the chosen concept?

- We think it is likely that a two wheeled bandsaw with a conveyor belt feeder (like the HarvestStar) would have more successfully collected the greens.

8.2 Design Resources

How did your group decide which codes and standards were most relevant? Did they influence your design concepts?

- Our group decided on which codes and standards were most relevant from our interview with people from Earth Dance Organic Farm School. They let us know about which codes and standards we should be aware of and make sure to follow the codes and standards that would allow our machine to be usable for food that would be consumed.

Was your group missing any critical information when it generated and evaluated concepts?

- The only piece of information that we would have liked and that we could not find was the ideal cutting speed for greens. In lieu of this information we assumed wood to be the best comparable material.

Were there additional engineering analyses that could have helped guide your design?

- If we had the time we would have liked to run an analysis on the blade tension. This would have allowed us to determine the deflection of the wheel brackets under load, which, in turn, would have allowed us to fine tune our wheel camber.
If you were able to redo the course, what would you have done differently the second time around?

- If we were able to redo the course, we would have given more consideration to the cost of the entire machine. Once the initial prototype was built we were almost out of money, even though we still had a large portion of the machine to finish building.

Given more time and money, what upgrades could be made to the working prototype?

- If we were to have more time and money we could of made our greens harvester more safe and fix the new problems that emerged after making our final prototype. We could cover the bandsaw parts and were not needed to cut and build a more solid frame to reduce vibration.

8.3 Team Organization

Were team members’ skills complementary? Are there additional skills that would have benefited this project?

- Since we all have mechanical backgrounds, we struggled with some of the electrical setup. In hindsight, it would have been beneficial to use an arduino and brushless motors but our team has not experience or knowledge in these subjects. Furthermore, our prototype required welding which we were not familiar with.

Does this design experience inspire your group to attempt other design projects? If so, what type of projects?

- Although the process was frustrating at times, the design process is a very rewarding experience. In the future, we would like to continue to work on mechanical design projects.
Bibliography


