ECE 445

Spring 2024

Senior Design Design Document

Automated Multi-Mode Garment Folding System with Arduino Control

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Link to Github Notebook: Github Notebook

1. Introduction

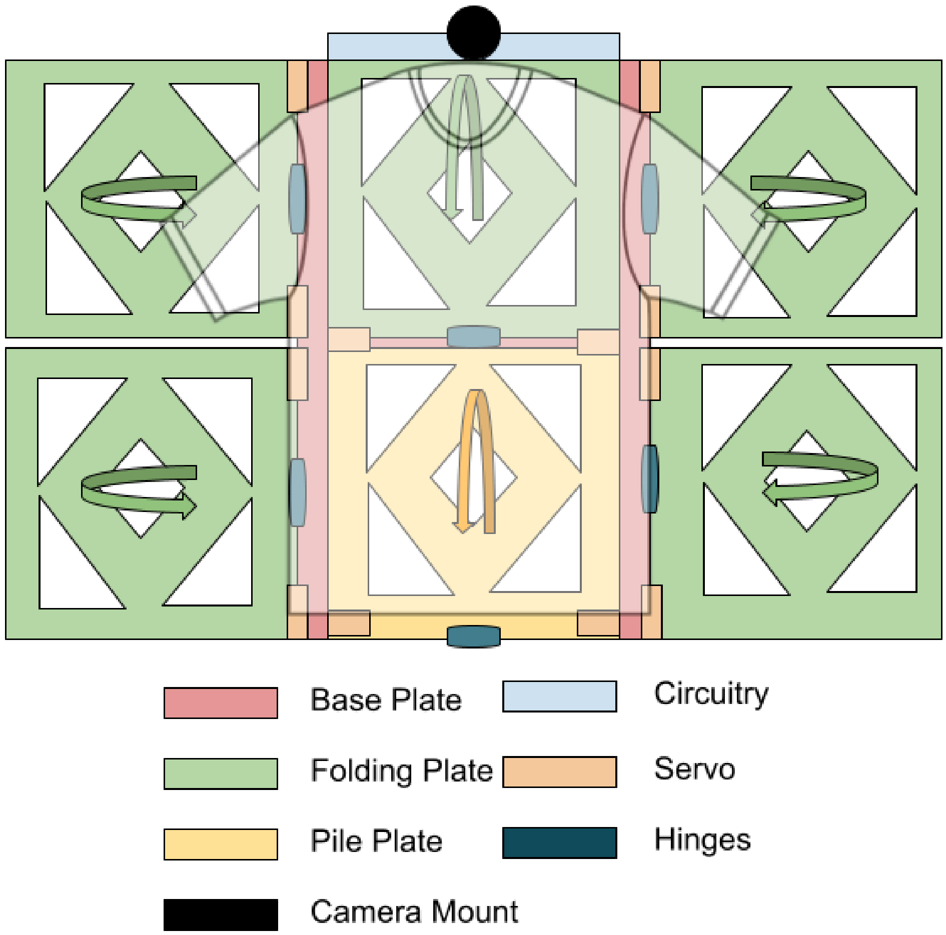
1.1 Problem

No one likes to fold laundry. It's dull, boring, and tedious. The only positive is that it gives you an excuse to listen to your favorite podcast that you may have had a backlog on. On top of that, folding laundry can prove to be a difficult task for the elderly and disabled. In commercial settings, employees of large retail clothing stores have reported getting carpal tunnel syndrome from the repetitive and manual task of folding clothes. Referencing the ADA, there are a long list of reasons that folding laundry can be difficult for people with physical disabilities. Our project would help mitigate these issues for people with physical disabilities. Our solution expands upon previous designs by offering multiple modes, a more compact size, and a cheaper alternative.

1.2 Solution

To solve this crisis, we want to create an automated multi-mode clothes folding system. This will allow the user to decrease the time and effort involved in folding laundry. The whole process takes place in three steps. A user will place one of three preset clothing items on the machine. An overhead camera is used to image the clothing item and send the data to a Raspberry Pi controller. The controller will run the image through a python program that will identify the item of clothing then send a series of instructions out to servos. The servos will operate mechanical folding panels that will properly fold the clothing item. A final panel will place the folded item into a pile.

1.3 Visual Aid



1.4 High-Level Requirements

- Image Recognition
    - The machine must be able to identify three different clothing items: t-shirt, pullover, trousers. To implement this, we will store a pre-trained ML algorithm that will accept an image and output the predicted clothing type. In order to consider this achieved, we will be requiring a correct clothing identification rate of 90%.

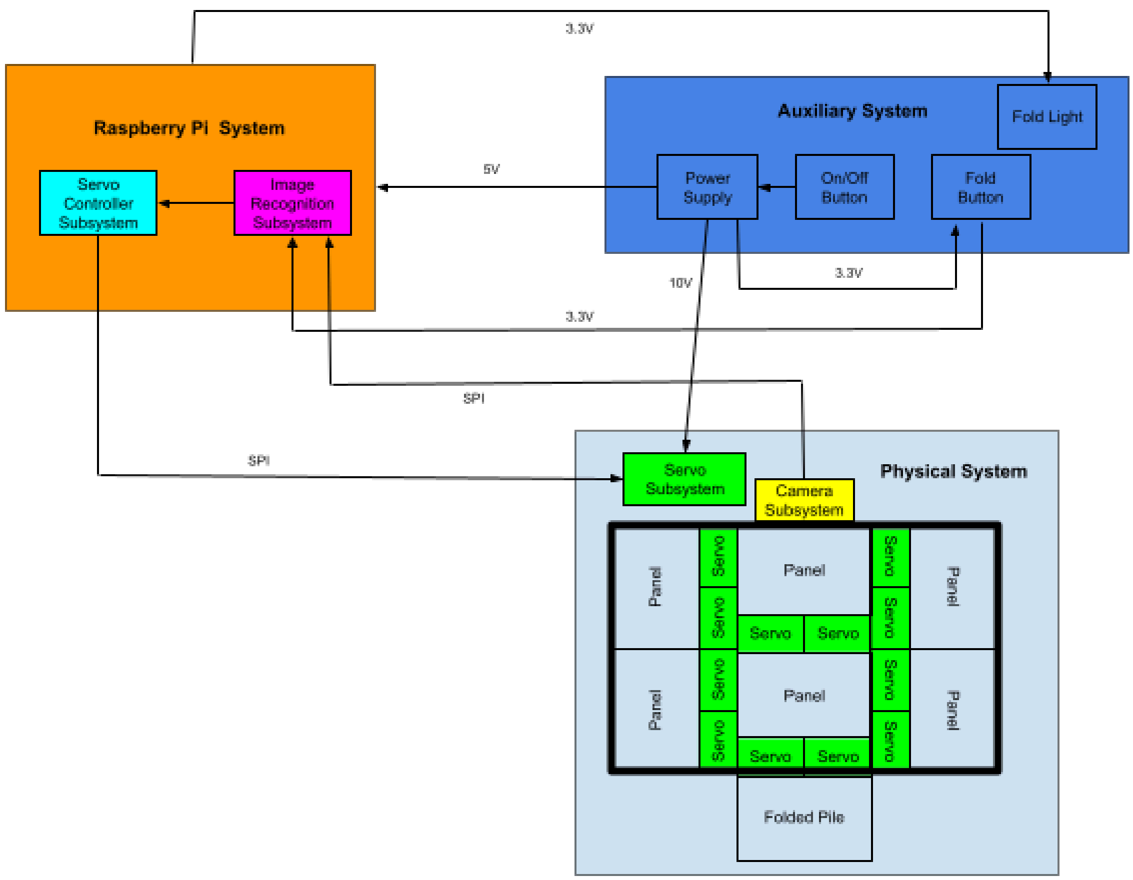
- Correct Folding Instructions
    - Raspberry Pi code must be able to correctly know what is on the folding machine using image analysis software described above. Once the correct item is determined, one of the three folding processes is selected and carried out. These folding instructions will be determined beforehand following conventional folding techniques. In order to consider this achieved, the machine must output the same exact instructions for the clothing type it

identifies. This goal is independent of the image recognition goal. That means that if the machine incorrectly identifies a pullover as a pair of pants, we still expect the machine to carry out the folding algorithm for pants to be considered a success.

- Correct Folding Mechanic
  - Servos and Panels must be able to properly fold and pile the clothes neatly and in good time. The folding mechanics will be predetermined and follow conventional folding techniques as described above. This will be considered complete when the clothes folded are in a neat condition with little to no incorrect overlap. The servos must also fold the clothes in a time less than 5 seconds.

2. Design

2.1 Block Diagram



2.2 System Overview and Requirements

- RaspberryPi System
  - Servo-Controller Subsystem
    - The servo controller will contain three different programs, one for each type of clothing. Depending on the type of clothing identified by the image recognition subsystem, the servo controller will pick the corresponding program.
    - Each program will control sets of servos in a sequential manner, allowing the previous set of servos to return to their original position before activating the next set.
    - The Raspberry Pi system will be connected to the servo motors through a PCB chip.

Requirement	Verification
The servo controller will contain three different programs, one for each type of clothing	- The servos are able to move in a way indicative of the three programs that are programmed

  - Image Recognition Subsystem
    - The image recognition system will be written in python and called on system boot. We will train a Convolutional Neural Network model provided by Tensorflow on a Fashion MNIST dataset provided by TensorFlow's Keras.
    - The fashion dataset contains about 18,000 images for the 3 labels (t-shirts, pullovers, trousers) that we will be using. We should be able to achieve at least a 90% correct classification rate.
    - We will use Keras's save feature to save and store the model to our micro-sd card. This will save significant time and memory during the boot phase of our automatic-folder. The model will be loaded into memory on system boot and the prediction function will take an image as a parameter. The model should be able to output a correct classification within 1 second of getting called.
    - Upon receiving a high signal from the fold button, the RaspberryPi will save a frame of the streamed video. It will pass this frame to the prediction method of the CNN model. It will then pass the output of the prediction method to the servo controller subsystem.

Requirement	Verification
Image Recognition subsystem will identify three different articles of clothing	- System can properly crop picture so that only clothing item is in view - System can resize cropped picture to 28x28 pixels - System can predict clothing type from resized, cropped images with at least 90% accuracy.

- Auxiliary System
  - Power Supply
    - Must be able to supply stable voltage for multiple subsystems that will each require different levels.
    - The Camera will require 3.3V
    - The Raspberry Pi controller will require 5V
    - The Servo Motors will require 5V
    - Linear Voltage Regulators will be used to vary the voltage to the different subsystems.
    - 8V wall-outlet adapter supply will allow for stable power for each subsystem when working at maximum capacity

Requirement	Verification
Power system will supply stable voltage and accurate voltage to all the subsystems	- Voltage on both side of linear voltage regulators are accurate - Power supply is receiving power from wall outlet - Power supply is supplying power to its output

  - Fold Button that will start the entire folding process. Sends a high signal to Raspberry Pi

Requirement	Verification
Folding button will start the entire folding process	- Raspberry Pi controller receives signal to start the processes - Raspberry Pi controller correctly starts once the start signal is received

- Folding Light that will inform the user when the machine is currently working and when it is ready for a new piece of clothing.

Requirement	Verification
Fold light will be active when the folding process is occuring	- Raspberry Pi controller sends power to folding light while running - Raspberry Pi controller sends no power while idling

- Physical System (Includes PCB)
  - Servo Subsystem
    - The servos will be mounted using screws to a metal or wooden frame for structural support. The servos will receive power from the power supply and a SPI input from the RaspberryPi. This SPI input will tell the servos which position to rotate to, allowing the system to fold the item placed on top.
    - The servos will act in a certain order depending on the instructions that are chosen from the item on the folding table. The SPI input will be delivered when the servos need to act. This makes up our instruction order.
    - The Servos will rotate up to 120 degrees providing the necessary force and guidance duration to allow the clothes to be folded without sending them in strange directions or folding upon themselves.
    - Servos operates at 5 volts at about 20-25 mA when at rest and operates at 100mA when working.

Requirement	Verification
Servos actuate to fold the clothes	- Raspberry Pi Controller sends out signals for servo actuation - Servo’s move to correct angle at correct speed

  - Camera Subsystem
    - The camera will be mounted on a rod pointing down at the mechanism. It will stream video to the RaspberryPi image recognition subsystem.

Requirement	Verification
Camera correctly captures image of the clothing item	- It is far back enough to correctly capture the folding area - Camera correctly captures and sends the image to the Raspberry Pi

- Panel Subsystem
  - Each panel will be mounted to 2 servos and will be constructed of a light-weight plastic-like material.
  - Each panel will have sections removed to allow airflow through. This prevents any major air disruptions which could cause mishaps in the folding process. This also reduces the amount of material needed to produce each panel.

Requirement	Verification
Panels can physically fold the clothes	- Clothes do not sag through panels - Panels have mounting point to connect to servos - Panels are strong enough to support clothing item

- Edge Cases
  - Item not recognized
    - If an item is not recognized as one of the three in our folding categories, the folding light will turn red and blink three times.

Requirement	Verification
If an item is not recognized, folding light will turn red and blink three times	- Image identification sends out error code for unidentified object - Raspberry Pi Controller sends out error code signal - LED lights up

  - No item on the folding table
    - If there is no item on the folding table, the folding light will turn red and blink once.

Requirement	Verification
If there is no item on the folding table, the folding light will turn red and blink once.	- Image identification sends out error code for empty table - Raspberry Pi Controller sends out error code signal - LED lights up

2.3 Supporting Material

In testing our image recognition program, we have achieved a 97.8% successful image detection rate. In a database of 70,000 clothing images, we used 60,000 to train the image recognition algorithm and tested the result on the remaining 10,000 images. This is where we achieved such a high success rate. In the future when our parts are acquired, we are going to test our image recognition program with more real-world examples.

2.4 Tolerance Analysis

The greatest challenge to overcome will be regulating the voltage to each sub-system as they each have a different voltage requirement. To achieve this, our design uses three different linear voltage regulators to achieve stability in the different subsystems.

The main power supply unit will be a 12V AC adaptor that will plug into a standard 120V wall outlet. The adapter provides a maximum of 3A, which provides more than our maximum draw, while having a voltage ripple of less than 200mV. Linear voltage regulators will step down the voltage to 5V for the servos and the Raspberry Pi, and 3.3V for the camera system. The use of linear voltage regulators come with two issues, heat and dropout voltage.

Dropout voltage is the minimum voltage input to get a stated voltage output and is governed by this equation:

$$Vin - Vout > Dropout$$

The maximum voltage regulator dropout voltage is 2 volts giving us the following equations:

$$8V - 5V > 2V$$
$$3V > 2V$$

To avoid thermal issues, the maximum current going out of the regulators must be below a certain number, which is governed by this equation:

$$Iout = (Tj - Ta)/((Vin - Vout)(\Theta jc + \Theta ca))$$

Setting Tj = 150 , Ta = 38 , Θjc = 10, and Θca = 90, the maximum current 373mA at 5V for the servos and 238mA at 3.3V for the camera.

3. Cost and Schedule

3.1 Cost Analysis

Labor Costs

We determined hourly rates by looking at the UIUC success report from 2021-2022, as shown below.

MAJOR	Employed Graduates	Graduates Reporting Salary	Average Salary	25th Percentile	50th Percentile	75th Percentile	Graduates Reporting Signing Bonus	Median Signing Bonus
Aerospace Engineering	41	27	$82,373	$70,000	$80,200	$85,000	14	$3,500
Agricultural & Biological Engineering*	14	10	$69,182	$70,000	$72,500	$75,000	--	--
Bioengineering	28	15	$76,979	$71,000	$75,730	$81,000	8	$5,000
Civil Engineering	54	38	$69,037	$65,000	$69,100	$73,500	19	$3,000
Computer Engineering	135	104	$109,176	$90,000	$110,000	$127,500	78	$15,000
Computer Science	93	70	$129,377	$112,500	$124,000	$142,000	61	$30,000
Electrical Engineering	59	48	$87,769	$76,000	$82,000	$95,000	34	$6,000
Industrial Engineering	37	20	$81,275	$75,000	$77,000	$88,000	17	$5,000
Materials Science and Engineering	26	15	$71,627	$70,000	$72,000	$79,200	9	$5,000
Mechanical Science & Engineering†	105	58	$79,118	$71,417	$79,000	$84,000	35	$5,000
Nuclear, Plasma & Radiological Engineering*	15	14	$76,486	$69,850	$75,000	$75,500	--	--
Physics†	26	12	$84,855	$50,000	$75,100	$121,000	5	$27,775
Systems Engineering & Design	36	20	$84,136	$76,000	$81,009	$92,500	12	$7,250
All Grainger Engineering	653	443	$92,813	$75,000	$83,000	$112,500	297	$8,500

Figure 1. Graduate salaries of students graduating from University of Illinois

The average Computer Engineering new graduate makes $109,000 a year, divide this by (40 hrs/week * 52 weeks/year) to estimate hourly wage to be around $52. The average Electrical Engineering new graduate makes $87,000, leading to $42 per hour.

	Tyler Hirsch	Bryson Maedge	Nolan Opalski	Total
Hourly Rate ($/Hr)	52.00	42.00	42.00	-
Expected Labor (Hrs)	60	60	60	180
Total Cost ($)	3,120	2,520	2,520	8,160

Parts

Part	Part #	Specs	Quantity	Total Cost ($)
Frame (3-D Printed)	N/A	11 x 20 x 0.5 inches	1	$10.00
Panel (3-D Printed)	N/A	10 x 10 x 0.5 inches	6	$30.00
Rod (3-D Printed)	N/A	12 inches long 0.5 inches diameter	1	$3.00
Servo	MG996R B0BYD9M1P3	13.5kg/cm torque 100 mA 5 V	12	$51.00
RaspberryPi	Model B B07TC2BK1X	Quad Core 64-bit SoC @ 1.5 Ghz 5 V , 3A	1	$62.00
Camera	Arducam 5MP Camera B012V1HEP4	1920 x 1080 p 54 x 41 degrees of view 3.3V , 3A	1	$10.00
Micro SD Card	PNY 32GB Elite Class B07R8GVGN9	32 GB RAM 100 MB/s	1	$5.00
PCB	N/A	MADE TO ORDER	1	$5.00
Power Supply	B073WSWT34	12V 3A	1	$10.00
Voltage Regulator	B08JZ5FVLC	Input: 4.5 - 24V Output: 5V , 3A	10	$13.00
Total:				$199.00

Part Links

Servo	https://www.amazon.com/Hosyond-MG996R-Digital-Motors-Helicopter/dp/B0BYD9M1P3
RaspberryPi	https://www.amazon.com/Raspberry-Model-2019-Quad-Bluetooth/dp/B07TC2BK1X
Camera	https://www.amazon.com/Arducam-Megapixels-Sensor-OV5647-Raspberry/dp/B012V1HEP4
Micro SD Card	https://www.amazon.com/PNY-Elite-microSDHC-Memory-P-SDU32GU185GW-GE/dp/B07R8GVGN9?th=1
Power Supply	https://www.amazon.com/Facmogu-Connector-5-5x2-5mm-5-5x2-1mm-Transformer/dp/B073WSWT34?th=1
Voltage Regulator	https://www.amazon.com/Weewooday-Regulator-Voltage-Converter-Transformer/dp/B08JZ5FVLC

Total Cost

Cost Type	Cost Value
Labor	$8,160
Parts	$199
Total	$8,359

3.2 Schedule

Week	Goal	Tyler	Bryson	Nolan
6	Acquire Parts	Servo, MicroSD	Raspberry Pi, Power Supply	Camera
7	3D Print Materials	Design Cad	Locate Printer/Print	Locate Printer/Print
8	Design PCB	Design the PCB	Design the PCB	Logistics/Put in order
9	Program Raspberry Pi	Python Code	Implement	Implement
10	Assemble	Test image recognition software	Physically put down frame/panels	Work on servos and frame
11	Assemble and Test	Test folding sequences	Physically put down frame/panels	Work on servos and frame
12	Practice Demo	Presentation	Presentation	Presentation
13	Final Presentation	Succeed!	Succeed!	Succeed!

4. Ethics and Safety

Due to the nature of our project, many of the ethical concerns listed in the IEEE and ACM Code of Ethics are upheld naturally (for example, the codes on intelligent systems don't apply because we are not implementing that capability.) In the IEEE code of ethics, there are two codes that I find to be extremely important as we progress. These two codes are I.1 and I.5. We want to hold the safety and welfare of the general public paramount while accepting criticism and updating our machine to fulfill the initial focus of helping the user of our machine. In order to fulfill this, we initially designed our project to help people with health conditions or impairments like arthritis, cerebral palsy, and other physically limiting conditions. As we go through the designing and construction phases, we will make sure to keep that in mind and not implement anything that competes with that focus. Finally, we should thoughtfully consider improvements and feedback that are offered to us from the recipients of our project.

In the ACM Code of Ethics, the most unique and relevant ethical concerns that are not previously mentioned in the IEEE's list are the Professional Leadership Principles. These will be paramount as a group to uphold since ultimately this is a learning opportunity. These codes of ethics pertain to allowing each member of the group to be able to contribute and best learn from this project. In order to ensure these are followed, a policy of open and considerate communication between group partners will be adopted. This will allow us to voice concerns while also considering one another's interests and overall experience throughout the project.

For the safety concerns, our project does not fulfill any of the special concerns listed on the website. We will not be using any batteries, large voltages, and no currents will be going through human subjects. Every member of the group has completed the Lab Safety Guidelines training and will strictly adhere to the rules and overall ethos of safety first. Our system will be designed in a way that no bodily harm could result from its regular use.

Citations and References

ACM. “”ACM Code of Ethics and Professional Conduct”.” (2018), [Online]. Available: https://www.acm.org/code-of-ethics (visited on 2/5/2024).

ADA. “”Laundromat tips for People with Disabilities”.”(2020),[Online]. Available: https://thedutchmanslaundry.com/laundromat-tips-for-people-with-disabilities/#:~:text=Folding%20and%20sorting%20clothes%20may,a%20more%20inclusive%20laundromat%20environment.

dfrobot. “”DSS-P05 Standard Servo”.” (2024), [Online]. Available: https://www.dfrobot.com/product-236.html (visited on 2/6/2024).

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