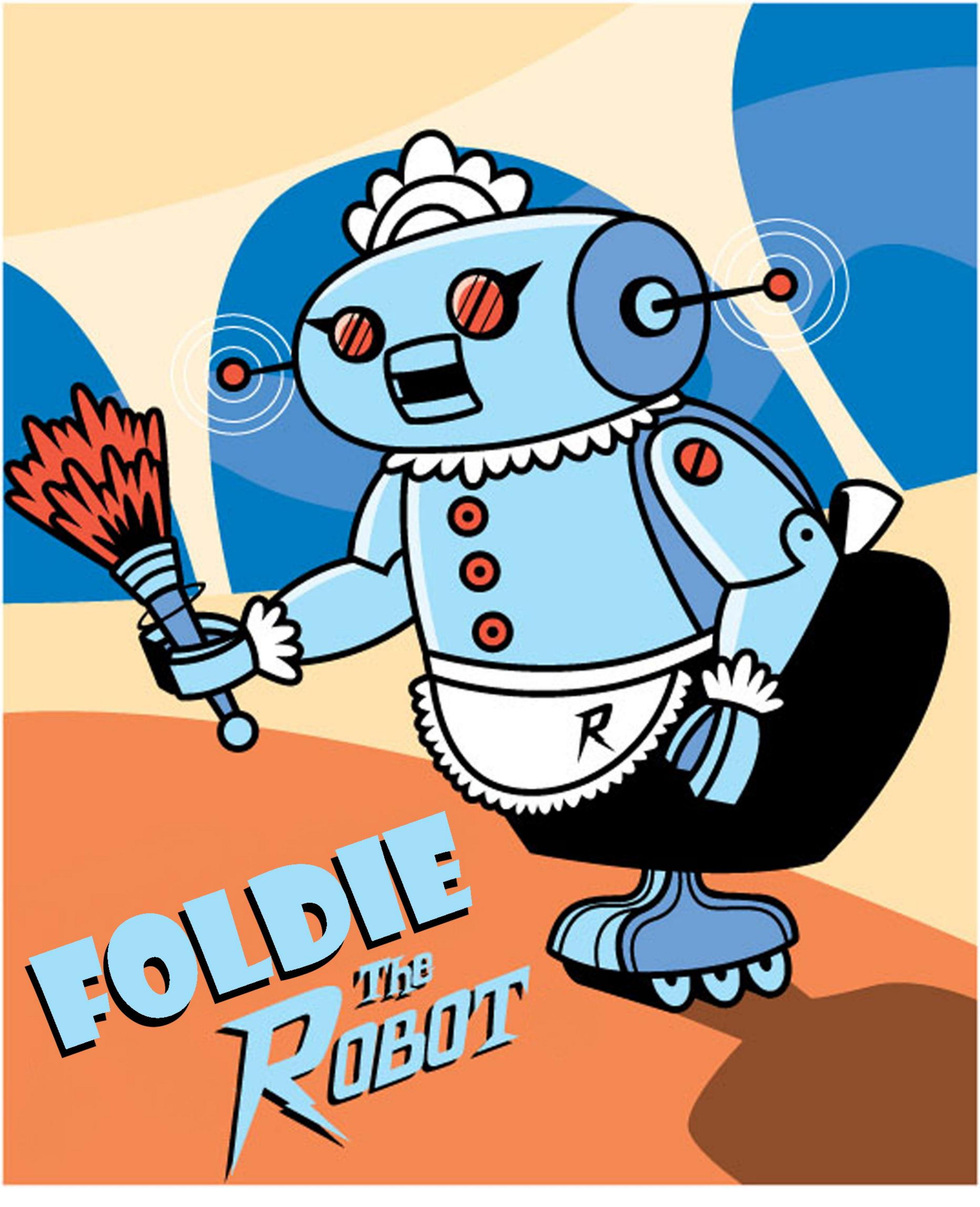
FOLDIE
The
ROBOT

Foldie – The Laundry Folding Robot

Contributors

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Abstract

This project addresses the issue of folding clothes. Utilizing the designs of industrial folding machines as inspiration, a machine able to fit within a cubic yard was constructed with the ability to fold towels and shirts. This design was accomplished by utilizing many mechanical and electrical engineering principles. While the system does not work perfectly, our group started from a concept and made that concept a reality.

Project Summary

Title

Automated Towel Folding Machine

a.k.a

'Foldie'

Sponsor

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Team Members and Roles

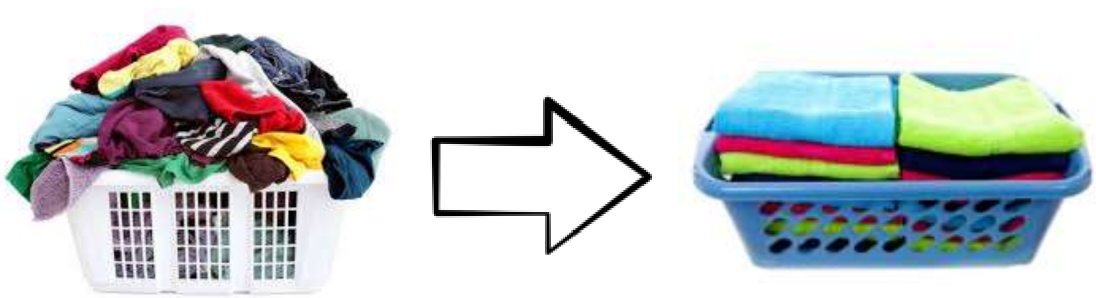
Name	Pitt Email	Major	Standing	Role
James Braza	jdb138@pitt.edu	Mechanical Engineering	Senior	Coordinator
Brandon Contino	bmc95@pitt.edu	Electrical Engineering	Senior	Planner
Derek Nichols	dan44@pitt.edu	Mechanical Engineering	Senior	Presenter
Kevin White	kmw111@pitt.edu	Mechanical Engineering	Senior	Resource Manager

1. Project Background

Industry Served

A laundry folding machine can benefit any entity that folds clothes. In our case, we chose to specify the entity for households as opposed industry as the industry setting already has multiple large machines to fold clothes[1,2,3]. In a broader terms, the industry served is household consumers.

The end product is a robotic machine that will take a crumpled basket of clothes and fold each individual article, placing them in an evenly stacked pile. In other words, go from a pile of crumpled clothes into a pile of folded clothes.



Motivation

Upon waking up in the morning, every human being puts on an assortment of clothes. Throughout the day, these clothes become dirtier, and consequently need washing. Washing and then the accompanying drying process is a fact of just about everyone's life; it's a necessary chore in modern society. After drying, the clothes are then folded and sorted, ready for future use.

Many of the necessary chores modern humans perform are assisted by machines. We have dishwashers to efficiently clean our dishes for us. There are lawn mowers to speed cutting grass and bagging the trimmings. Vacuum cleaners eliminated the tedium of sweeping up messes. The cleaning and drying of our clothes is performed by a washer and a dryer; however, one of the last tedious tasks left to be automated is what comes after clothes are dried: folding and sorting laundry.

Folding and sorting laundry takes time and energy. Most people put off their laundry not because it's dirty, but because folding and sorting is both painstaking and time consuming. The overarching goal of this entrepreneurial project is to make efforts to automate this process.

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1 Cromex Industrial. "Fully Automatic Bath Towel Folding Machine." *Cromex Industrial*. Cromex, 2014. Web. 16 Sept. 2016.

2 Western State Design. "Commercial Industrial Laundry Equipment." Chicago Dryer Commercial Folding Machines. N.p., n.d. Web. 20 Sept. 2016.

3 "Automatic Cloth Folding Machine Industrial Laundry Bed Sheet Folder for Hotel (ZD3000-V)." *Made-in-China.com*. N.p., n.d. Web. 20 Sept. 2016.

Refining the Project Scope

There are many types of clothes in the world, defined by variables such as size, weight, material, shape, etc. Some of these properties are functions of others (ex: cloth weight depends on size and material), but most are unique. The category of a given clothing item and its properties are easily discerned by humans. These properties are then used to fold and sort the clothing item. However, this is actually a very difficult process for a machine to execute. There are an infinite number of ways a cloth can be crumpled, and coming up with an algorithm to address every case must be very robust. There are industrial folding robots that have come about from many years of R&D, but none of them have a crumpled cloth enter the machine.

Due to the scope of Pitt's Senior Design class, and given the amount of time the team members have to dedicate to the project, we have chosen to greatly simplify the problem statement. The project will still be very difficult, but much more doable for the scope of a one college three credit course. The project will focus on one aspect of creating a folded cloth. We choose to ignore how the cloth is oriented and fed into the machine, instead we focus on creating a folded cloth from a flattened shape.

Additionally, because of the variety of the shapes of clothes, we choose to fold a more controlled shape. Towels are always of a rectangular shape and are of similar materials. Thus, our starting point would be to fold towels. The simplified problem statement is now:

Mechanize the process of folding towels.

The added value of our system is that the user would not need to actually go through the multi-step process of folding a towel. The human input of placing the towel exists in both manual folding and within the automated process we create. However, it removes the time to complete the folds. Thus, our system can save the human operator time on a per towel basis.

This does not mean we desire to focus on only folding towels. The goal is to eventually have our machine be able to fold shirts (short or long sleeves), pants (short or long legs), rectangular underwear, and towels. This excludes winter apparel, socks, and miscellaneous undergarments.

Significance and Impact to Industry

Commercial folding has been around for many years, but it has yet to make it to the residential market. Having a machine fold clothes would be able to save users time and energy which would grant them the ability to do more of the things that they love. We are our own sponsors. We took it upon ourselves to create and work on this project because we realized that, while solutions for washing and drying clothes have been around for many years, there is still not an automated way to approach laundry folding for household consumers.[4][5]

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[4] Daily Mail Reporter. "How a Lifetime of Laundry Takes the Average Mother Five Months to Wash." *Mail Online*. Associated Newspapers, 19 Apr. 2010. Web. 20 Sept. 2016.

[5] Del Prado, Guia Marie. "This Robot Can Do One of the Most Dreaded Chores for You." *Tech Insider*. N.p., 15 Oct. 2015. Web. 19 Sept. 2016.

Project Continuation

This project is the first step in a series of design iterations meant to tackle an issue that the team has discovered in everyday life. The designs and prototypes built are created from the team's ideation after proper research.

2. Project Objectives

Project Goal

To develop a design and construct a machine for residential use to aid in the folding of towels. The machine must be able to fold multiple times with high satisfaction and quality of fold.

Objectives

Objective 1 - **Concept Development**: Develop numerous possible designs centered around different folding principles. Draft preliminary drawings and potential folding algorithms for the machine's operation. Evaluate the set of conceptual designs for metrics such as cost, speed, human interaction, aesthetics of the fold, and overall robustness.

Objective 2 - **Detail Design:** Create CAD models of the machine, design sensor networks, and write detailed pseudo-code for the algorithm. Perform a detailed analysis of the design and construct a list of all necessary components for the design.

Objective 3 - **Prototype Development and Iteration:** Order all components for the machine and construct the design as detailed by the previous objective. In order to perform fabrication, utilize the SSOE Center for Product Innovation, Pitt Robotics and Automation Society Lab, and Pitt Student Electronic Resource Center. Perform tests with varying towel sizes and evaluate the machine's capability. Iterate the design based on the results from the performed tests for improved performance.

Objective 4 (if time permits) - **Common Clothes Integration:** Add capability to fold additional clothing garments. The planned order of additional garment integration is pants, shorts, rectangular underwear, and then shirts.

Specifications and Functional Requirements

This design project needs to accomplish and satisfy multiple goals. The guidelines of this project are specified here, in the functional requirements:

Assumptions

- The clothing item is a towel
- The clothing item is input to the machine by an external method
    - Humans
    - Loading machine or attachment

Towel Size - fold towels of variable size

- Wash cloth: 13” x 13” (~1 ft^2)
- Bath Sheet: 35” x 60” (~15 ft^2)

Towel Material - fold towels independent of their cloth material

- Cotton to polyester

Folding Time - fold towels in time < 90 seconds

- Fold 30 towels in < 45 minutes

Fold Quality - a wrinkle-free high quality fold

- Visually appealing
- Final fold length + width < 27”
    - Minimizes towel footprint

Footprint - able to fit in laundry rooms

- Entryway can accommodate any towel
- Total Volume < 1 yd^3

Power - run off outlet power

- Available in households

Noise - create less sound than a washing machine

- Sound Volume < 78 dB[6]

Endpoints – Deliverables and Metrics for Success

We do not have a sponsor for this project, so our deliverables and metrics are based off of creating a working prototype. A successful project will include all of the following:

1. Multiple design iterations of conceptual designs
2. Complete CAD model, along with component drawings
3. Complete electrical schematic of the system
4. Mechanical or electrical analysis of the system or individual components
5. A success machine prototype capable of folding towels of varying sizes
6. Documentation of the prototype and its mechanism

3. Project Planning

Resources

We plan on utilizing vendors such as Home Depot, Lowes, Allied Electronics, Jameco, DigiKey, Robot Central, Mouser, MCM Electronics, Sparkfun, Adafruit, Grainger, McMaster-Carr and any other unforeseen necessary vendors.

Additionally, for design advice, we will use locations and professors such as our sponsor (Dr. David Schmidt), Dr. William Clark, SCPI employees, and SERC advisors.

For research, we intend to source from the internet through Google, Thingiverse, Instructables, McMaster Carr descriptions, and robotics forums.

[6] "Decible Sound Ruler." *Decible Sound Ruler*. TLC (Southern) Ltd., 2000. Web. 20 Sept. 2016.

Anticipated Design Iterations

Once the main design is created, there are certain features of the design that will likely require alterations. These iterations will be accommodated by building the model in parts. The main parts of the design can be created and assembled while the smaller and more delicate parts can be built around the larger parts. This allows for prototyping of the intricate parts around the major parts.

Some specific design elements that are likely to require iteration are the following:

- The conveyor belts
- The folding arms
- The exit chute

Support from Project Sponsor

We do not anticipate needing continuous support from our project sponsor, other than occasional design reviews and general consultation. This has been discussed with our sponsor.

Support from Swanson Center for Product Innovation.

The SSOE Swanson Center will be fully utilized. We intend to use the employees for advice on the fabrication of the machine. Additionally, we intend to use shop resources such as the manual mill/lathe, drill press, 3D printers, laser cutters, sand blaster, dremel tool, soldering iron, other general shop equipment. It will also be useful for assembling the parts into the final product and assessing design feasibility.

Support from Subject Matter Experts

All expected support from subject matter experts will come from online research. Being such an new technology, there exist very few competitors in the field. Thus, our support will be through resources such as videos, online articles, and consultations with professors knowledgeable in electromechanical concepts.

Potential Risks and Anticipated Failures

Risk #1 - Laundry folding algorithm simply does not work

Workaround: Extensively prototype the algorithm. This can be done by bringing in towels of variable size and using items from around Benedum such as a vacuum, cardboard, racks, meter sticks, posters, etc. By testing the algorithm and creating/testing cases that are designed to induce failure, we can best prototype the algorithm.

Risk #2 - Laundry folding machine is too expensive

Workaround: Assessing the speed of the machine when compared with human speeds. Then we need to realistically look at the problem with a $400 budget and make sure that our motors are optimized given their allocated price points. We should look to scrap as many materials as possible. We will try to complete the design in under $300 to leave $100 to spare for our mistakes.

Risk #3 - Laundry folding algorithm is inconsistent

Workaround: Leaving plenty of time in the semester to redesign components to account for inconsistent designs. Additionally, space can be left in the budget to pay for these redesigns. Lastly, the our resources can be brought in to help rapidly plan, design, and fabricate improvements.

<u>Milestones</u>

Milestones that we will use to track our performance are the following:

- Completed design concept
- Completed CAD model
- Functional prototypes
  - Conveyor belt
  - Parallel fold arm
  - Perpendicular fold arm
  - Exit mechanism
- Complete sensing integration
  - Wiring and circuit design
- Control algorithm testing
  - Receiving inputs and establishing process flow
  - Compatibility with multiple types of towels

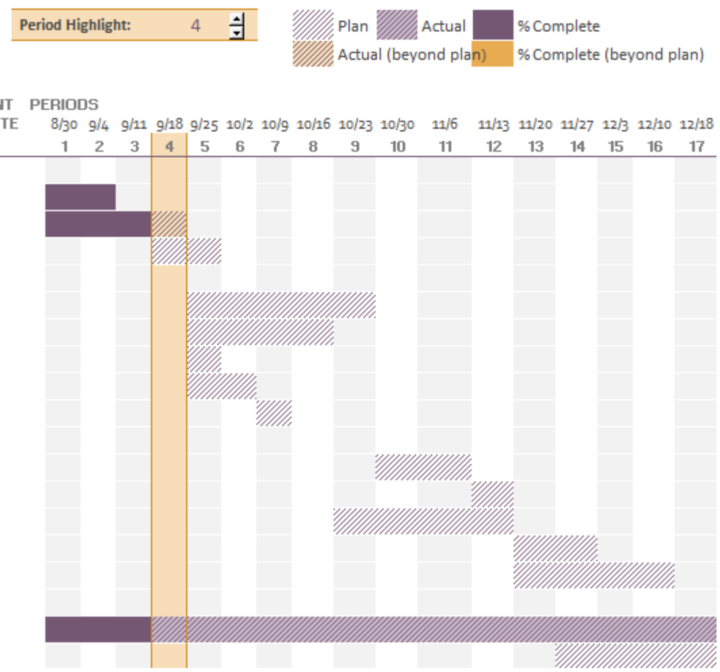
<u>Budget</u>

The team will operate on an expected $400 budget. Half that budget will come from the Swanson School's MEMS department and the other half will come from the ECE department. The budget will be broken down into mechanical and electronics components in future weeks. As of now, our basic budget will be broken down into ~$100 for structural components and ~$200 for electronics, with ~$100 to spare for revisions.

<u>Timeline</u>

Group 19

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
Conceptual Design					
Research Current Methods	1	2	1	2	100%
Brainstorm Various Folding Mechanisms	1	3	1	4	80%
Decide on a Final Conceptual Design	4	2			0%
Detail Design					
CAD Modelling of Machine	5	5			0%
Write Psuedo-Code Algorithm	5	4			0%
Determing Sensors	5	1			0%
Spec Out & Create BOM	5	2			0%
Order Parts	7	1			0%
Prototype Development and Iteration					
Fabricate Components	10	2			0%
Assemble Machine	12	1			0%
Code Algorithm	9	4			0%
Test Machine Operations	13	2			0%
Iterate on Design	13	4			0%
Documentation					
Take Pictures, Save Designs, Keep Log	1	17	1	17	20%
Write Report	14	4	0	0	0%



4. Project Execution

Analysis & Design

Our design will incorporate the knowledge gained from multiple areas of the MEMS curriculum. The parts will be designed in SolidWorks which was taught in MEMS 0024, Intro to Mechanical Design. The design will consist of separate subassemblies which will all work together. Designing using this technique was taught in MEMS 1029, Mechanical Design 2. Electrical components and sensors will be utilized in multiple areas of the design. Analyzing the required voltage per component is a skill learned from MEMS 0031, Electrical Circuits. Coding and algorithms will be created using the foundations built by ENGR 0011 and ENGR 0012. We will perform rudimentary stress analysis on the parts experiencing the largest forces in order to determine whether they will last for infinite life. These parts can be run through ANSYS stress tests with larger than actual loads applied to test the worst case scenarios.

Verification

Our machine will be able to perform the indicated measures repeatedly, while maintaining a high quality of fold. Anything less than a high quality fold will result in a requirement that is not passing standard.

5. Project Organization

Team Meetings

The team will meet bi-weekly throughout the semester. Team meetings will be held Monday nights from 8 pm - midnight in a Senior Design Room and either Friday or Saturday on the 12th floor of Benedum for about three hours.

Team members will communicate via pitt email, Slack (a group messaging app), phone call, text message, or in person conversations.

The team members will collectively keep each other up to date, particularly when one member cannot make a given meeting. We all have some degree of overlap, be it in club activities or common coursework. There will not be one given member who records data, we all will. Team files will be collected in a Google Drive folder.

Work Space

Mondays: Senior Design Rooms Third Floor
Fridays: BEH 1219 and Makerspace (BEH B06)
Project Storage: Dr. Clark's 2nd Floor Lab
Miscellaneous Meeting Locations: Robotics and Automation Society Lab (BEH 1212), Mascaro Suite 3rd Floor Meeting Room, and ESC Office (BEH G32B).

Sponsor Meetings

As stated above, our advisor is the course professor, Dr. David Schmidt. He is our faculty sponsor and primary advisor. We had a discussion where he okayed us to optionally periodically meet with him for advice on the design and the project as a whole. These meetings will be held in his office via appointment or during regular class time. All meetings will be in person, as Dr. Schmidt is accessible within the university and he is additionally three of the teammates' professor in other mechanical engineering classes. Any minor correspondences will be held through pitt email or phone call if necessary.

The team should interact as if an entrepreneurial project in the real world, where the sponsor may be inaccessible on a regular basis to the teammates. These meetings would be held on a per request basis, which is how the team plans to operate.

Sharing, Distribution and Archival of Project Data

A shared google drive folder will be shared for the accumulation of data, designs, pictures, and documents. The group members will utilize a slack messenger app for quick communications, as well as sending researching information. All of our data from Slack will eventually be archived in our google drive for reference.

Return of Equipment

We should not be needing to borrow any equipment, but under the circumstance that that changes, our planner will work with the sponsor to ensure all equipment is returned.

6. Project Outcomes

Educational

The outcome of this project is to learn many principles of mechatronic design. In other words, develop more knowledge in the areas of:

Mechanical Design

- Design thinking - developing a good design the first time
    - Fabrication - how the different components will be manufactured
    - Rapid prototyping - prototyping mechanisms before finalizing them in a design
    - Robust/repeatable process - ensuring the process will work the same way consistently
- Mechanical design - designing the machine to be mechanically solid
    - Stress and fatigue analysis - designing components to be structurally sound over time
    - Materials selection - selecting materials to balance desired characteristics with cost
    - CAD workflow - prototyping the machine in CAD and making machinist drawings

Electrical and Controls Design

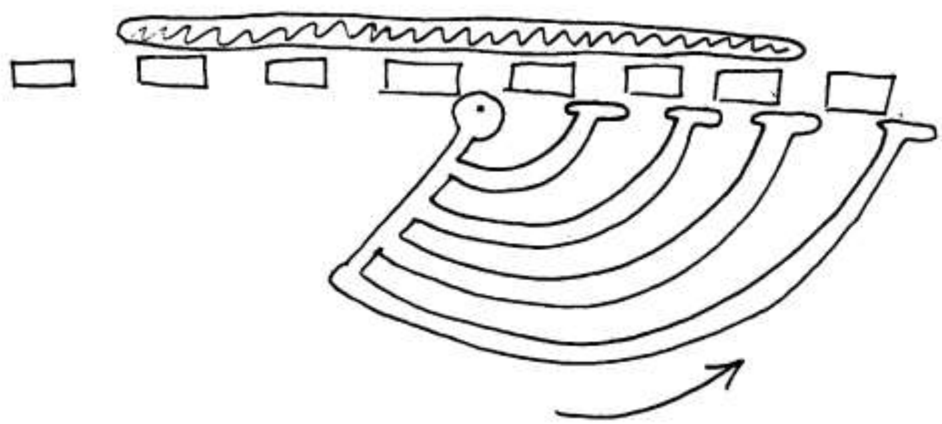
- Power distribution - powering the system
    - Breadboarding - rapidly prototyping the power distribution
- Motor selection and control - picking motors to minimize cost and power demand to create desired torque and speeds
    - Specing Motors - Lean about metrics such as stall current and torque
- Sensing - picking and implementing sensors to given the machine intelligence
    - Understanding signals - quantifying the signals that go to and come from each sensor
- Microcontroller Use - everything to do with controlling the system
    - General Purpose I/O - controlling signals

Software Design

- Logic - defining the states of a machine
    - Syntax - learning about code syntax, data types, etc.
    - Algorithm Planning - creating pseudo code to plan an algorithm

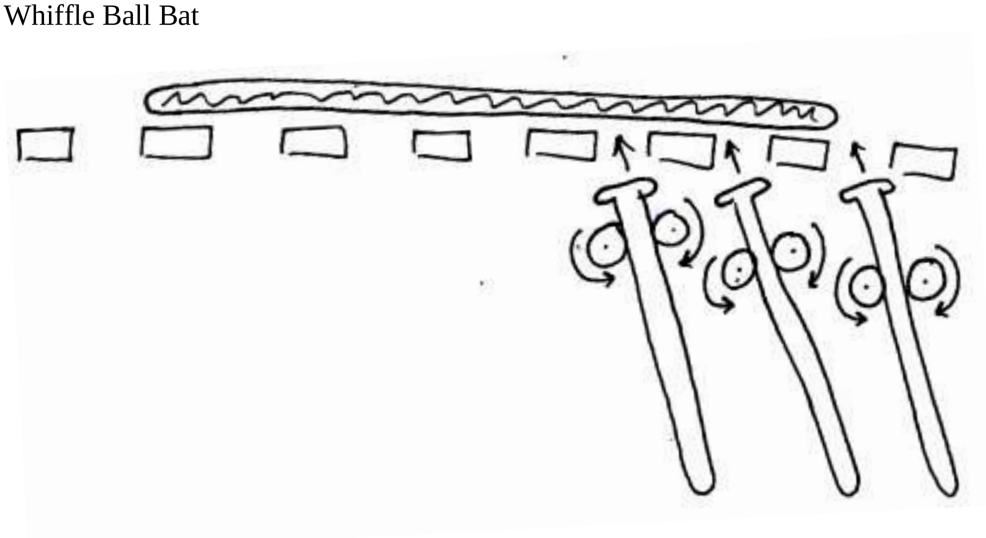
Preliminary Design Concepts

- **Circle Folder**
  - Concentric Circles



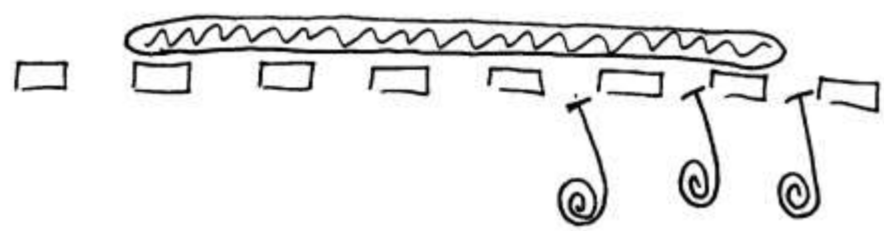
This design is adequately able to fold the garment in half about a central point. It is able to easily utilize multiple points of contact which move at necessary speeds while only using one motor; however, this motor must be high torque and fast in order to execute the fold. Also, this design would require an excessive amount of unused space near the bottom of the machine to allow for the housing of the part. This part would also be large and difficult/expensive to produce. Necessary analysis that would be required for this part would be to analyze the specifications of the motor and to determine the necessary speed to ensure that the fold would be achieved.

  - Whiffle Ball Bat



This design uses parts that resemble whiffle ball bats which are attached to motorized rollers. These bats are fed up at different rates (faster on the outside) which allows the garment to fold over. This design requires one motor for each set of rollers and calculations would have to be performed to determine what speed each roller would need to be to allow for the fold to be executed. The motors would not necessarily need to be high torque at the weight is distributed across multiple motors. The parts are smaller than the circle folder, but a significant amount of space is still taken up below the conveyor belts. Necessary analysis that would be required for this part would be to analyze the specifications of the motors and to determine the necessary speed of each motor to ensure that the fold would be achieved.

- Tape Measurer



This design utilizes tape measurers which are motorized. These tape measurers move upwards to fold the garment over. These tape measurers are fed up at different rates (faster on the outside) which allows the garment to fold over. This design requires one motor for each tape measurer and calculations would have to be performed to determine what speed each motor would need to be to allow for the fold to be executed. The motors would not necessarily need to be high torque at the weight is distributed across multiple motors. This design would require new housings for the tape measurers which allows them to be motorized. This design would require a fair amount of separate designs for the housings, but the space it would take up would be minimal. Necessary analysis that would be required for this part would be to analyze the specifications of the motors and to determine the necessary speed of each motor to ensure that the fold would be achieved.

- Selected Design

The design that was selected was that incorporating the tape measurers. This is because the space it takes up is minimal which satisfies one of the main design requirements for the entire design of the towel folding machine. Also, tape measurers are inexpensive and only a short length of tape is required meaning only one has to be purchased. The housings for the design can be printed inexpensively.

Group 19 10/25/2016

MEMS Senior Design Assignment 4: Design Review Comments

Reviewers:

- Group 1
    - Amanda Boyer
    - Ty Zatsick
    - Robert Ward
    - Greg Jakubiec
    - Nathan Narr
- Other Bystanders
    - Ricky Hollenbach

Critiques:

	Critique	**Outcome**
1	How do you get sleeves to be fed in perpendicular to the belts when they come in after hanging by gravity	This is outside of our design criterion (see impact section below). This is something that would need to be addressed in the future for expanded functionality
2	Are you sure the measuring tape actuator can hold a torque without flexing?	We are using 3 - 4 tapes in “parallel” on either side for added strength/rigidity. Additionally, we can add in gearing to better tension the tape measure actuators
3	It seems like your whole system will be pricey, how are you keeping your costs low, so that you can build your full machine?	We are building our own conveyor belts, and utilizing cheap/ free methods of prototyping to ensure we keep our costs low and can achieve the whole machine.
4	How are you going to make sure that all of your systems fit and work together?	We are utilizing in context assembly in SolidWorks to ensure that all of our parts come together exactly as we need them too. This also allows us to create complex systems in relation to each other with ease.

Impacts:

Our team had answers to critiques 2 - 4. These are all issues we had previously thought of and discussed. Thus, these critiques had no impact to our team and will not be addressed

Due to the already large size of our scope, we have decided to not incorporate folding long sleeves into the machine. If we accomplish our defined scope, and have a robust design, then we will try adapt the machine to fold other clothes, including long sleeved shirts.

Updated Summary:

The main addition to our project is the team decided to fabricate the conveyer belts. This decision was made because new conveyer belts were outside of our price point. Additionally, we would have had to purchase additional tools to join two ends of the belt together.

After some research on DIY belts, we decided to take twine and wrap it in multiple loops. Then, the loops will be covered in duct tape to provide rigidity and friction. Lastly, for added friction rubber paint will be applied to the outer surface to give a more finished look.

The belt fabrication was done using the aid of 3D printed jigs. Two iterations were done on the jigs. The first one was not sufficient for our needs as it made it hard to define the 2" pulley OD. The second one sped the time up a lot and made possible to fabricate a belt in about 10 minutes. Additionally, it made it possible to have a nearly uniform length on each of the belts.

MEMS Senior Design Assignment 5: Adopted Design Concept

Each component of Foldie required its own individual design. The components requiring the largest number of design iterations were the tape measure actuators, conveyer belts, and the egg slicer. However, the tape measure actuators proved to be the most difficult to design as there have already been six different designs created and tested. The strengths and weaknesses of each preliminary design were ranked using a Pugh chart so that one of the preliminary concepts could be selected for the finalized design.

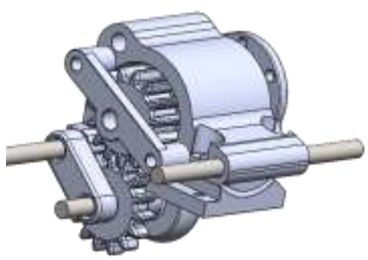
1. Prepare a Pugh chart summarizing the relative strengths and weakness of each of your preliminary designs. Based on your Pugh chart, select one of the preliminary concepts as a finalized design. Justify your selection in detail.

		Folding Mechanisms					***Presence/Absence Sensors***	
Design Criteria	**Weight**	**Tape Measure Actuator**	**Circle Folder**	**Homemade Belts**	**Purchased Belts**	**Egg Slicer**	**Infrared Detection**	**Contact Sensor**
Aesthetics	1	2	1	-2	3	1	1	0
Cost	2	3	1	3	-3	3	2	3
Effectiveness	3	2	1	1	2	2	2	2
Robustness	3	3	-1	3	2	1	1	0
Size	2	2	-3	0	2	2	2	1
Completion Speed	1	0	0	2	2	1	3	3
Unweighted	>0	5	6	3	4	4	5	6
	0	1	0	1	1	1	0	0
	<0	0	0	2	1	1	1	0
Weighted		27	-3	18	15	21	21	17

The final design was chosen based on the aesthetics, cost, effectiveness, robustness, size, and completion speed of each part. These are often the most important factors when selecting a design. Choosing between the tape measure actuator and the circle folder was easy as the difference in weighted value was so high. The tape measurer actuator, while slightly more complicated, is smaller and much more compact. Making homemade belts brings down the quality of the design but saves the group over $150 compared to purchasing belts, so it was a sacrifice that had to be made. While the quality of the homemade belts is average, they are still able to perform their job adequately.

2. Detailed description (dimensions, materials, CAD model, etc.) of the finalized (adopted) design concept.

Adopted Design

Category	**Tape Measure Actuator**	**Egg Slicer**
SolidWorks Files		 
Dimensions	The piece is able to fit within a 7 cm x 8 cm x 7 cm box	Each holder is approx 2 cm wide and each blade is around 8 in long, 0.6 in wide, and ¼ in high. The shaft used is 8 mm in diameter and 36 in long
Materials	The parts were 3D printed using PLA and assembled with the use of steel shafts, screws, rubber sealant, and measuring tape	Rod is made from steel, blades laser cut from chipboard, and the holder was 3D printed using PLA

3. Bill of materials (if applicable). List all materials and parts required. Include anticipated vendor source for each part.

Item	Unit Cost	Quantity	Total	Source
Tape Measure	$8.95	2	$17.90	Amazon
Rubber Sealant	$17.13	1	$17.13	Amazon
Twine	$14.49	1	$14.49	Amazon
3-M Duct Tape	$9.15	1	$9.15	Amazon
8mm OD Steel Rod	$5.70	5	$28.50	McMaster
8mm ID Flange Bearings	$2.88	15	$43.20	vxb.com
Torsion Springs	$3.95	0	$0.00	McMaster
IR LED	$0.32	15	$4.73	Digikey
IR Transistor	$1.04	15	$15.60	Digikey

Parts to be purchased are listed in the bill of materials above. Other parts were 3D printed in Benedum's MakerSpace using MakerBot Replicator. Other materials were salvaged around Benedum while motors and screws were taken from spare Robotics Club parts. Some parts were donated by our team and also Pitt's Robotics Club.

4. Summarize anticipated analysis and test required to verify the design against sponsor established requirements and specifications.

Analysis to be performed on the design includes circuit analysis to determine the necessary voltage required for each element of the system (motors and sensors). Additionally, static analysis will need to be performed in areas of high stress which would likely be located at the areas where the egg slicer reaches high speeds. Using skills learned in Mechatronics, an Arduino can be used as a controller to control the entire system.

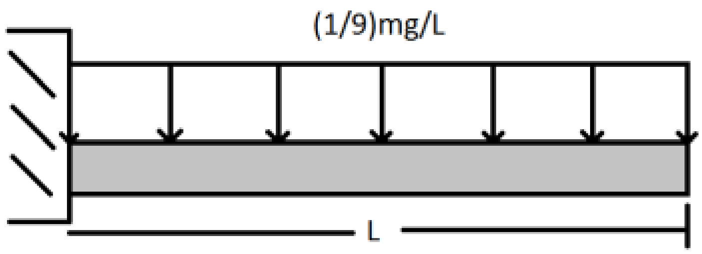
5. Has your sponsor approved the design concept?

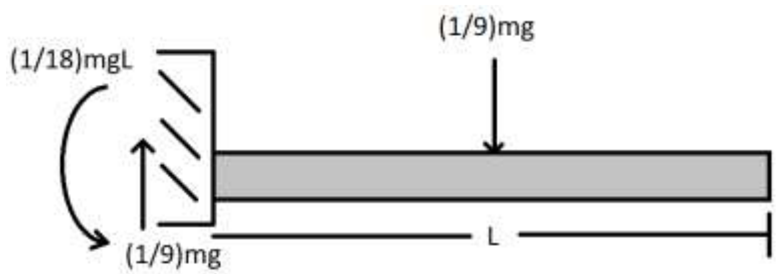
Our sponsor is Dr. David Schmidt. He has neither approved nor disapproved of the concept as he said we evaluate our own designs and are responsible for making a functional machine. Within our team, yes, we have approved the design concepts. We internally prototype the designs and then critique it. After that, our team approves the design if it's robust and functional.

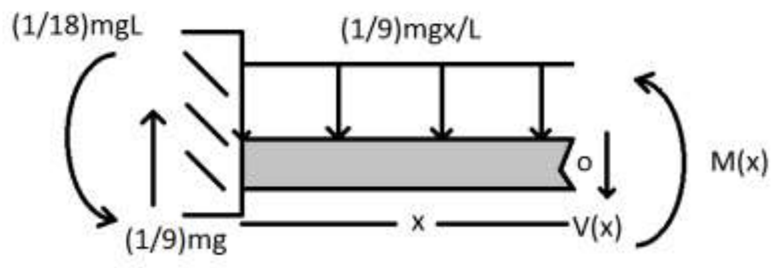
MEMS Senior Design Assignment 6: Supporting Analysis

Analysis to be performed on the design includes static analysis on the egg slicer blades in order to determine if the weight from a towel will deform them in any way. This will be done by representing the egg slicer blade as a cantilever beam - a technique learned in Mechanical Design I. Additionally, analysis was performed on the gears in order to determine the transmission ratios between the gears. Information on this topic was gained in Mechanical Design II. Throughout the whole design process, many designs were analyzed in order to find the strengths and weaknesses of each. Being able to assess the effectiveness of a design, along with the knowledge of how to use SolidWorks, was taught to us in Intro to Mechanical Design. Each form of analysis incorporated a different class from the MEMS curriculum.

- **Mechanical Design I (MEMS 1028)**
    - Using skills from Mechanical Design I, FBDs could be made of the egg slicer blades in order to determine if the design was strong enough to hold the towel without any significant deformation. This was done using beam deflection analysis using the equation of the elastic curve. By simplifying each blade of the egg slicer as a cantilever beam, the maximum deflection, shear force, and bending moment could be found.
    - Main assumptions: maximum towel will be no heavier than 5 lb, weight is evenly distributed across the 9 egg slicers, blades are made of wood with E = 10 GPa, the blades are 8 in long, ⅛ in tall, and 0.6 in wide, blades act as cantilever beams







$$y''EI = M(x)$$

$$y''EI = -\frac{mg}{18L}(x^2 - 2Lx + L^2)$$

$$y'EI = -\frac{mg}{18L}\left(\frac{1}{3}x^3 - Lx^2 + L^2x\right) + C_1$$

$$yEI = -\frac{mg}{18L}\left(\frac{1}{12}x^4 - \frac{1}{3}Lx^3 + \frac{1}{2}L^2x^2\right) + C_1x + C_2$$

$$yEI|_{x=0} = 0 \Rightarrow C_2 = 0$$

$$y'EI|_{x=0} = 0 \Rightarrow C_1 = 0$$

$$y = -\frac{mgx^2}{216EIL}(x^2 - 4Lx + 6L^2)$$

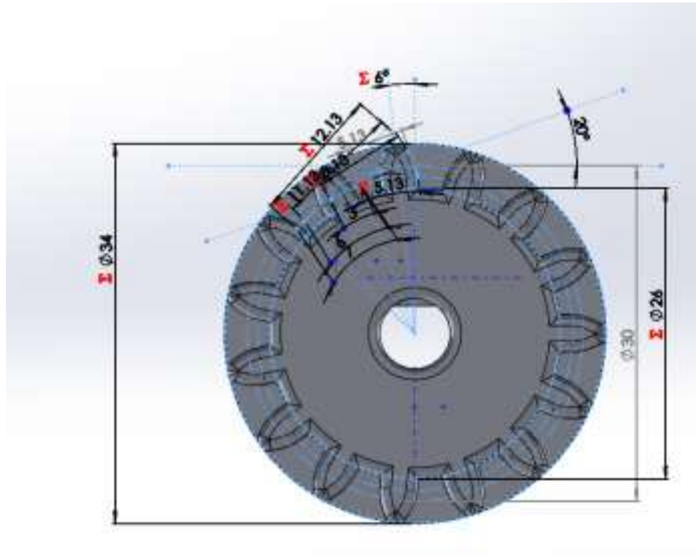
$$y|_{x=L} = -\frac{mgL^3}{72EI} = -\frac{mgL^3}{6Ebh^3}$$

Variable	Value
Mass of Towel, m	5 lb ≈ 2.268 kg
Length of Blade, L	8 in ≈ 0.2032 m
Elastic Modulus of Blade, E	10 GPa
Base Length of Blade, b	0.6 in ≈ 0.01524 m
Height of Blade, h	0.125 in ≈ 0.003175 m

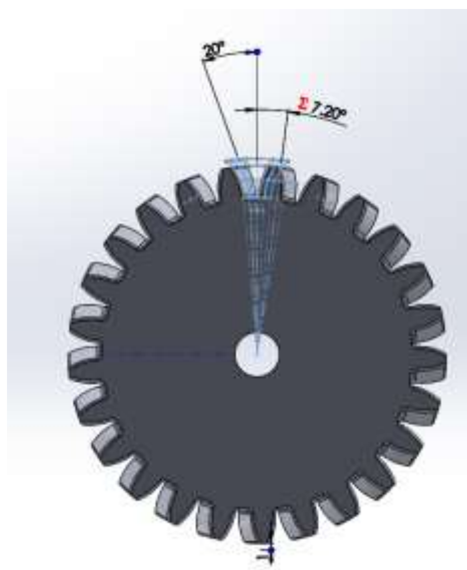
- Using these values, the deflection at the end of each egg slicer blade is equal to 0.00638 m or 6.38 mm. This deflection is minimal; therefore, the analysis is able to validate the design.

- **Mechanical Design II (MEMS 1029)**
  - This course taught us about the various terms associated with gear designs starting out with spur gear teeth and then going into the various terms associated with gear selection such as pressure angle, module/pitch diameter, and other terms like addendum and dedendum.
  - There were multiple instances of gears in this design, some had a 1:1 ratio and others had a 2:1 ratio. The modules we used were 2 and 1 respectively. The gears were all used to connect shafts to the drive shaft. The pitch diameter varied on the spacing of the drive and slave shafts. All gears used a pressure angle of 20 degrees.
  - One of the gears used was a spur gear. The involute profile was created by idealizing a string of the same length being pulled to various locations around a center point. This

was automated using SolidWorks' Equation Manager. The sketch used to generate one gear tooth is shown below:



- At a different point in the design we used a helical gear to help with the smoothness of torque transfer, to make the gears quieter, and extend their lifetime. The helical gear's shape was again automated using SolidWorks' Equation Manager. It's sketch is shown below:



- **Intro to Mechanical Design (MEMS 0024)**
  - The design process was crucial to the design of our machine. Based on the overall complexity of our machine, we had to incorporate many design principles into the design
    - The machine needed to be designed for manufacturing based on the constraints of one semester and our limited budget. We had to work with Pitt's fabrication facilities, most notably the MakerSpace and SCPI
    - Our machine also needed to be designed for assembly because we did not want to have to put in the hours tapping extraneous holes or redoing parts

- MEMS 0024 taught how to ideate over and over and not reject designs but come up with many simple ones to help converge on an overall better idea. We followed this methodology for many hours, coming up with about 100 different hand sketches on an array of different designs. The hand sketches were then discussed and evaluated based on their feasibility, manufacturability, and aesthetics.
    - For example, we came up with one folding algorithm that required clothes to be drawn along two offset rods. This process created a neatly folded shirt that was of store quality. However, this process was complicated and was going to be difficult to manufacture and control. So the idea ultimately had to be scrapped even though it was a robust process.
- In addition to the design process, MEMS 0024 also gave us exposure to SolidWorks which was used extensively by each group member throughout the design of the model.

MEMS Senior Design Assignment 7: Project Impact

Project Impact

Our deliverable impacts not only our sponsor, but it also impacts the SSOE community. Our sponsor, Dr. Schmidt, will be able to use our 'prototyping process' board to show future students a hands on demonstration of the design process. It proves that the first design is not (typically) going to be the best, and that there are constantly going to be areas for improvement. We describe the features of each design revision and how each design can be further improved.

Design Process

Foldie was ideated through an iterative process in which, first, a bunch of folding methodologies were laid out. Then, while designing the machine, we again went through an iterative process to design mechanisms which could perform various folding mechanics. Next, we went through an iterative design on each individual mechanism in order to make them work robustly and efficiently at minimal costs. Our lasting impact, as stated above, is a board representing the iterative design process we went through in the creation of the 'tape measure actuator' folding mechanism.

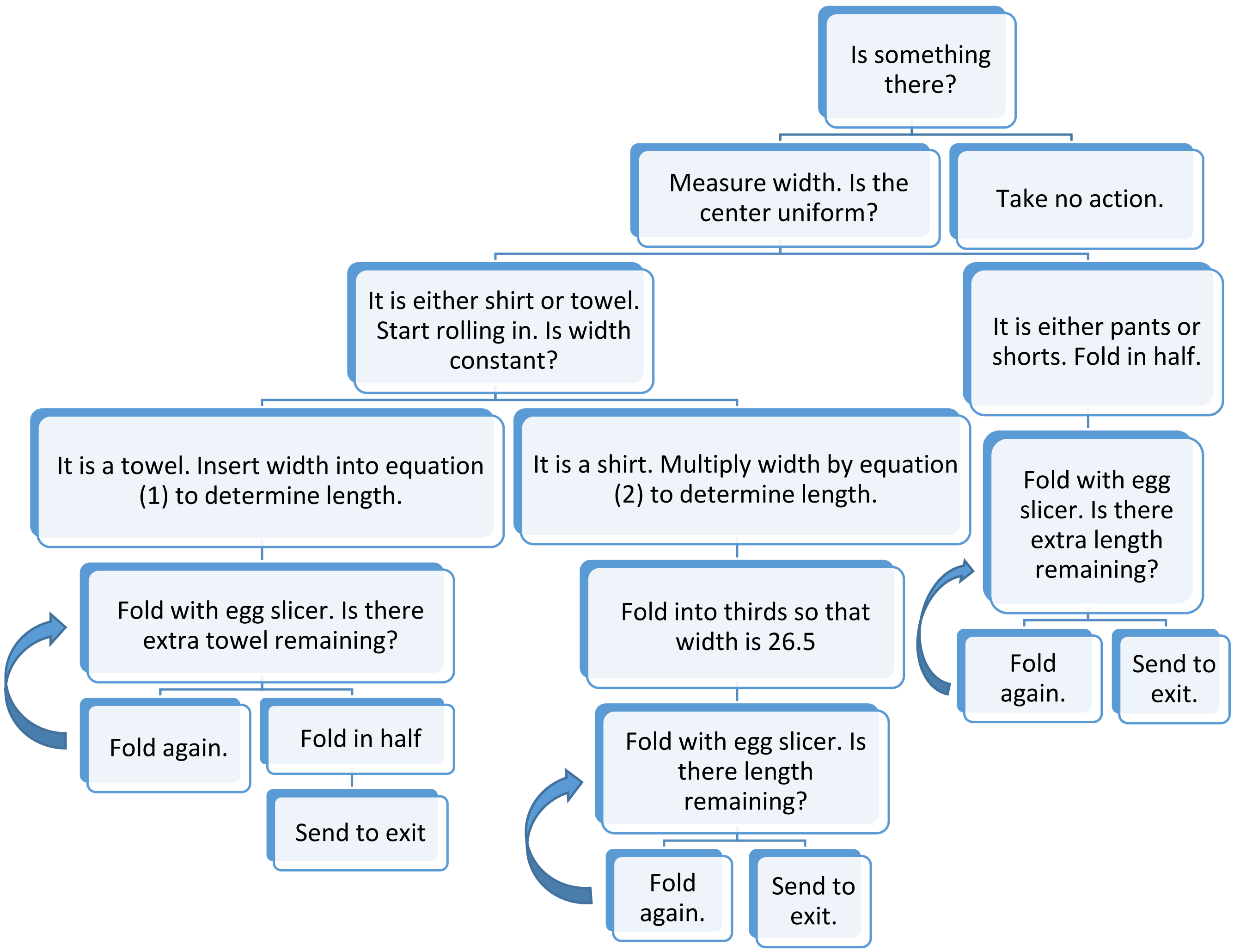
Deliverable: Tape Measure Actuator

This 'prototyping process' board offers:

- A physical way to observe the design process.
    - Changes made in each revision are visually evident
    - Students can physically interact with each revision
        - Ex: they can pull on the tape and feel how the tape measure more efficiently dispenses tape
- Debunk the myth that a final design should be done quickly
    - This board shows the amount of effort that went into the design, and that it took 7 revisions to arrive at a viable design
    - **A design is only a failure when you stop trying to make it a success**
- Teaches students how to look for areas to improve on a design
    - Interact with their peers for design critiques
    - Look at every aspect of the design thoroughly to find the minute details that will ensure the success of the future revision
- Shows students how to use the resources around them
    - The revisions were all created from parts our team acquired around Benedum
        - The iterations were free thanks to the MakerSpace's filament and the Robotics Club's fasteners/motors

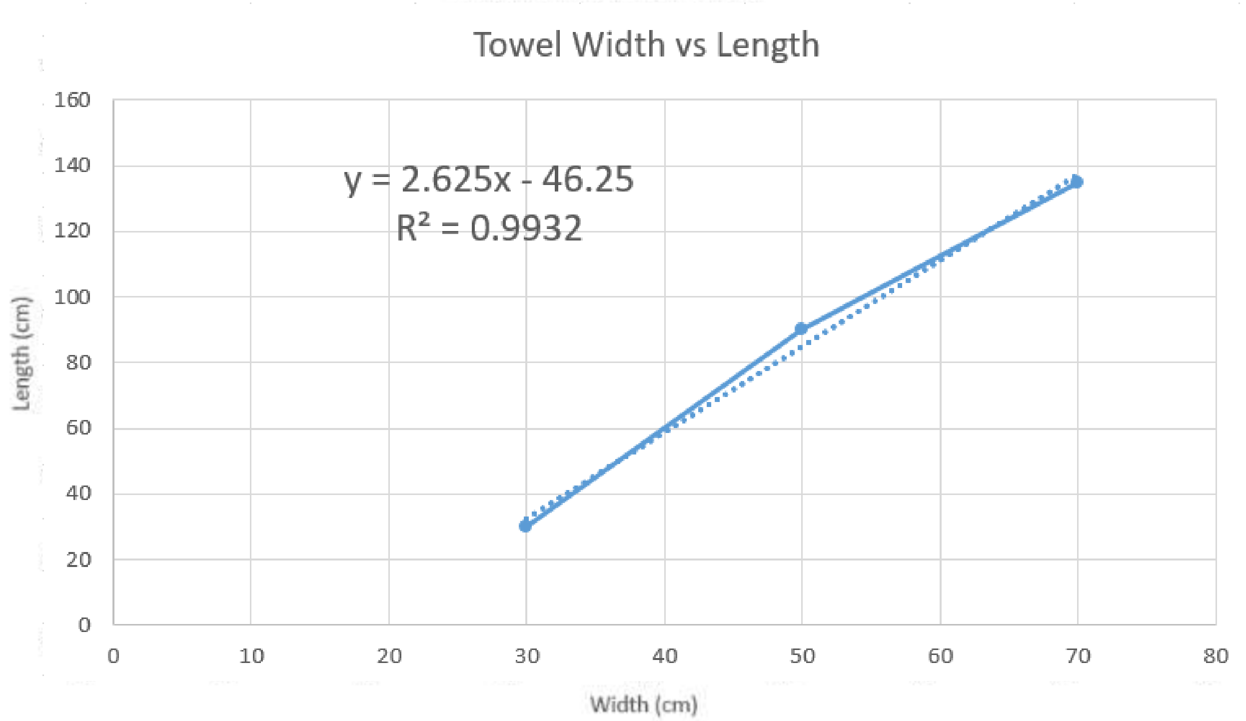
Basic Folding Algorithm

Note: If "yes", then move to the left. If "no", then move to the right. Equations are referenced on the following page.



Where:

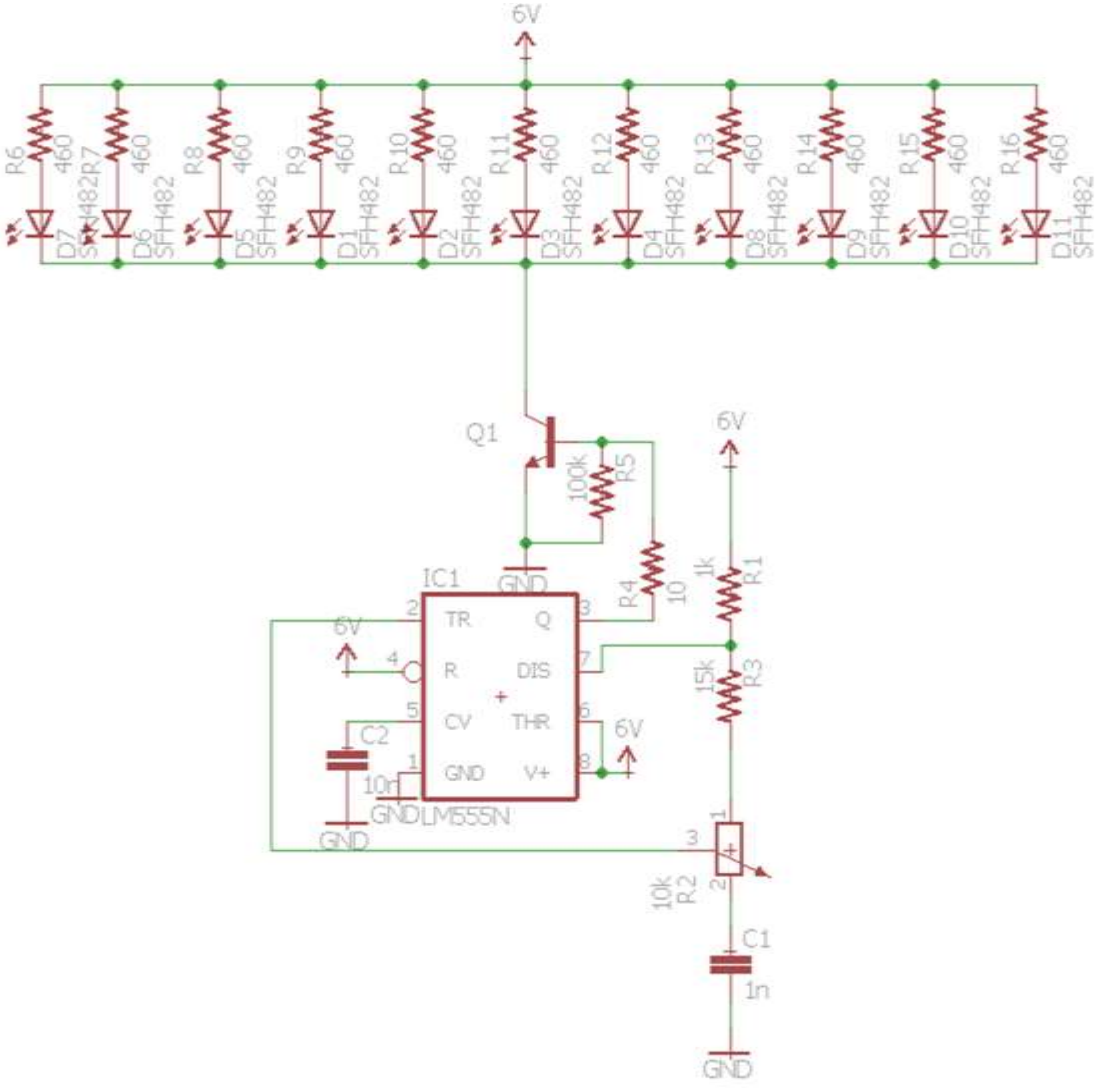
(1)


Towel Width vs Length
y = 2.625x - 46.25
R² = 0.9932
Length (cm)
Width (cm)
0
20
40
60
80
100
120
140
160
0
10
20
30
40
50
60
70
80

(2)


T-Shirt Width vs Length
y = 0.6412x + 38.908
R² = 0.9814
Length (cm)
Width (cm)
60
65
70
75
80
85
90
95
40
45
50
55
60
65
70
75
80

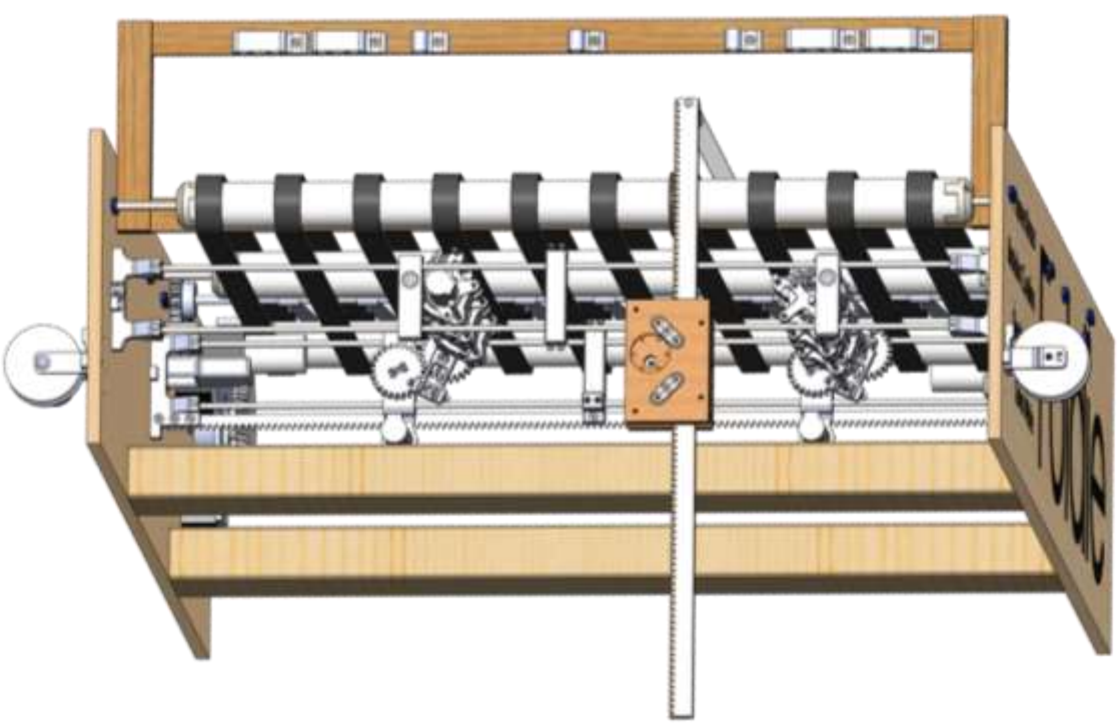
This identification is accomplished using a stitcher circuit. Using IR sensors and LEDs, the length and distribution of the item can be discerned by recognizing which LEDs are blocked and which are not. This stitcher circuit is shown below. Knowing the article of clothing helps Foldie to determine which steps to take in the folding process.



Supply					Load					
Name	**Volts**	**Secondary Amps**	**Primary Amps**		**Name**	**Voltage**	**Min Amps**	**Avg Amps**	**Max Amps**	**Supply Source**
iomega	5	2.5	0.85		TMA1	6	0.13		3.2	Lacie
pso853	5	3.5	0.6		TMA1Actuator1	6	0.13		3.2	iomega
deer	5	2.4	0.5		TMA2Actuator2	6	0.13		3.2	pso853
RS-1203	5	3	1.5		TMA2	6	0.13		3.2	pso853
Seiko1	12	3	1		TMA2Actuator1	6	0.13		3.2	RS-1203
Phihong	24	2.5	1.6		TMA2Actuator2	6	0.13		3.2	Lacie
OK	5	1	0.5		Conveyor Stepper	24	Unkown	1.3A	Unknown	Phihong
Lacie	5	4.2	1.5		Stitcher Circuit	5	Unknown	Uknown	Unknown	OK
Seiko2	12	3	1		CreaseFolderMotor1	12	Unknown	Unknown	Unknown	Seiko2
					CreaseFolderMotor2	12	Unknown	Unknown	Unknown	Seiko2
Max Power Supply		25.1	9.05		CreaseFolderPulleyMotor	12	Unknown	Unknown	Unknown	Seiko
					Egg Slicer Motor1	12	Unknown	Unknown	Unknown	Seiko
					Egg Slicer Motor2	12	Unknown	Unknown	Unknown	Seiko
					Arduino	5	Unknown	Unknown	Unknown	OK
Test Results	1 TMA	187mA								
	2TMA	750mA		Couldn't start at the same time... too much spike						

	MEMS Budget	$200.00		MEMS Remaining		-$127.66		Total Remaining		-$46.85	
	ECE Budget	$400.00		ECE Remaining		$80.81		Percent Remaining		-7.81%	
Acquired?	**Purchaser**	**Item**	**Unit Cost**	**Quantity**	**Shipping**	**Total**	**Source**	**PN**	**Reimbursed?**	**Reimburse Submitted?**	**Account**
Y	Kevin	Tape Measure	$8.95	2		$17.90	Amazon		Yes	Yes	MEMS
Y	Kevin	Rubber Sealant	$17.13	1		$17.13	Amazon		Yes	Yes	MEMS
Y	Kevin	Twine	$14.49	1		$14.49	Amazon		Yes	Yes	MEMS
Y	Kevin	3-M Duct Tape	$9.15	1		$9.15	Amazon		Yes	Yes	MEMS
n/a	James	8mm ID Flange Bearings	$3.20	0		$0.00	Misumi	CFL688ZZ	n/a	n/a	MEMS
Y	James	8mm OD Steel Rod	$5.70	6		$34.20	McMaster	88625K67	n/a	n/a	MEMS
Y	Kevin	8mm ID Flange Bearings	$2.88	15		$43.20	vxb.com	MR688-ZZ	No	Yes	MEMS
n/a	James	Torsion Springs	$3.95	0		$0.00	McMaster	9287K242	n/a	n/a	MEMS
Y	Brandon	IR LED	$0.32	15		$4.73	Digikey	IR333-A	n/a	n/a	ECE
Y	Brandon	IR Transistor	$0.88	15		$13.17	Digikey	TSMP58138	n/a	n/a	ECE
Y	Brandon	Motor Driver	$23.49	2	$0.00	$46.98	RobotShop	RB-Cyt-153	n/a	n/a	ECE
Y	Brandon	Arduino Mega	$36.99	1	$0.00	$36.99	RobotShop	RB-Ard-33	n/a	n/a	ECE
Y	James	Extension Springs	$9.26	2		$18.52	McMaster	9654K109	n/a	n/a	MEMS
Y	Derek	8-32 5/8" Screws	$2.91	1		$2.91	McMaster	90276A196	n/a	n/a	MEMS
Y	Derek	8-32 Nuts	$1.60	1		$1.60	McMaster	90480A009	n/a	n/a	MEMS
Y	James	6mm Acetal Bushing	$3.32	12		$39.84	McMaster	2640T11	n/a	n/a	MEMS
Y	Kevin	Spray Foam Insulation	$4.17	1		$4.17	Home Depot		No	Yes	MEMS
Y	James	6mm OD Shafts - 6'	$9.54	5	$4.33	$52.03	McMaster	8920K22			ECE
Y	James	2mm OD Pins	$8.03	1	$4.33	$12.36	McMaster	91595A037			ECE
Y	Kevin	Tape Measure Motors	$11.10	6		$66.60	DX Soul	901415115		Yes	ECE
Y	James	Steel Cable	$6.75	1	$4.33	$11.08	McMaster	3450T24			ECE
Y	Kevin	Frame Supplies	$21.00	1	$0.00	$21.00	Home Depot				MEMS
I	Brandon	More Motor Drivers	$23.49	2		$46.98	RobotShop	RB-Cyt-153			ECE
I	Brandon	Limit Switches	$1.95	4		$7.80	RobotShop	RB-Cyt-153			ECE
Y	Kevin	Filament	$30.00	2		$60.00	Amazon		No	Yes	MEMS
Y	Brandon	IR Receiver	$1.04	15		$15.60	Digikey	TSOP34838			ECE
Y	Brandon	MOSFET p-type	$1.62	3		$4.86	Digikey	IRF9Z20PBF			ECE
Y	James	Makerbot Filament	$43.55	1		$43.55	Amazon				MEMS

Final Design




Foldie
James Braza
Brandon Contino
Kevin White


James Braza

Bill of Materials for Final Design

Feature	Item	Quantity	Unit Cost	Total Cost
8-32 Nut, Bolt, and Screw Kit		1	$15.00	$15.00
MakerBot Filament		1	$43.55	$43.55
Frame	MDF Frame Base (2"x4")	1	$21.00	$21.00
	Bearings	10	$2.88	$28.80
	Bearing Mounts	10	3D Printed	-
	Screws	15	Kit	-
	Bolts	23	Kit	-
	Nuts	23	Kit	-
	Motor Mount	1	Laser Cut	-
	Stand Off (2"x4")	3	Scrap	-
	Gear	1	3D Printed	-
Belts	Twine	1	$14.49	$14.49
	Duct Tape	1	$9.15	$9.15
	Rubber Paint	1	$17.13	$17.13
Belt Drivers	PVC Pipe	3	Scrap	-
	End Brackets	5	3D Printed	-
	End Bracket Geared	1	3D Printed	-
	Steel Shaft	3	$5.70	$17.10
Egg Slicer (Entry and Exit)	Steel Shaft	2	$5.70	$11.40
	Nuts	22	Kit	-
	Bolts	22	Kit	-
	Shaft Gear	2	3D Printed	-
	Motor Gear	2	3D Printed	-
	Motor Bracket	2	3D Printed	-
	Chip Board	1	Scrap	-
	Blade Brackets	18	3D Printed	-
Tape Measure Actuator (TMA)	Steel Rods	5	$9.54	$47.70
	Steel Pins	1	$8.03	$8.03
	Extension Springs	2	$9.26	$18.52
	Nuts	16	Kit	-
	Bolts	16	Kit	-
	Bushing	8	$3.32	$26.56
	Custom Parts		3D Printed	-
	Tape Measurers	2	$8.95	$17.90
Crease Folder	Custom Parts		Laser Cut	-
	Steel Cable	1	$6.75	$6.75
LED Mount	Wood (1"x2")	1	Scrap	-
	Yard Stick	1	Scrap	-
	Nut	8	Kit	-
	Bolt	8	Kit	-

Electronics	IR LED	9	$0.32	$2.88
	IR Transistor	9	$0.88	$7.92
	IR Receiver	9	$1.04	$9.36
	MOSFET p-type	3	$1.62	$4.86
	Motor Driver	2	$23.49	$46.98
	Arduino Mega	1	$36.99	$36.99
	Motors (TMA)	6	$11.10	$66.60
	Stepper Motor (Belt)	1	Donation	-
	Motors (Other)	4	Scrap	-

Total Cost: $478.67

FOLDIE – THE LAUNDRY FOLDING ROBOT

Project Engineers: James Braza, Brandon Contino, Derek Nichols, and Kevin White

Project Faculty Advisor: Dr. David Schmidt

PITT | SWANSON ENGINEERING
MECHANICAL & MATERIALS SCIENCE

ABSTRACT

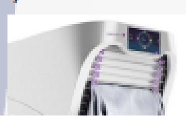
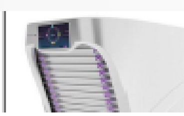
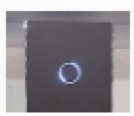
This project addresses the issue of folding clothes. Utilizing the designs of industrial folding machines as inspiration, a machine able to fit within a cubic yard was constructed with the ability to fold towels and shirts. This design was accomplished by utilizing many mechanical and electrical engineering principles. While the system does not work perfectly, our group started from a concept and made that concept a reality.

INTRODUCTION

Our team started brainstorming problems that we could address for a self-directed senior design project as far back as the spring semester of 2016. We came to the realization that folding clothes, even though it takes a significant amount of time, has never been addressed on the residential scale.

Breaking down the numbers, the average human takes around 30 seconds to fold an article of clothing, has around 45 clothing items per load of laundry, does laundry every 1.5 weeks, will fold laundry for 75 years of his/her life, and will fold laundry for two kids for 18 years a piece. These are approximations, but their foundations are sound. Crunching these numbers, that means that the average person will fold laundry for nearly 60 days of his/her life. This proves that it is an issue worth addressing.

There are certain companies that are attempting to address this issue already; however, they have not yet been released to the market, are large, and will cost a substantial amount of money. These include companies like Foldimate, Laundroid, and CloPeMa.

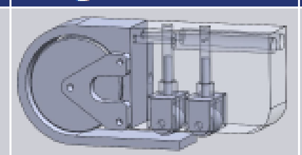
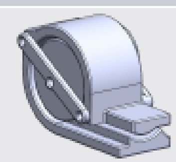





DESIGN PROCESS

With our idea and design criteria, we brainstormed ideas for machines able fold laundry – coming up with greater than 100 ideas over the course of two months. Some of these ideas seemed better than others, so we tested the ones that seemed the most feasible. In doing so, we ultimately decided on our design which is shown at the end of the previous section.

This design still required a fair amount of alterations and experimentation. In fact, we broke the design down into eight different components: the frame, belts, pulleys, egg slicer, exit method, tape measure actuators (TMA), crease holders, and the circuit. Each component required its own design, prototyping, and analysis.

Perhaps the greatest amount of design iteration took place on the tape measure actuators. The TMA motorizes a tape measurer and utilizes this motion to fold an article of clothing in half. With a total of seven revisions, each design continually addressed the shortcomings and improved upon its predecessor. Seen below are three of the designs for the TMAs.

Rev	Design	Shortcomings
1		• Too large for design requirements • Tape had 20mm excess space • Pulley spun out of plane
2		• Much smaller but tape still had 5mm of excess room • Tape blade had no pushing force • Shaft mounts were to weak to hold multiple TMA's in parallel

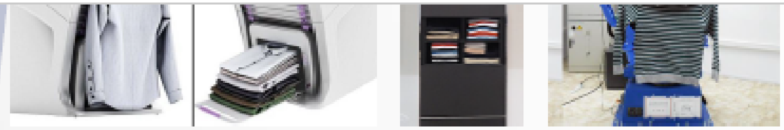
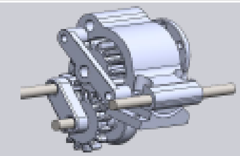
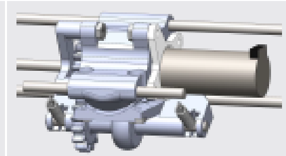


Figure 1: a) Foldimate, b) Laundroid, c) CloPeMa

4		• Method of attaching gear tensioner was not functional • 3D printed threads were tedious to tap and weak
7		• Inlaid nuts replaced threaded holes • Compression springs better tensioned • DC encoded motor was changed

OBJECTIVE

The goal of this project was to develop and design a machine for residential use to aid in the folding of towels and shirts. The machine must be able to fold multiple times with high satisfaction and quality of fold.

DESIGN CRITERIA

Assuming that the clothing item is a towel and that the clothing item is inputted into the machine by an external method (e.g. humans, loading machine, external attachment, etc.), there are certain design constraints that had to be met for the project. These were the criteria used for the design of the entire system.

Towel Size **– fold towels of variable size**
- Wash cloth: 13" x 13" (~1 ft 2)
- Bath Sheet: 35" x 60" (~15 ft 2)

Folding Time **– time to complete fold**
- Fold towel in < 90 seconds

Fold Quality **– a wrinkle-free high quality fold**
- Visually appealing
- Final fold length + width < 27"

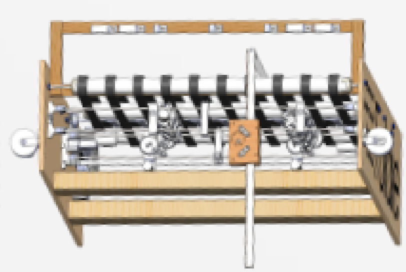
Cost **– total cost for entire system**
- Must cost less than $600

Towel Material **– fold independent of cloth material**
- Cotton to polyester

Footprint **– able to fit in laundry rooms**
- Entryway can accommodate any towel
- Total Volume < 1 yd^3

Power **– run off outlet power**
- Available in households

Noise **– less sound than a washing machine**
- Sound Volume < 78 dB



CIRCUIT CONSTRUCTION AND ALGORITHM IMPLEMENTATION

There are predominately two circuits in the design: one for control and the other for power. The control circuit is seen in Figure 2, and the power circuit involved strategic combination of old power adapters and load balancing to power the machine.

The algorithm was executed on an Arduino Mega because of its low cost, extensive I/O pins, and short development time. Although currently a rough rendition, further iterations will result in an optimized, more robust algorithm.

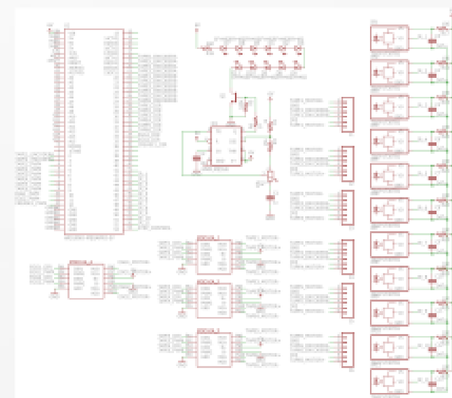
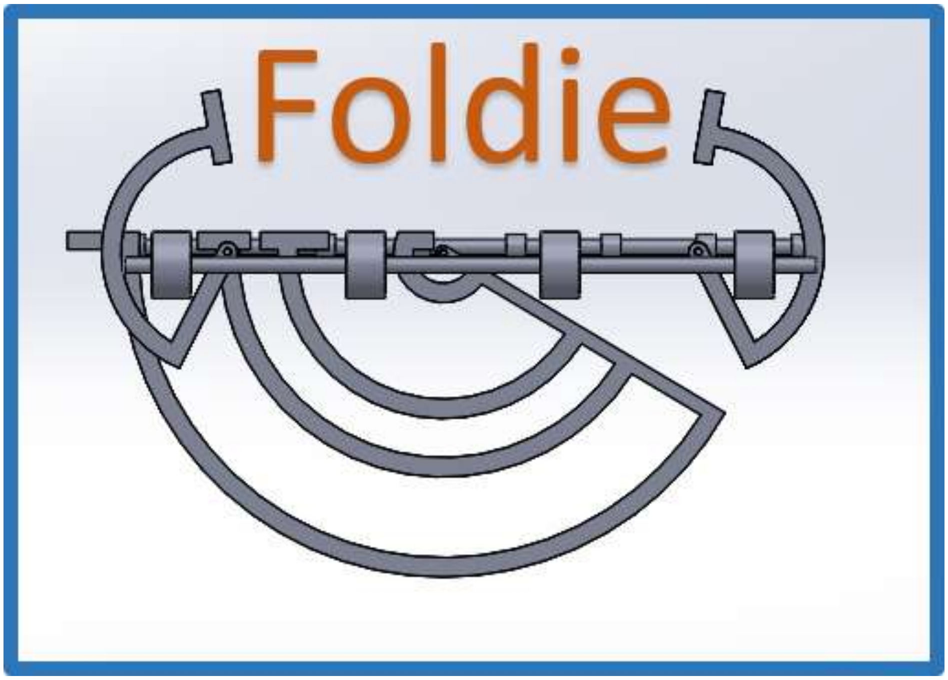


Figure 2: Schematic for the control circuit

ACKNOWLEDGEMENTS

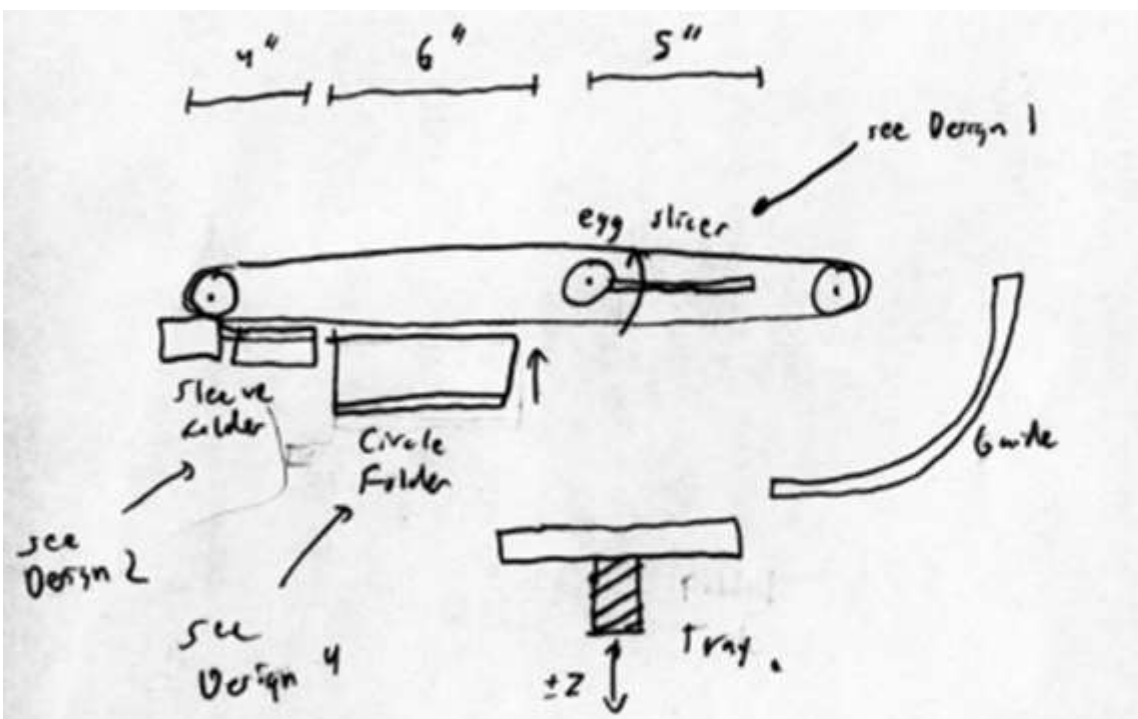
We would like to thank Dr. David Schmidt for sponsoring the team and keeping us inspired, the MEMS and ECE departments for their generous budgets, Andy Holmes and Jeffrey Speakman of the SSOE's SCPI for their 3D printing/fabrication assistance, Jim Lyle and Bill McGahey of the SSOE's SERC for their electronic components and 3D printing, the MakerSpace for all of their PLA filament and storage space, Erin Sarosi for her laser cutter assistance, and Dr. William Clark for letting us experiment with the robot SIR-1.

Miscellaneous Pictures



Foldie

(From Humble Beginnings)




MakerBot Replicator
MakerBot Replicator


THE XYZ
OF 3D
PRINTING
James Brazo
Brandon Contino
Derek Nichols
Kevin White
Foldie

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