Automatic Cloth Folding Machine

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Contents

1. Introduction

1.1 Objective

For many people, the worst part of doing laundry is having to fold all the clothes once they come out of the dryer. This activity is not only tedious and time-consuming, but also requires some efforts to fold all the clothes in the same size. As a result, some people just dump their laundry into drawers without organizing them. This often leaves a mess in the closet and gives trouble for people when they are finding their clothes.

In order to cope with the problems stated above, we propose a low cost folding machine that could automatically fold the clothes when a piece of laundry is placed on the machine. This machine is easy to use and requires little human involvement, which is significantly useful for people who do not have time or not willing to organize their clothes. The machine is able to detect the clothes automatically and fold them in a neat way. For safety reasons, the folding procedure will only initiate after users leave their hands from the machine.

1.2 Background

Washers and dryers have become so commonplace that people do not think of them as a new concept. Since Hamilton Smith patented the rotary washing machine in 1858, our ways to deal with laundry have not changed for almost 160 years [1]. We get used to the process that put our dirty laundry into the washer and dryer, but it is the final step that folding the laundry troubles us the most. A recent Kickstarter campaign ThreadStax that helps people to fold, stack and dispense their clothes manually, raised a total of $ 181,058 out of a $50,000 goal, and this shows how troublesome for people to organize their clothes [2].

As many can imagine, folding clothes is tedious for human, but it is even harder for machines. However, it is not impossible to achieve such a task through machines. Hotels, hospitals and many factories have machines that can fold large amount of towels, sheets, and other fabrics. These machines are typically huge in terms of size, and requires large amount of power to operate [3]. For household laundry, the only available machine in the market is called Foldimate, but it costs from $700 to $850 and has not started the pre-orders yet [4]. Our design is at much more affordable, while achieving the similar function in a smaller environment and lower power consumption.

1.3 High-level Requirements List

- The user interface correctly indicates each operating state through LEDs.
- Servo motors must have a torque of $5.63kg \cdot cm$ to flip the board 180° in 2 seconds, and must have feedback mechanism for control circuit to initiate reverse flipping process.
- For safety reasons, folding procedure only starts with no obstacles on board.

2. Design

The overall design requires five modules: power supply, control unit, sensing unit, user interface and mechanical components.

2.1 Block Diagram

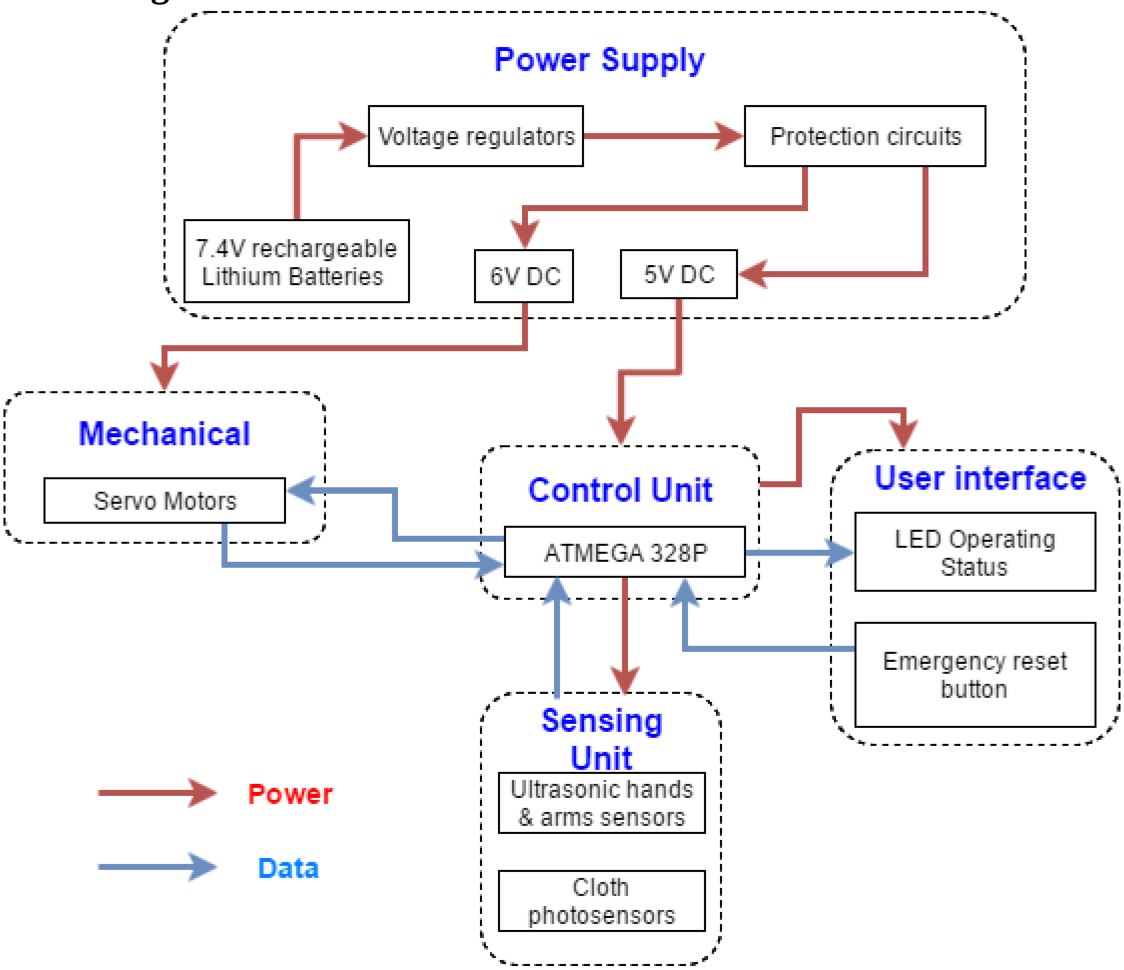

Figure 1. Block Diagram

2.2 Physical Design

Our physical design will be based on existing folding board on the market. We will have the machine shop split the board into boards A, B, C and D and make three custom hinges with extended rod between the boards. These rods will be attached to the rotation axis of the servos. When the servos rotate, they also rotate the rods and therefore flip the boards. Two photosensors denoted as PS1 and PS2 will be mounted on board A and D to detect presence of clothes. Three ultrasonic sensors will be attached on the left edge of board B to detect any obstacles like hands and fingers. Below is an illustration of our physical design:

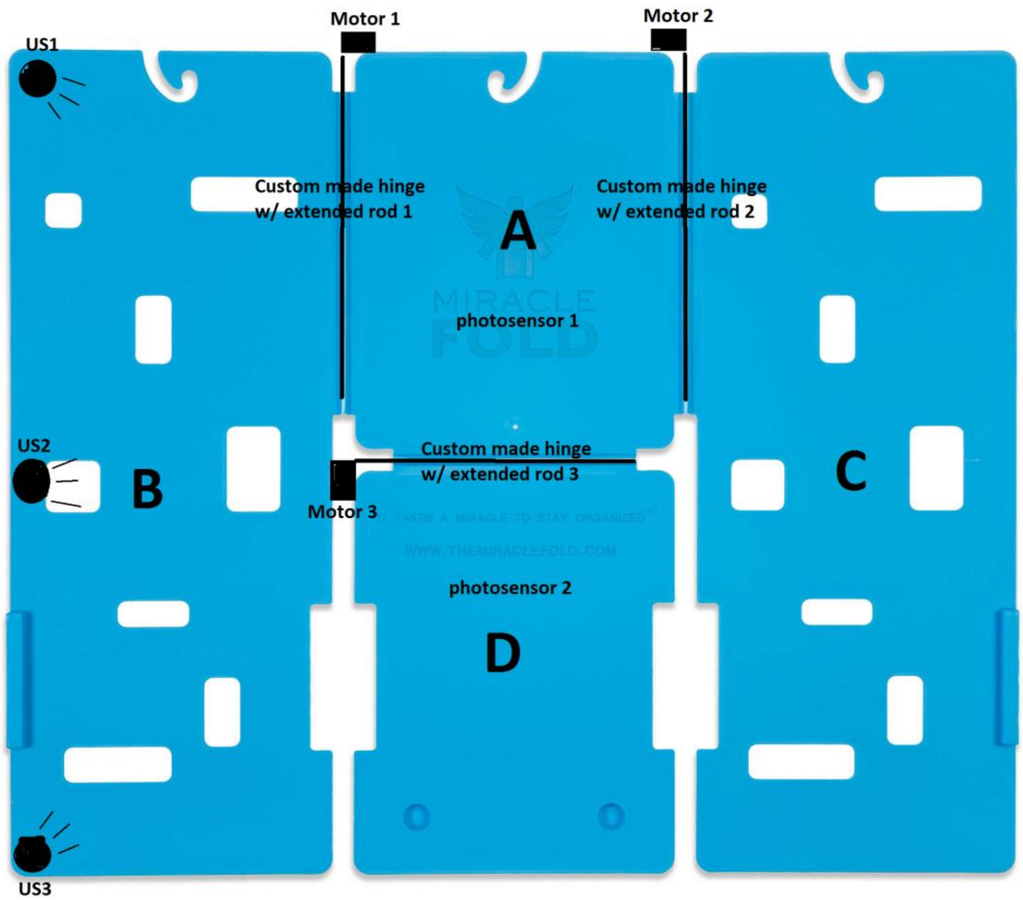

Figure 2. Physical Design of Flip Board

2.3 Block Design

2.3.1 Power Supply

This project will be powered by existing 7.4V DC rechargeable Lithium battery on the market. Output from the lithium battery will go through our custom made protection and regulator circuit before passing into the control unit, sensing unit, mechanical unit, and user interface.

(1) Protection Circuit:

We are going to use the chip LTC4365 [5] to be our battery circuit protection chip. The chip prevents the battery from over discharge by disconnecting the circuit. When the battery provides a voltage less than 4.7V, it will disconnect the supply voltage source and therefore prevent the motor from burning.

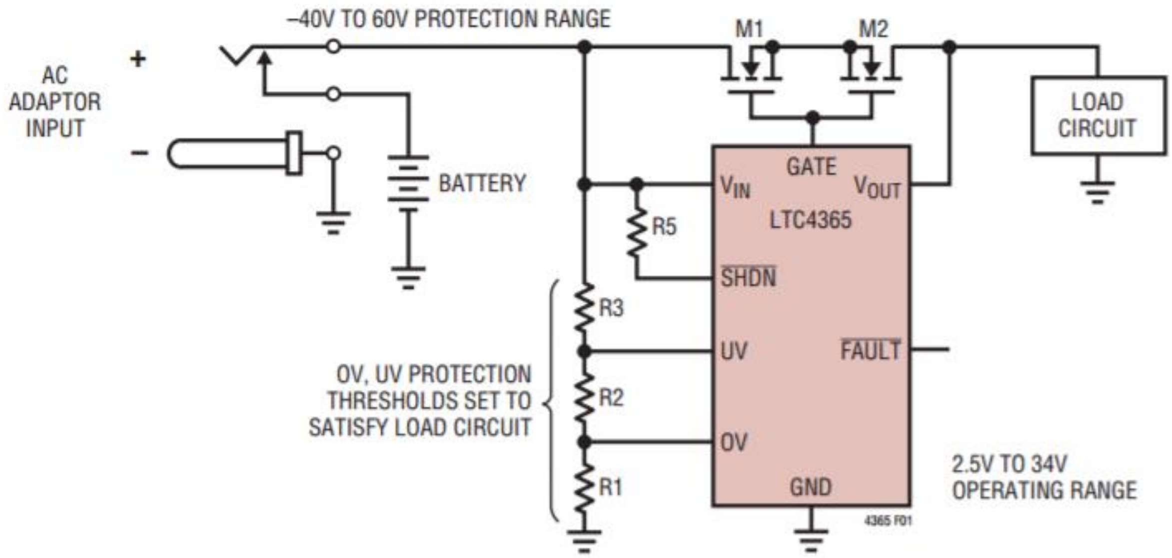

Figure 3: Protection Circuit Diagram [5]

$$R_3 = \frac{V_{OS(UV)}}{I_{UV}} * \frac{UV_{TH} - 0.5V}{0.5V} \quad [5]$$

$$R_1 = \frac{(V_{OS(UV)}/I_{UV}) + R_3}{OV_{TH}} * 0.5 \quad [5]$$

$$R_2 = \frac{V_{OS(UV)}}{I_{UV}} - R_1 \quad [5]$$

According to the above equation, $V_{OS(UV)}$ is the undervoltage offset voltage, which we choose to be 0.3mV. UV_{TH} is the undervoltage threshold voltage, which we choose to be 4.7V. OV_{TH} is the overvoltage threshold voltage, which we choose to be 18V. The value of I_{UV} is typically 10nA and the value of R5 is typically 510Ω from the datasheet [5].

Therefore, we can calculate that R3 = 252kΩ, R2 = 22.167kΩ, R1 = 7.833kΩ.

Requirements	Verifications
1. The protection circuit should turn off the circuit below 4.7V in order to protect the circuit from burning out.	1 (a) Connect the input of the protection circuit to a function generator and then sweep the input voltage from 8V to 0V. (b) Connect the output of the protection circuit to

	the multimeter or oscilloscope to confirm output voltage is near 0V when the input voltage drops below 4.7 V.

(2) Regulator:

We will use the IC chip LMZ21701[6] to build our low-dropout voltage regulator. Our goal is to regulate the output voltage to be 5V and 6V when input voltage is 7.4V. The output voltage can be adjusted by changing the value of R_{FBT}. The input voltage range is from 3 to 17V and the output voltage range is from 0.9 to 6V [6].

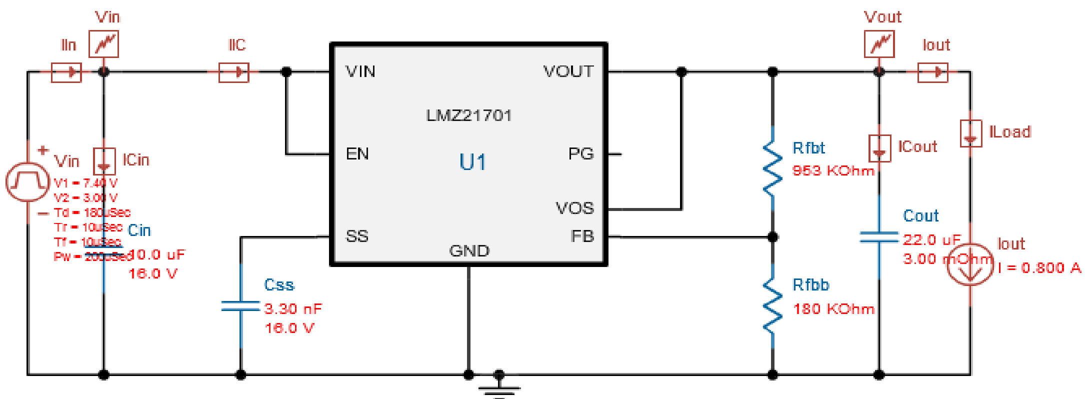

Figure 4: Low-dropout Voltage Regulator for 5V Circuit Diagram

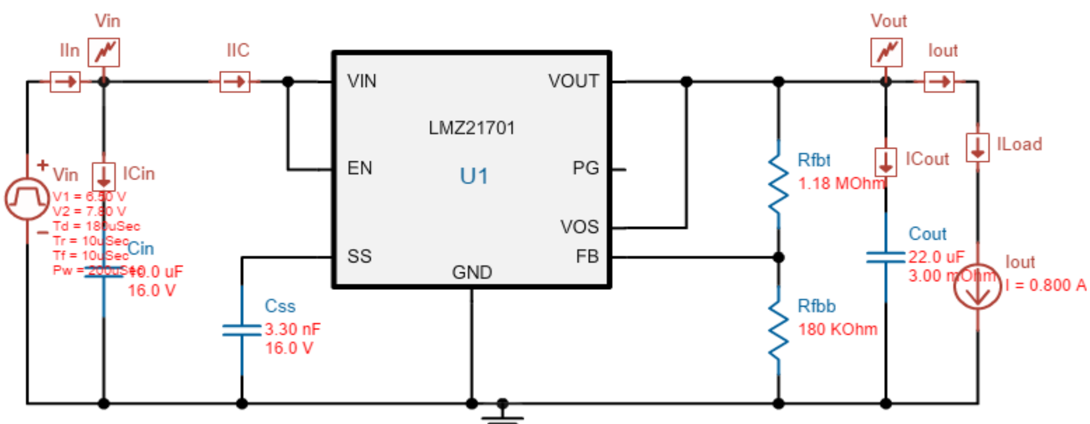

Figure 5: Low-dropout Voltage Regulator for 6V Circuit Diagram

Calculation:

We choose the input capacitor to be greater than 10µF and the output capacitor to be in the range between 10µF to 200µF from the datasheet [6].

We choose the feedback resistor R_{FBB} to be 180kΩ.

$$R_{FBT} = R_{FBB} \times (\frac{V_{OUT}}{0.8} - 1) \text{ [6]}$$

According to the equation above, we can calculate that the R_{FBT} for 5V voltage regulator should be 945 kΩ. and R_{FBT} for 6V voltage regulator should be 1.17MΩ.

Requirements	Verifications
1. The output voltage for LDO should be within ±0.2V of the assigned value.	1 (a) Connect the input of the voltage regulator to a power supply and then sweep the input voltage from 0 to 7V. (b) Connect the outputs of the voltage regulators to a multimeter or oscilloscope to see whether the output voltage is 5V ± 0.2V or 6V ± 0.2V for two regulators.

Simulation

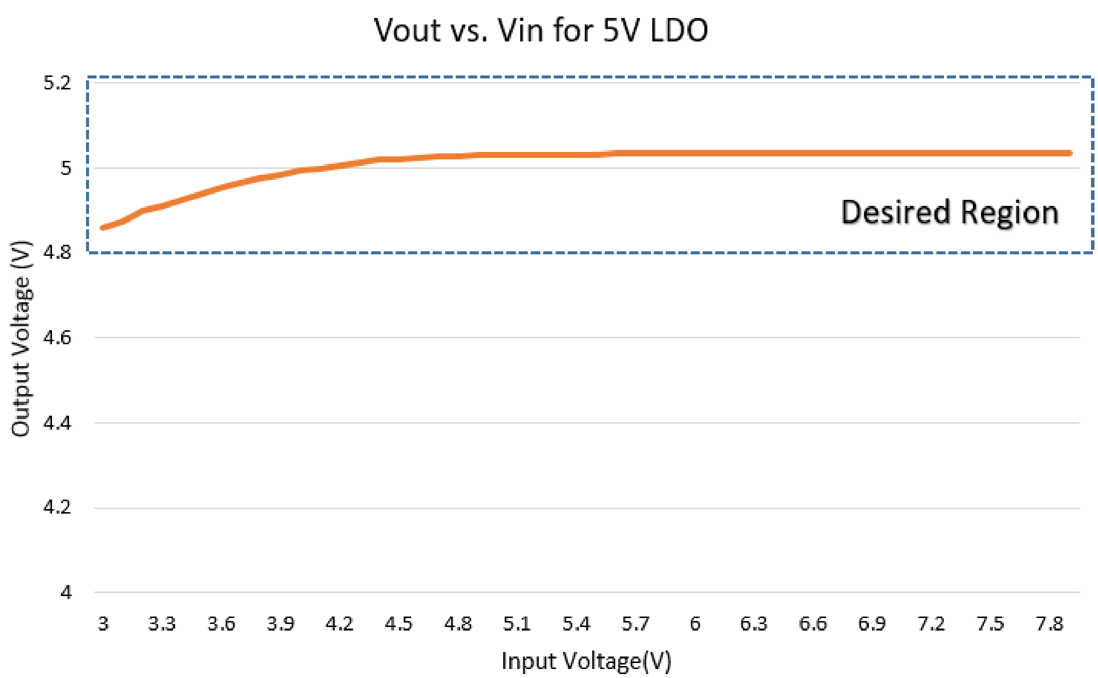

Figure 6: The simulation plot of 5V voltage regulator

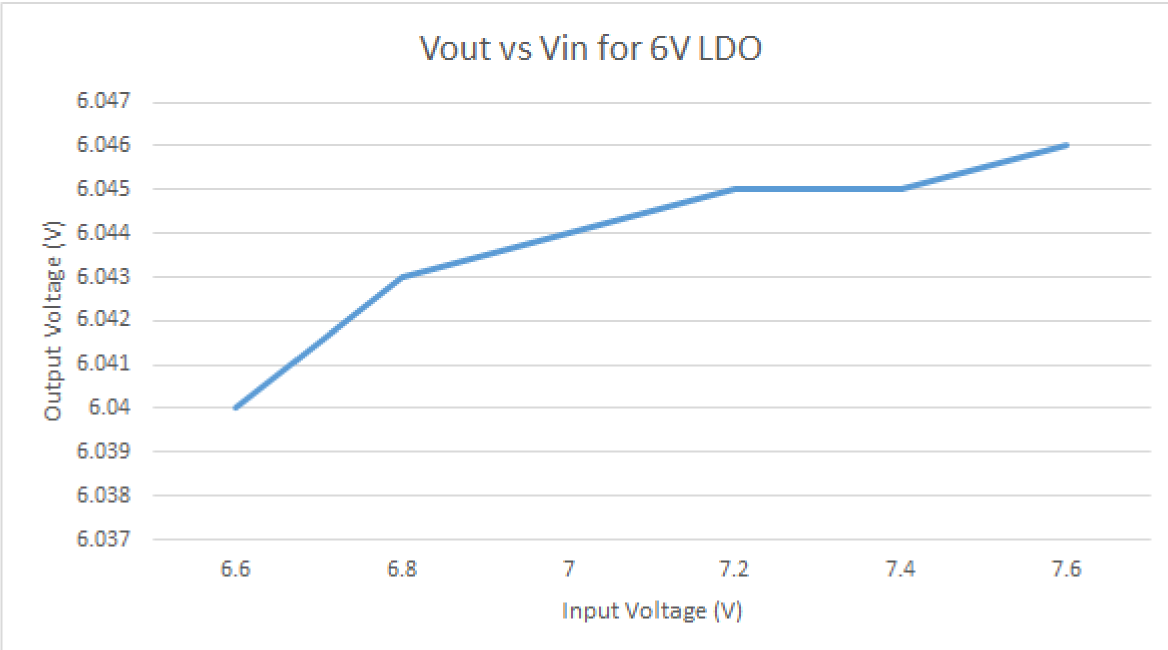

Figure 7: The simulation plot of 6V voltage regulator

2.3.2 Control Unit

The core of the project is the control unit which consists of a programmable microcontroller, ATMEGA328P. It processes data from all components and send commands accordingly for proper operation. The entire operation procedure will be developed in C programming language. The prototyping will be done with ATMEGA 328P mounted on an Arduino Uno development board. Once the prototyping is finished, we will design our own PCB board to mount ATMEGA 328P microcontroller chip and solder other components onto it.
Comparing the other programmable microcontrollers, ATMEGA328P is the best component choice to integrate the whole project for several reasons:

1) The integration of digital and analog I/Os.

Many programmable microcontrollers have smaller size and less power consumption, but only has digital I/Os. Our design requires PWM signal to control servo motors, digital I/O to receive signal from ultrasonic sensors, and analog I/O to read servo feedback and voltages from photosensors.

2) Compatibility

ATMEGA328P is compatible with our other design components. For example, it is able to decode the analog signal from the servo motors as well as the pulse width signal from ultrasonic sensors. Other microcontrollers may not have the corresponding decoder, and building one by ourselves is not optimized for the best functionality.

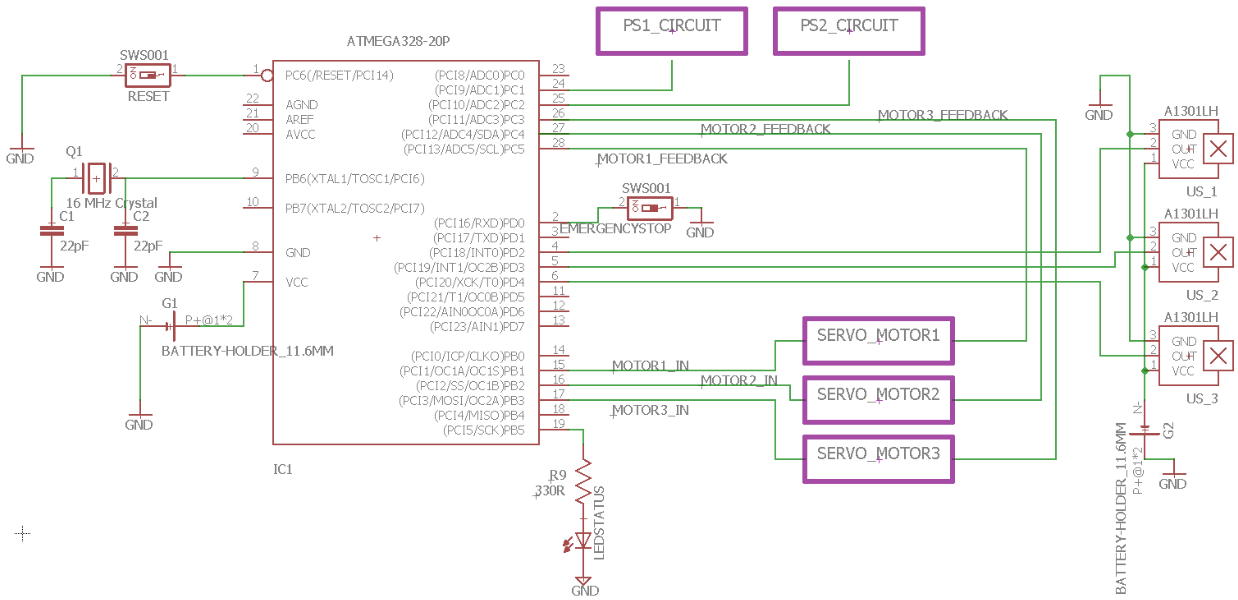

Figure 8: Control Unit Schematic

Operation:

The machine begins at idle state, which means the sensing unit is waiting for clothes while the mechanical unit is in standby. When a piece of laundry is placed on board and the photosensors are covered, microcontroller starts to check if the folding procedure is safe to begin. Three ultrasonic sensors on the left edge of board B (Figure 2) detects any human hands and arms. As long as there is no obstacle on the board, the folding procedure begins.

The microcontroller sends a PWM (pulse width modulation) signal to the servo motor 1 (as indicated in Figure 2) to command a 180° clockwise rotation and flip board B forward. During the rotation, the position post integrated in the servo motor produces a real-time analog feedback signal about rotation angle. As soon as the microcontroller detects that the targeted angle of rotation (180°) is achieved, it sends another PWM signal to make the servo motor rotate counter-clockwise for another 180° and therefore flip board B backward. When the board B returns to its original position, the folding of board B is complete, and board C is ready to flip. The operation for board C and D is the same as board B, but the folding procedure follows the flipping order of B-C-B-D. The reason we need to flip board B twice is that for long sleeve shirts, the sleeve is going to be folded on board B again after the flipping of board C. Therefore, by flipping board B twice, our design is able to handle wide range of clothes.

Requirements	Verifications
1. Able to send PWM signal to the servo motor to spin both clockwise and counterclockwise for 180°.	1. (a) connect power and ground of the motor to a 6V voltage source. (b) connect the signal wire to a digital pin on Arduino. (c) send a servo motor command for rotating 180° forward. (d) use a protractor to measure the angle, and check if the rotation is 180°. (e) repeat the process for spin backward.
2. Able to interpret analog position and obstruction feedbacks from servo motors.	2. (a) Open up Arduino IDE's serial monitor. (b) Send servo motor a command of 180° forward rotations. (c) Use hands and arms to stop the movement of the board when reach 90 degrees. Read from serial monitor to confirm it indicates 90° ±5° and "obstructed".
3. Able to interpret digital data from the ultrasonic sensors.	3. (a) Open up Arduino IDE's serial monitor. (b) Put hands and arms within board area then read from serial monitor to confirm it says "with hands". (c) Put hands and arms outside the board area then read from serial monitor to confirm it says "no hands". (d) Repeat process for at least 6 locations in the board area.
4. Able to interpret data signals from the photosensors.	4. (a) Open up Arduino IDE's serial monitor. (b) Place a piece of cloth covering the PS1 and PS2 sensors and read from the serial monitor to confirm it says "with cloth". (c) Remove the cloth and read from the serial monitor to confirm it says "no cloth".

The operation flowchart is shown on next page as figure 9.

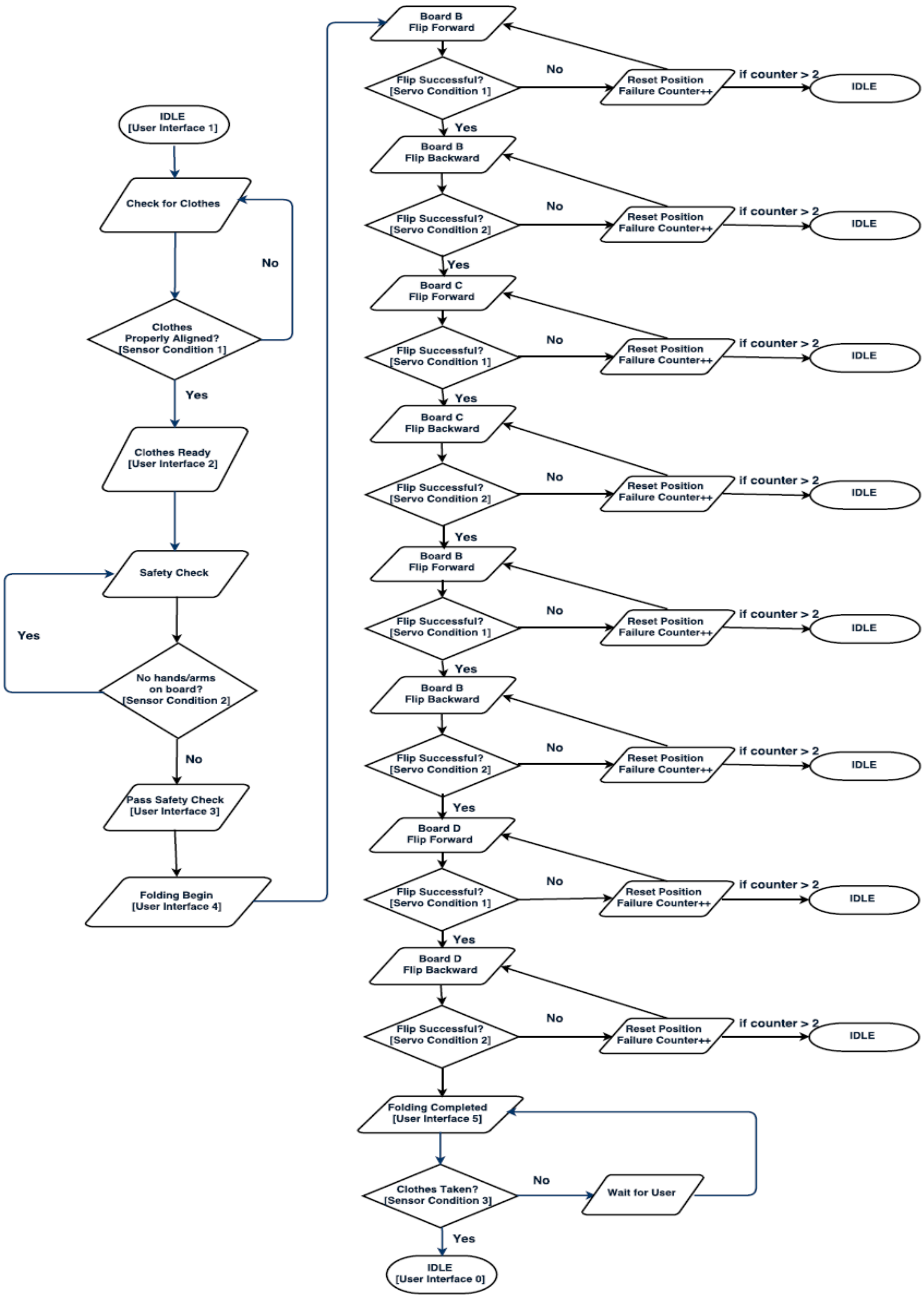

Figure 9: Operation flowchart

States	Name	PS1	PS2	US1	US2	US3
Sensor Condition 1	Cloth Presence	1	1	X	X	X
Sensor Condition 2	No Hands	1	1	0	0	0
Sensor Condition 3	Cloth Taken	0	0	X	X	X

Table 1: Sensors condition for Figure 9 flowchart

States	Direction	Target	Success if Achieve	Fail if not achieve in
Servo Condition 1	Flip Forward	180°	170°-180°	1 second
Servo Condition 2	Flip Backward	0°	0°-10°	1 second

Table 2: Servo condition for Figure 9 flowchart

2.3.3 Sensing Unit

This unit consists of three ultrasonic sensors with detection range of 70 cm for hands and arms detection, and two photosensors mounted on board A and D for cloth detection.

(1) Photosensors

Working principle of the photosensors is very easy. Without any cloth covering the photosensors, they produce relatively higher voltage values back to the Arduino analog input pins. When they are covered, the cloth will block out most of the light previously received by the photosensors. Then photosensors can produce relatively much lower voltage values back to the microcontroller analog input pins. In the Arduino software program, we have an initial voltage, a final voltage and a threshold voltage. The initial voltage represents the ambient light condition without any clothes; the final voltage is the light condition after the photosensors are covered by the clothes; and threshold voltage determines whether the change in voltages at photosensors is caused by presence of clothes. For example, if final voltage minus initial voltage is greater than threshold voltage, the program will output “with cloth”. Otherwise, the program outputs “without cloth”. By designing this way, we minimize the possibility of false detection for photosensors in dark environment. The threshold value will be determined by extensive testing with different colors, materials of cloth and different ambient lighting conditions. We will find a balanced threshold value that can accommodate as many circumstances as possible.

Requirements	Verifications
1. Must be able to drop output voltage from 4.3V to 2V when the sensor is covered. 2. Consumes less than 1W of power.	1. (a) Connect the outputs of photosensors to a multimeter. (b) Put cloth on board covering PS1 and PS2, read from the multimeter to confirm a low voltage reading. (c) Remove cloth from the board, read from the multimeter to confirm a higher voltage reading than in (b). 2. (a) connect the sensor to a multimeter to measure the current. (b) calculate the power consumption to see if it meets 1W requirement.

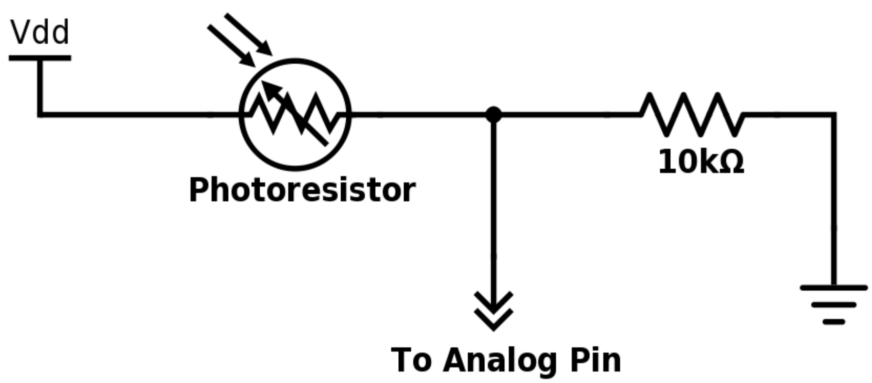

Figure 10: Photosensor Schematic

The test circuit is built on a breadboard, and we have a following relationship between photosensor output voltage and illuminance. The illuminance is measured using a lux meter, while voltage is measured by digital multimeter. When the photoresistor is completely covered, illuminance is 7 and output voltage is 0.625V. In bright lab environment, illuminance is 276 and the sensor produces a voltage of 4.37V.

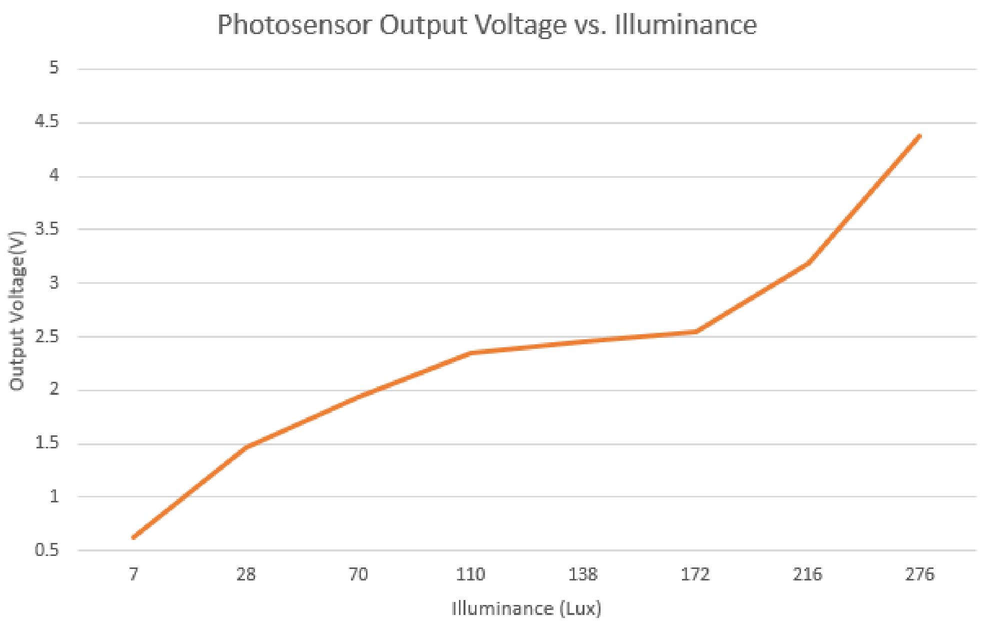

Figure 11: Photosensor and Illuminance Relationship

(2) Ultrasonic Sensor

The three HC-SR04 ultrasonic sensors (US1, US2 and US3) mounted on the left edge of board B are responsible for detecting human hands and arms. They have detection range of 2 cm - 4m and can return a distance value back to microcontroller digital input pins. The working mechanism of the ultrasonic sensor can be better explained with the timing diagram from its datasheet [7]:

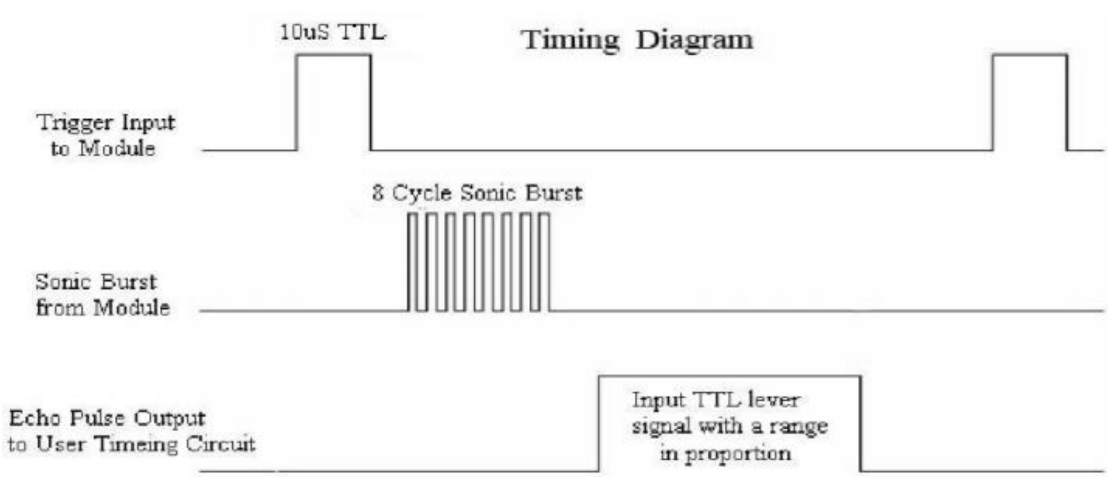

Figure 12. Timing diagram of HC-SR04 ultrasonic sensor [7]

The microcontroller sends a pulse to the trigger input to initiate detection. Upon receiving this pulse, the sensor outputs 8 cycle of sonic burst at 40 KHz. After the sonic burst is finished, the echo pin of the sensor goes high and remain high until the sonic burst hits an object and that object reflects the sonic burst back to echo pin. Based on how long the echo remained high, the distance can be calculated.

In the software design, we will program the maximum detection range of each ultrasonic sensor. These distances must be large enough to cover the entire board area (68.6cm×59.7cm) and yet small enough to be free of interference from irrelevant objects. These distances will be obtained experimentally.

Requirements	Verifications
1. Must be able to detect object distance from 5cm to 70cm away.	1. (a) Connect the Arduino to computer via USB cable, open up Arduino IDE's serial monitor. (b) Put hands and arms 5cm away from the sensor, read from the serial monitor to confirm that the sensor outputs an actual distance between itself and the object. (c) Repeat the process until 70cm with 5cm step each time.
2. Consumes less than 1mW of power.	2. (a) connect the sensor to a multimeter to measure the current. (b) calculate the power consumption to see if it meets 1mW requirement.

2.3.4 User Interface

(1) LED User Interface

The LED status circuit will indicate the current mode of operation as shown in the table below:

State Number	Status	LED Output
User Interface 1	IDLE	White
User Interface 2	Clothes Ready	Yellow
User Interface 3	Pass Safety Check	Green
User Interface 4	Folding	Red
User Interface 5	Folding Completed	Blue

Table 3: User Interface Status

Requirements	Verifications
1. The current goes through our RGB LED should be lower than 70 mA to be power efficient.	1. (a) connect a single LED to 5V supply and in series with a 1kΩ resistor. (b) use multimeter to measure the current through LED. (c) check if current is less than 70mA.

(2) Emergency reset button

This emergency reset button will be placed at an obvious, easy to find location on the board for user to manually stop and reset the operation in case of emergency. When this button is pressed, the motor will stop at its current location, and then reset their position as in idle state.

Requirements	Verifications
1. Debounced when outputs digital signal.	1. (a) Connect the output of the button to oscilloscope. (b) Press the button. (c) Verify the waveform to see if there is only a single transition (from low to high, or high to low).

2.3.5 Mechanical

The mechanical components are three servo motors. These servo motors can flip the board upon receiving a signal from microcontroller and can also produce analog position and obstruction feedback to microcontroller.

(1) Servo Motor

Requirements	Verifications
1. Able to produce a torque of 5.38 kg·cm minimum at supply voltage of 6V.	1. (a) Connect the signal pin of servo motor to Arduino. (b) Connect the power of servo motor to a 6V supply. (c) Attach a lever to the rotation axis of the motor.

	(d) Attach a spring scale to the lever. (e) Send a command to rotate the servo motor forward for 180° in one step. (f) Read the force on the spring scale. (g) Calculate torque to see if it is greater than 5 kg·cm.
2. Able to rotate both clockwise and counterclockwise faster than 0.5s/60°.	2. (a) Connect the signal pin of servo motor to Arduino. (b) Connect the power of servo motor to a 6V supply. (c) Send a command to rotate the servo motor forward for 180°. (d) Start timer as soon as the servo starts to rotate. (e) Stop timer as soon as the servo stops. (f) Check if the speed meets requirement. (g) Repeat for backward rotation.
3. Able to achieve a degree of rotation within 5% of assigned value.	3. (a) Connect the signal pin of servo motor to Arduino. (b) Connect the power of servo motor to a 6V supply. (c) Send a command to rotate the servo motor forward for 30°. (d) Use a protractor to measure the degree of rotation (e) Repeat the measurement for 60°, 90°, 120°, 150°, and 180°.
4. Consumes less than 15W of power.	4. (a) connect the sensor to a multimeter to measure the current. (b) calculate the power consumption to see if it meets 15W requirement.

Torque Calculation

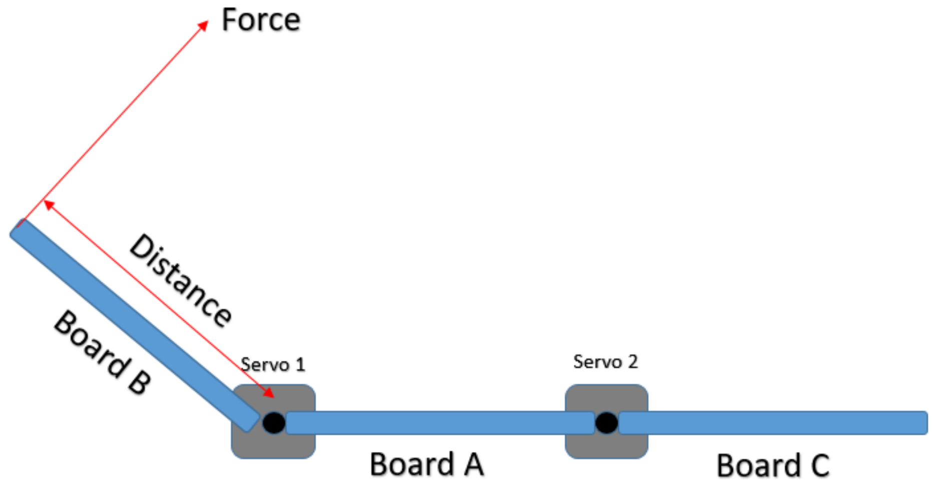

Figure 13. Torque calculation diagram

Bare Board B or C:

$$\tau = F \times d = 2.4N \times 22cm = 52.8N \cdot cm = 5.38kg \cdot cm$$

Board B or C with T-shirt:

$$\tau = F \times d = 2.51\text{N} \times 22\text{cm} = 55.22N \cdot cm = 5.63kg \cdot cm$$

Board D with T-shirt:

$$\tau = F \times d = 1.83\text{N} \times 27.9\text{cm} = 51.07\text{N} \cdot \text{cm} = 5.21\text{kg} \cdot \text{cm}$$

2.4 Tolerance Analysis

One of the most critical task we face in this project is to achieve position and/or obstruction feedback from the servo motor back to the microcontroller. There is only one servo motor on the market that has an analog feedback wire yet this servo motor nearly meets our torque requirement. The advertised torque of the feedback servo motor is 6.8 kg · cm, and our torque requirement for flipping the board alone is 5.38 kg · cm. After redesigning the hinge from ECE machine shop and additional cloth and circuitry on the board, the torque could be insufficient to flip the board.

Since normal servo motor has built-in position potentiometer inside the housing, it is a close loop system itself, but an open loop system with respect to microcontroller. In order to close this feedback loop we propose three possible solutions if the feedback servo motor does not have enough torque:

(1) Open a high torque servo motor housing, find the position potentiometer pin, solder an additional analog feedback wire onto that pin and route this wire back to microcontroller analog input pin. Then design the code in microcontroller that utilizes this analog signal to achieve position and obstruction feedback.
(2) Install two additional ultrasonic sensors on board B and C to detect the distance between their respective board to the other board it will flip onto. If this distance is less than a 4 cm, the microcontroller can deem as complete folding and therefore reverse folding can be initiated.
(3) Utilize gyro sensor or axis accelerometer to detect rotational motion of the board.

The worst case scenario is that we cannot provide this position and obstruction feedback to microcontroller. In this situation, the operation of the motor is based on time sequence instead of feedback. For example, we give a set amount of time for the motor to operate. When this time runs out, the next step of flipping will begin regardless the results of previous step. In addition, a time constraint is implemented on the motor so it will not keep attempting to get to target degree when unable to rotate any further therefore preventing overheat and breakdown.

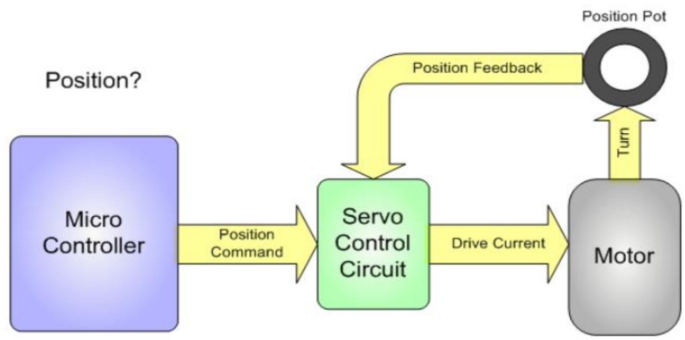

Figure 14: Normal Servo Motor[8]

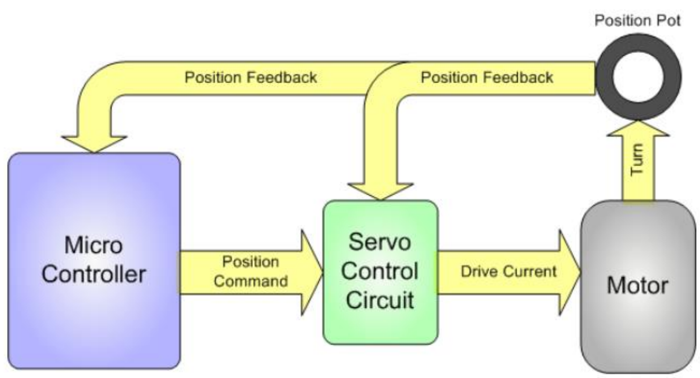

Figure 15: Feedback Servo Motor[8]

3. Prototyping Cost and Schedule

3.1 Labor

Assume labor cost is $35/hour per engineer. There are 3 engineers working on this project in total. Each of us work 16 hours per week for 7 weeks. Therefore, the total labor cost is

$$Labor\ Cost\ =\ \$35/hr\ \times 3\ engineers \times 16\ hrs \times 7\ weeks = \$11760$$

3.2 Parts

Below is a table of parts we will need for prototyping, not the final design parts.

Vendor	Item	Unit price	Quantity	Total
Arduino	Uno development board with ATMEGA 328P	$16	1	$16
Amtel	ATMEGA 328P	4.46	3	$13.38
ElecRight	Ultrasonic Sensor	$2	5	$10
D8	Photo Sensor	$0.4	8	$3.2
TowerPro	MG958 Servo	$11.5	4	$46
Miracle	Folding board	$27	1	$27
TowerPro	MG995 Servo	$7	2	$14
TI	LMZ21701 regulator	$0.44	8	$3.52
TI	BQ2970 Protection	$0.6	8	$4.8
Adafruit	Analog feedback servo	$14	1	$14
ECE Machine shop	Labor hours	N/A	3	N/A

EBL	Lithium batteries and charger	$14	1	$14
Parts Total				$165.9

Table 4: Component Cost

$$Grand\ Total = \$165.9 + \$11760 = \$11925.9$$

3.3 Schedule

Week of	Xudong	Anran	Suicheng
02/27/2017	Prepare for design review. Test out voltage regulator and protection circuit with actual IC chips.	Prepare for design review. Finish attempting servo motor feedback solution 1.	Prepare for design review. Test out voltage regulator and protection circuit with actual IC chips.
03/06/2017	Finish mounting motors onto folding board after retrieving it from machine shop. Help with servo motor analog feedbacks software programming.	Finish servo motor analog feedbacks software programming.	Design and order PCBs for regulator and protection circuits.
03/13/2017	Start writing software program for photosensors.	Start mounting sensors to their respective locations on the board for testing.	Start writing software program for ultrasonic sensors.
03/20/2017	Finish integrating sensors routine written by each teammate. Finish user interface program logic.	Finish integrating sensors routine written by each teammate.	Finish integrating sensors routine written by each teammate. Finish user interface program logic.
03/27/2017	Finish the entire	Finish the entire	Finish the entire

	operation logic according to our flowchart.	operation logic according to our flowchart.	operation logic according to our flowchart.
04/03/2017	Design and order PCBs for control unit.	Prepare assembly plan for next week's use.	Design and order PCBs for sensors and user interface.
04/10/2017	Assemble the entire project.	Assemble the entire project.	Assemble the entire project.
04/17/2017	Testing and refinement.	Testing and refinement.	Testing and refinement.
04/24/2017	Prepare for demo.	Prepare for demo.	Prepare for demo.
05/01/2017	Finish writing final report and class checkout	Finish writing final report and class checkout	Finish writing final report and class checkout

4. Ethics and Safety

We will use 7.4V rechargeable lithium batteries. In order to protect the circuit, we will design a protection circuit that prevents battery overcharge and overdischarge, a voltage regulator that provides multiple voltage values and maximum current limiting feature.

What's more, it is possible that the users don't have enough time to remove their hands after placing the cloth on the cloth folding machine. The folding machine may hit the user's hands, which leads to hand injury. In order to solve this problem, we will put three ultrasonic sensors on the left side of the board B. The sensors will detect human hands and arms to ensure the folding process will only start when no hands and arms are detected. Furthermore, we will also add some LED lights or sound beeps to warn the user before the folding procedure starts.
After the folding process has started, if the folding board is obstructed by user's hands, for example, before reaching at least 170 degrees, our analog position and obstruction feedback ensures that our folding board will pause its operation for 1 seconds, attempt two additional time before returning to idle state. The pause when obstructed gives user time to remove his or her hands from the board area.

In our project, we will strictly obey the principle of IEEE Code of Ethics #1 and #9: "to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment", "to avoid injuring others, their property, reputation, or employment by false or malicious action" [9]. In our project, there are two safety problems: the power supply safety problem and user hands removing problem. To cope with these problem, we design the voltage regulator and use ultrasonic sensors to avoid the potential endanger to the public as well as the injury to the user. According to the IEEE Code of Ethics #8 "to treat fairly all persons and to not engage in acts of discrimination based on race, religion, gender, disability, age, national origin, sexual orientation, gender identity, or gender expression" [9], we will treat each member equally and help each other without any discrimination on race and gender.

5. Citations

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