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SENIOR DESIGN PROJECT

Smart Laundry FoldBot

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Contents

1	Introduction	1
1.1	Problem	2
1.2	Solution	2
1.3	High-Level Requirements	3
2	Design	4
2.1	System Overview with Block Diagram	5
2.2	Subsystem Overview	7
2.2.1	Subsystem 1: Grabbing System	7
2.2.2	Subsystem 2: Folding System	9
2.2.3	Subsystem 3: Computer Vision System	10
2.2.4	Subsystem 4: Control System	11
2.3	Subsystem Requirements	13
2.3.1	Requirements for the Grabbing System	13
2.3.2	Requirements for the Folding System	13
2.4	Tolerance Analysis	15
2.4.1	Grabbing System Tolerance Analysis	15
2.4.2	Computer Vision Tolerance Analysis	16
2.5	Requirements and Verification	18
2.5.1	Grabbing System	18
2.5.2	Folding System	19
3	Cost and Schedule	20
3.1	Cost	21
3.2	Schedule	22
4	Ethics and Safety	25
4.1	Ethics	26
4.2	Safety	26
4.2.1	Electrical Safety	26
4.2.2	Mechanical Safety	27
4.2.3	Laboratory Safety	27
5	Appendix	28
5.1	Inverse Calculation for Robot Arm	29

Chapter 1

Introduction

1.1 Problem

The automation of clothes folding in industrial settings presents significant challenges and opportunities for innovation. Presently, large-scale users such as dry cleaning facilities, clothing recycling centers, major retail outlets, and hotels face stringent demands for rapidly and efficiently folding a diverse array of garments. This task is predominantly performed manually, which is not only costly but also lacks efficiency.

Although there are a few products available in the market, they are limited to simple folding tasks and require garments to be perfectly flat and precisely positioned on a specific area of the workbench. This still necessitates considerable human intervention and fails to meet the needs of industrial-scale operations. Consequently, there is a notable absence of solutions that fully automate the entire garment sorting and folding process.

1.2 Solution

To tackle the challenges outlined, we have developed a new industrial-grade automatic clothes-folding robot. This robot seamlessly integrates into existing production lines, allowing users to input various types of disordered clothing directly.

Equipped with a mechanical gripper and a vision module, the robot accurately sorts and positions garments onto a folding board that is compatible with most clothing types. The garments are quickly folded and dispatched either to a conveyor belt or storage unit, depending on user needs. This solution boosts production efficiency, reduces labor costs, and accelerates processing speeds in the garment cleaning and recycling industries.

Figure 1.1 shows a brief figure depicting our system for visual aid.

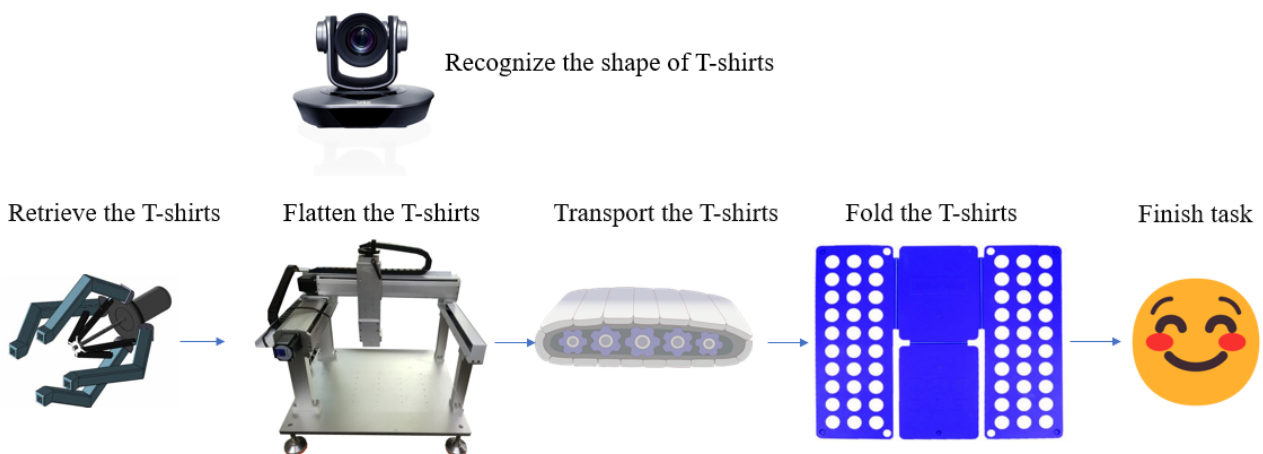


Figure 1.1: Clothes folding robot workflow chart

1.3 High-Level Requirements

1. Visual Model Technology:

- **Requirement 1:** For segmentation tasks, our machine vision model should clearly identify several pieces of clothing within the field of view with an accuracy rate of more than 90% and successfully segment them. Figure 1.2 shows the basic situation we deal with in the vision model, 90% Segmentation accuracy means the Green Blocks in Figure 1.2 should have less than 10% false result.
- **Requirement 2:** For the coordinate guidance tasks mandated by the control system, the machine vision model should accurately provide the coordinate positions of the T-shirt collar and cuffs with no less than 95% accuracy, enabling effective operation of the control system. Figure 1.2 shows the basic situation we deal with in the vision model, 95% accuracy means less than 5% false results for red dots. The Blue line between the red dots should be the position Robot Arm should grab.

2. Control System for Grabbing and Transport:

- **Requirement 3:** In terms of the long-term operational quality of the system, our objective is to utilize reinforcement learning in conjunction with traditional PID control for the robotic arm system. The aim is to minimize the error of the final robotic arm grasping position relative to the specific coordinates provided by the visual model to less than ± 3 mm.
- **Requirement 4:** Regarding the position of the clothes after being transported to the folding plate, the final center of the clothes cannot deviate from the central axis of the folding plate by ± 3 mm. Figure 1.3 illustrates the bias requirement of clothes position.

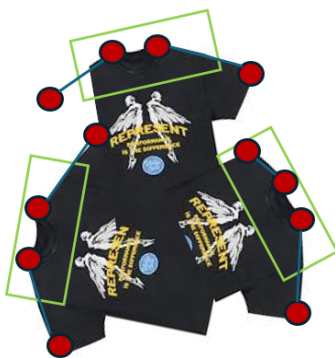


Figure 1.2: Vision Mission Illustration

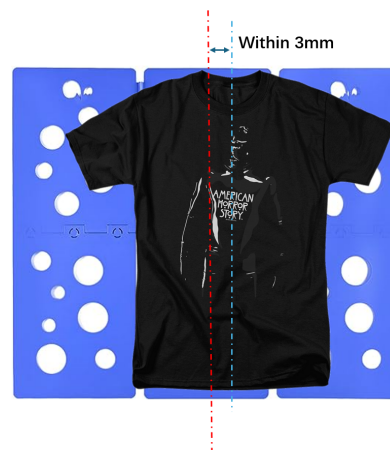


Figure 1.3: Transport Mission Illustration

Chapter 2

Design

2.1 System Overview with Block Diagram

Smart Laundry FoldBot project has four main sub-systems, the Central Control System, the Folding System, the Grabbing System, and the Vision System.

Figure 2.1 shows the position of each subsystem.

Figure 2.2 shows the basic interaction mode and execution flowchart for the whole system.

Figure 2.3 shows how sub-systems integrate and how the signal transmits.

Figure 2.4 shows the first vision of FoldBot we built in the ZJUI laboratory

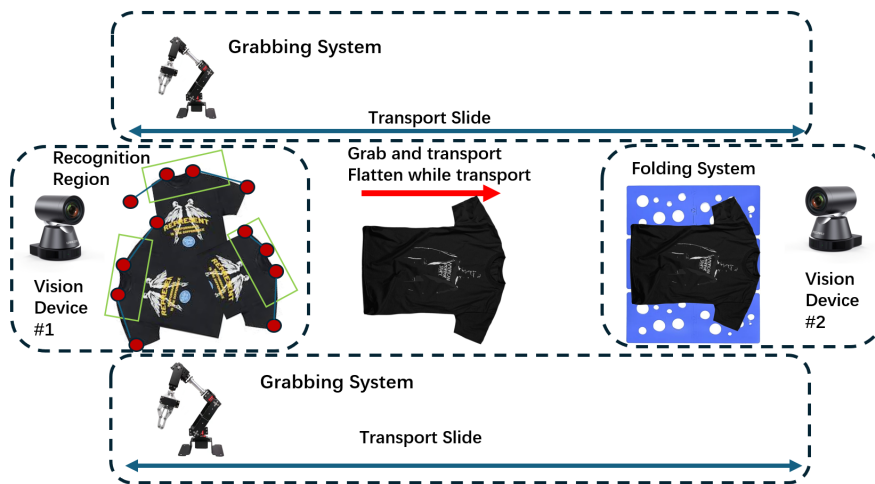


Figure 2.1: Subsystem Position Illustration

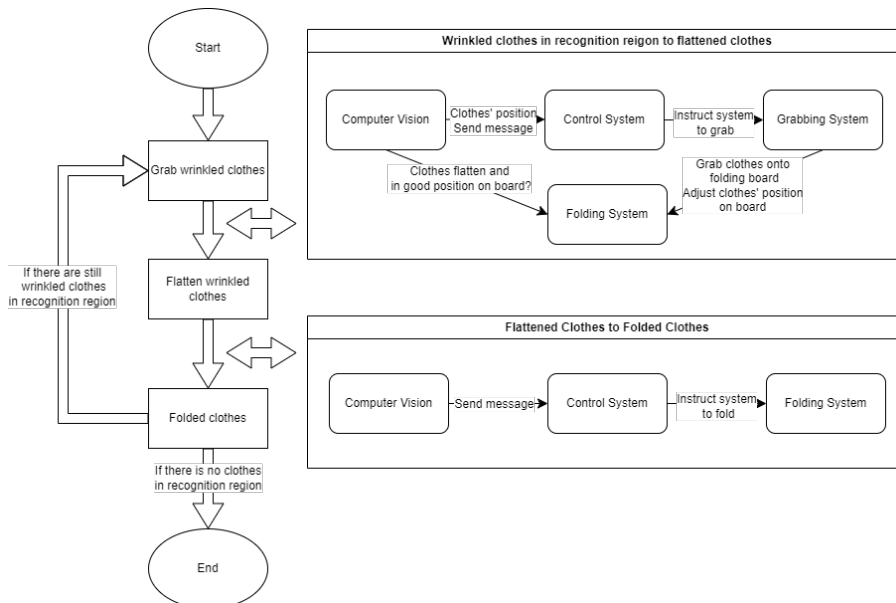


Figure 2.2: System Functionality Illustration

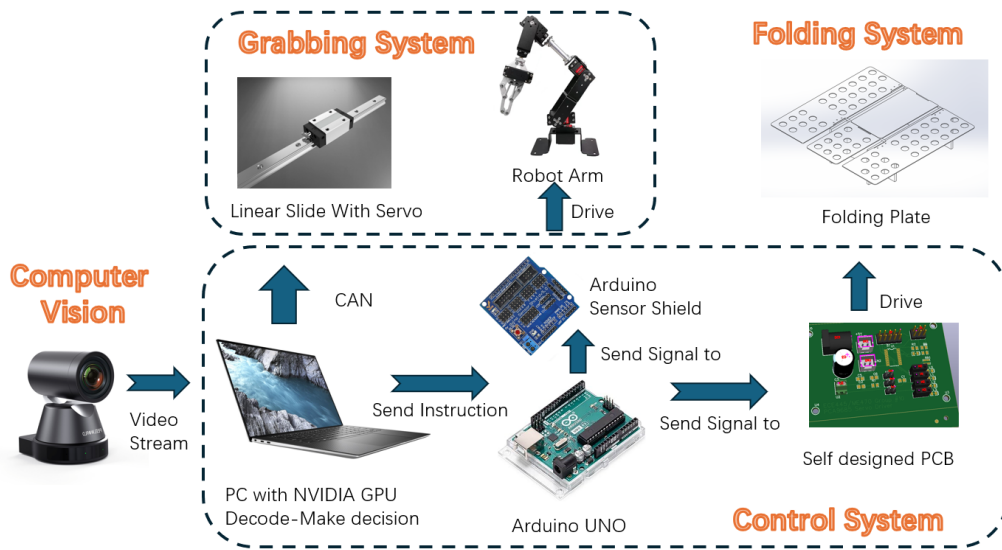


Figure 2.3: System Integration

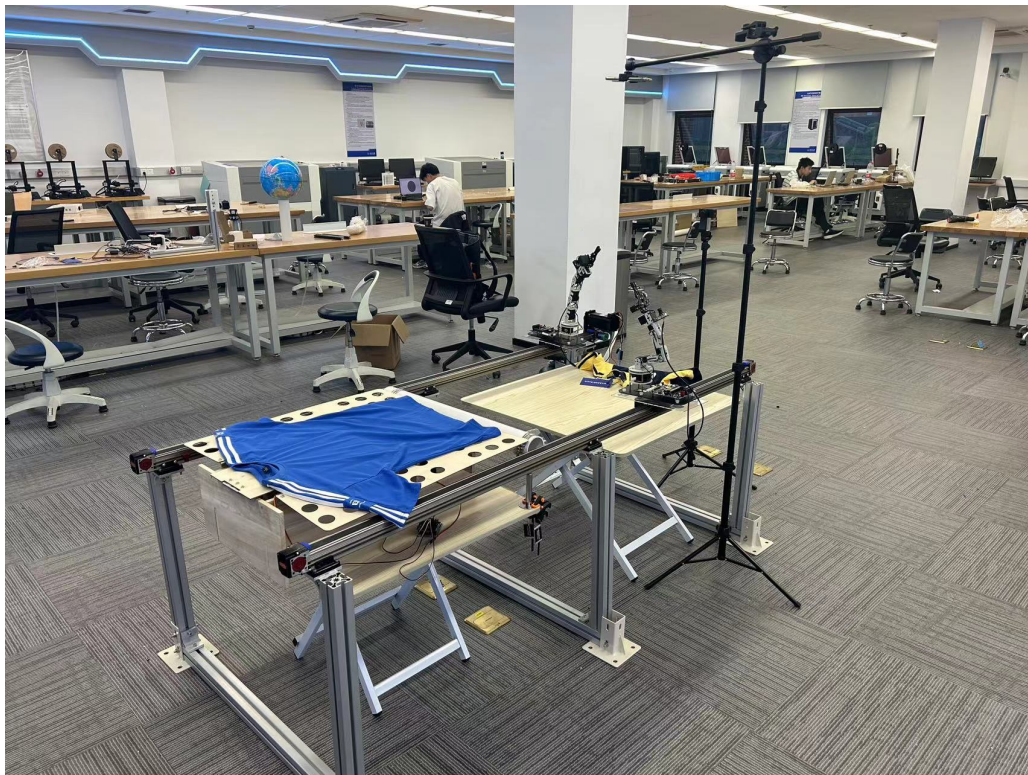


Figure 2.4: Industrial clothes folding robot

2.2 Subsystem Overview

2.2.1 Subsystem 1: Grabbing System

Purpose:

There is academic research on using Deep Reinforcement Learning and Computer Vision to classify and flatten clothes. Sun, Li (1) has shown deep reinforcement learning's promising capability for flattening Wrinkled clothes. Y Tsurumine (2) has shown deep reinforcement learning's capability for clothes smoothing. Cychnerski (3) has shown the neural network's capability for clothes detection.

The grabbing system is designed to grab wrinkled clothes from a clothes recognition region and transport clothes to the folding system. While transporting, the grabbing system should flatten the T-shirt through mechanical design.

Components:

The grabbing system comprises two six-axis robot arms and two transport slides. In the recognition region, vision device No.1 can automatically identify the shoulder of each piece of clothing. Subsequently, the robot arms would be able to accurately grab the clothes' shoulders and transport them to the folding system. Figure 2.6 shows the robot arm connected on the slide. Figure 2.5 shows the connected grabbing system in the laboratory.



Figure 2.5: Connected Grabbing System

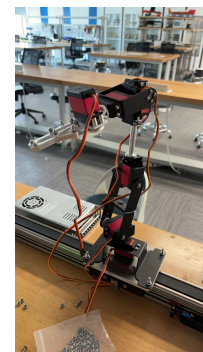


Figure 2.6: Connected Robot Arm



Figure 2.7: Connected Roller

Long Roller to Flatten Clothes

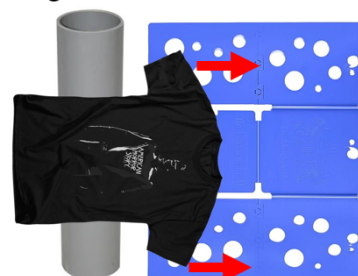


Figure 2.8: Roller Flatten Illustration

To flatten the clothes while transporting the clothes, we deploy a long roller device to flatten the T-shirt. The long roller device will ensure that when the robot arm places the clothes on the folding system. Empirically, the clothes will remain flat. Figure 2.8 shows how the long roller works during the transport process.

Operations and Interactions:

Our design uses two symmetric six-axis robot arms to grab T-shirts on their shoulders.

After robot arms grab the shoulders successfully, the transport slides will transport the entire garment to the folding system. Figure 2.1 shows how the grabbing system works to grab and transport the T-shirt to the folding system.

The clothes picked up by the robot arm will pass over a long roller device located in front of the folding system. Finally, the clothes would be flat on the folding board of the folding system.

2.2.2 Subsystem 2: Folding System

The folding system consists of four folding panels. Each folding board is driven by a servo. Figure 2.9 shows the workflow of the folding system.

- **Left Board:** Positioned on the left side, folds 180 degrees to the right, folding the left portion of the clothing.
- **Right Board:** Located on the right side, it folds 180 degrees to the left, mirroring the action of the left core board.
- **Center Lower Board:** Situated below the central part of the clothing, folds upwards 180 degrees, folding the lower part of the garment.
- **Center Upper Board:** Located above the central part of the clothing, folds about 45 degrees. Rails or clothing-receiving devices will be installed behind this board (depending on the needs of the industrial user). The folded clothes will pass through a slide and slide to the conveyor belt or clothes-receiving device.

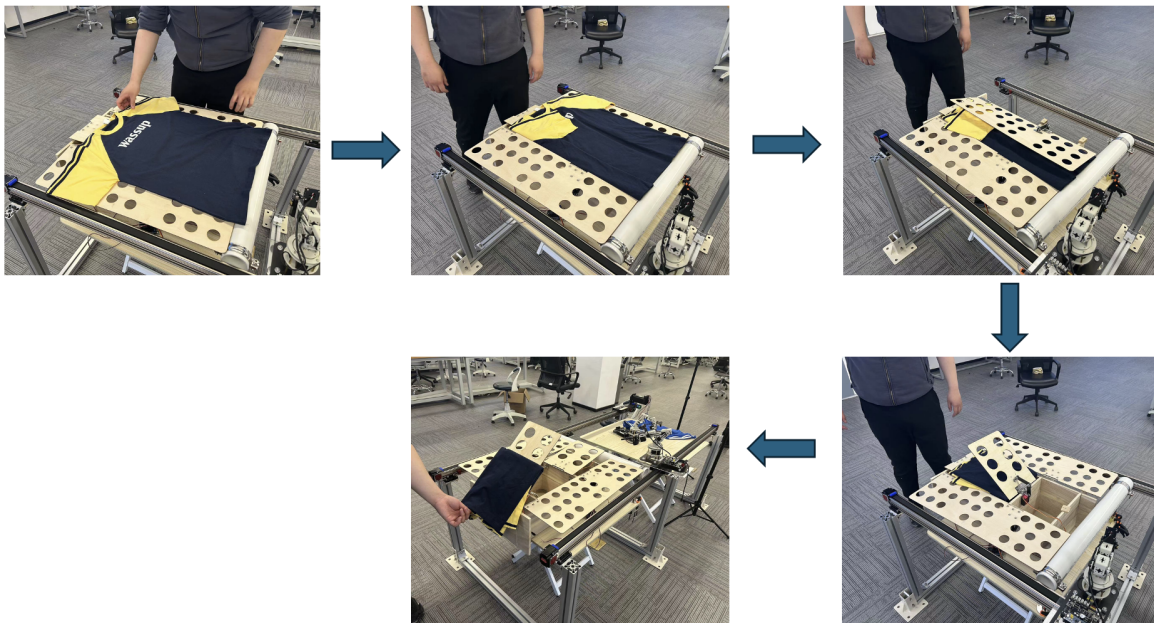


Figure 2.9: Folding system workflow chart

2.2.3 Subsystem 3: Computer Vision System

Purpose: We consider train a Fast-RCNN model to precisely identify shoulder positions on shirts. Camera above the table will transmit the image to vision model. The vision model will identify shoulder positions on shirts and generate a (x,y) coordinate on the plate, which finally enable the robot arm to grab clothes at that position.

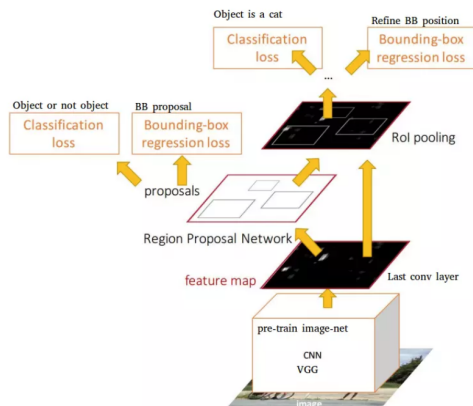


Figure 2.10: Fast RCNN structure

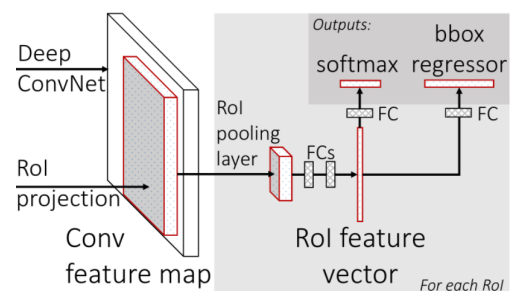


Figure 2.11: Fast RCNN structure

Components: We use a camera hung on an aluminum structure to take photos and transmit the images to a PC. We use a laptop PC with NVIDIA GPU as central control and machine learning calculation. The PC will be able to run Fast-RCNN to recognize the grabbing coordinate on the shoulder of the T-shirt.



Figure 2.12: Structures of hanging camera(Two black camera stands)

2.2.4 Subsystem 4: Control System

Purpose: Our purpose for the control system is that the control system can handle the video streams and calculate the kinematic variables the grabbing and folding systems need.

Components: We use the same laptop mentioned above to transmit signals and control the components. Figure 2.13 shows how the PC connects and controls all subsystems using various extension devices.

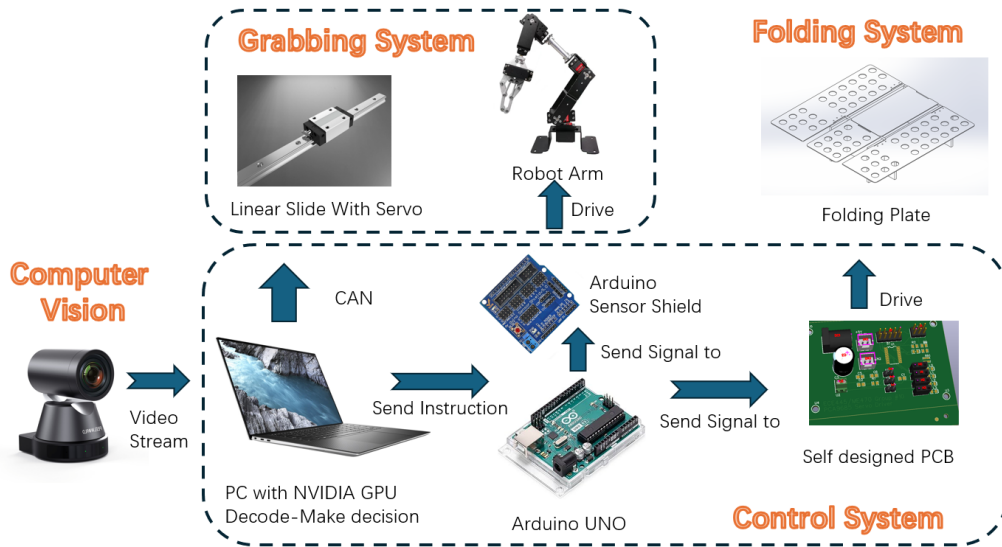


Figure 2.13: Control System Interaction

For grabbing system control, we use Arduino servo control to control robot arms and USB CAN open protocol to control the transport slide.

For folding system control, we use our self-designed PCB SoC based on PCA9685PM LED control chip to execute the motions of the folding board. Figure 2.14 is the wiring between components on the PCB and figure 2.15 is the schematic of the PCB.

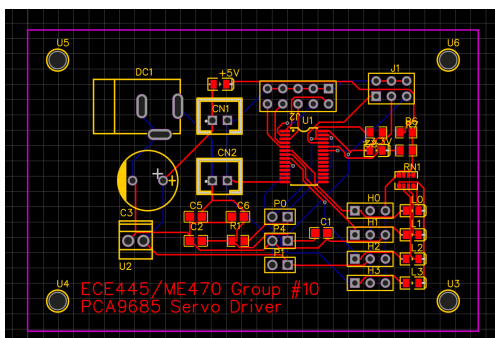


Figure 2.14: PCB Illustration

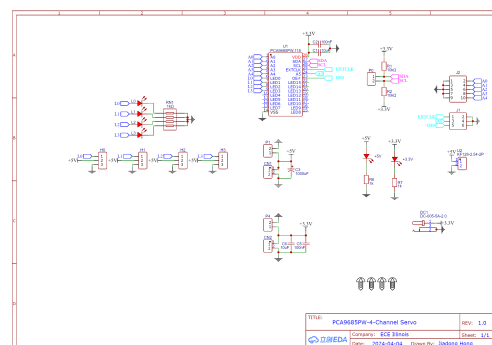


Figure 2.15: PCB Schematics

Operations and Interactions:

First, The control laptop receives and decodes the video stream, and then sends the stream to the machine-learning model.

Second, based on the result of the ML model, the laptop sends control signals and messages to Arduino and Servo PCB.

Finally, the FoldBot executes motions, vision device will monitor the motions and send feedback video streams to the laptop.

Figure 2.16 shows how the control system works abstractly.

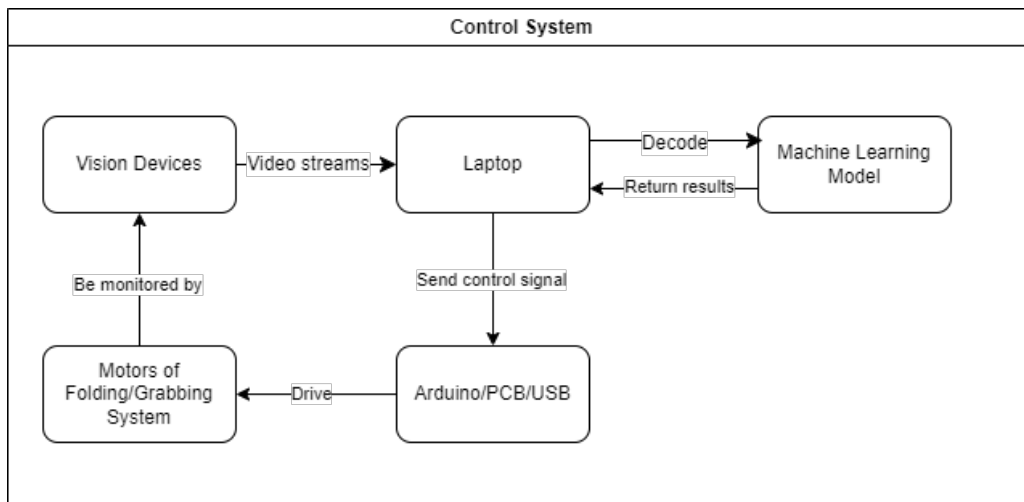


Figure 2.16: Control System Flowchart

2.3 Subsystem Requirements

2.3.1 Requirements for the Grabbing System

The grabbing system is tasked with the automated handling of T-shirts post-dryer, involving precise grabbing, effective flattening, and accurate placement on a folding mechanism. This system combines mechanical design and control algorithms to manage variably positioned and oriented garments.

- **Fetching Role:**

- **Requirements:**

- * *Grasping Stability and Speed:* The claw mechanism must ensure a stable grasp on T-shirts moving at speeds up to 10 cm/s within a 2-meter square operational area. Testing conditions include a range of T-shirt sizes (S, M, L, XL) and materials (cotton, polyester, blends).
 - * *Visual Recognition System:* Must accurately determine T-shirt position and orientation with a precision threshold where the deviation from the target grabbing point is less than 1 cm, achieving this accuracy within 1.5 seconds. The system should adapt to variations in lighting conditions within a luminance range of 200-800 lux.

- **Flattening and Placing Role:**

- **Requirements:**

- * *Flattening Effectiveness:* Achieve a flattening outcome where residual wrinkles are less than 1 cm in height, and the process duration does not exceed 4 seconds per T-shirt. The mechanism must adjust its flattening strategy based on pre-identified T-shirt material characteristics.

- **Methods:**

- * Mechanical mechanism design to incorporate adjustable pressure plates with feedback control to modulate force based on the T-shirt's fabric type and detected wrinkles. This system should self-calibrate for different garment thicknesses within 3 operational cycles.
 - * Implementation of a reinforcement learning algorithm for intelligent clothing flattening, designed to optimize flattening paths and pressure application points. The algorithm requires a maximum of 5 learning iterations to adjust to a new T-shirt type, with a subsequent operation efficiency improvement target of 20%.

2.3.2 Requirements for the Folding System

The folding system encompasses an electric mechanism designed for the precision folding of T-shirts and their orderly stacking. This system leverages an electromechanical approach to ensure consistent and accurate folding, followed by stacking in a predefined arrangement.

- **Folding Clothes:**
 - Requirements:
 - * *Operational Force and Speed:* The system must generate adequate force to manipulate T-shirts, with folding arm rotational speeds adjustable between 0.4 rad/s and 1.2 rad/s. The system shall achieve a folding precision where the variance from the intended fold line is less than 0.8 cm, with a consistency rate of 99% across all T-shirt sizes.
 - Mechanism: A servo-driven electro-mechanical system with integrated sensors for real-time fold quality feedback, enabling dynamic adjustment to fold parameters to maintain accuracy under varying load conditions.
- **Stacking Clothes:**
 - Requirements:
 - * *Alignment Accuracy:* Stacked T-shirts must exhibit a high degree of alignment, with each subsequent layer aligning within a tolerance of 1.5 cm of the one below it, and necklines uniformly oriented, accounting for all standard T-shirt sizes.
 - Purpose: To ensure a systematic and orderly stacking process, facilitating subsequent handling, storage, or packaging activities with minimal manual adjustment requirements.

2.4 Tolerance Analysis

2.4.1 Grabbing System Tolerance Analysis

The six-axis manipulator was selected for its ability to transport and flatten clothes onto the folding board. The crucial parts for its tolerance analysis are its capacity to precisely grab the shoulder of T-shirts and stably carry T-shirts.

We have verified that the end effector of the robot arm can grab items with weights equal to 500g, which is enough for grabbing clothes.

Also, we use inverse kinematic methods to calculate the rotation angle for each steering engine and compare the actual grabbing point with the correct point. The bias of the length of links, bias of length measurement, and error of computation will finally lead to the offset of the position of the end effector, so we will stimulate grabbing cases and evaluate the error. Four of the six steering engines can determine the position of the end effector. The first engine is used to determine the orientation and other three engines are used to determine the destination from the original point. We notated length of links as L_1, L_2, L_3, L_4 and rotation angles for the four steering engine as $\theta_1, \theta_2, \theta_3, \theta_4$. So given coordinate x, y , we calculate $\theta_1, \theta_2, \theta_3, \theta_4$ using equations below.

$$\theta_1 = \arctan\left(\frac{x}{y}\right)$$

$$L_1 + L_2 \cos(\theta_2) + L_3 \cos(\theta_2 + \theta_3) + L_4 \cos(\theta_2 + \theta_3 + \theta_4) = 0$$

$$L_2 \sin(\theta_2) + L_3 \sin(\theta_2 + \theta_3) + L_4 \sin(\theta_2 + \theta_3 + \theta_4) = \sqrt{x^2 + y^2}$$

We then write code to test whether the end effector can be able to arrive at the target position and we find that the error is within 1cm. Which is acceptable for our task. The code is listed in the appendix.



Figure 2.17: Six-Axis Manipulator

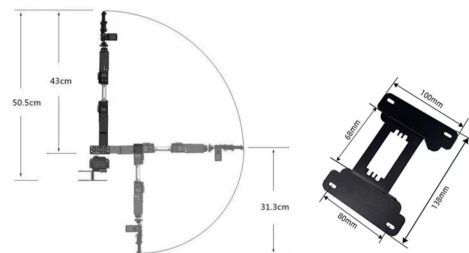


Figure 2.18: Manipulator Size

Figure 2.18 illustrates the manipulator's z-axis stroke reaching approximately 75cm, confirming its capability to handle and flatten T-shirts through gravity.

2.4.2 Computer Vision Tolerance Analysis

In this section, we compare the computing power required by computer vision models with the computing power that the GPU in current control and signal processing systems can provide. We conclude that current devices are fully sufficient to support computer vision inference tasks.

The Fast RNN framework we use is modified based on the VGG-16 computer vision model. So in fact, the computing power required by the computer vision model is determined by the computing power requirements of VGG-16. The industry already has mature literature on the computing power requirements of computer vision tasks. Vassilieva(4) from Hewlett Packard Enterprise made a clear benchmark for the mainstream computer vision models. In our vision system, we use a laptop PC with NVIDIA GPU GTX1650ti, there is also theoretical computation power throughput among different technology websites, TechPowerUp(5) made detailed GPU specs on their website.

Computer Vision Model Requirements

Figure 2.19 is from the slides made by Vassilieva(4). The figure shows the detailed computing power needed by mainstream models. The acceleration method used in the model is parallel computing of GPU, which is also the method we used in our vision model. As figure 2.19, the VGG-16 needs 15.5 GFLOPS for the forward pass inference task and needs 528 megabytes cache in GPU memory.

Popular models				
Name	Type	Model size (# params)	Model size (MB)	GFLOPs (forward pass)
AlexNet	CNN	60,965,224	233 MB	0.7
GoogleNet	CNN	6,998,552	27 MB	1.6
VGG-16	CNN	138,357,544	528 MB	15.5
VGG-19	CNN	143,667,240	548 MB	19.6
ResNet50	CNN	25,610,269	98 MB	3.9
ResNet101	CNN	44,654,608	170 MB	7.6
ResNet152	CNN	60,344,387	230 MB	11.3
Eng Acoustic Model	RNN	34,678,784	132 MB	0.035
TextCNN	CNN	151,690	0.6 MB	0.009


 10

Figure 2.19: Computer Vision Model Computing Power Benchmark

GPU Specifications

Figure 2.20 and figure 2.21 are from the website made by TechPowerUp(4). The figures show the key specifications of GPU GTX1650ti we are using for computer vision tasks. As figure

2.21 shows, the memory of GPU is 4 gigabytes, which is way larger than 512 megabytes. Figure 2.20 shows that even if we use the most precise 64-bit floating point calculation, GPU can still process 95.04 GFLOPS, which is also much larger than 15.5 GFLOPS.

Theoretical Performance	
Pixel Rate:	47.52 GPixel/s
Texture Rate:	95.04 GTexel/s
FP16 (half):	6.083 TFLOPS (2:1)
FP32 (float):	3.041 TFLOPS
FP64 (double):	95.04 GFLOPS (1:32)

Figure 2.20: GTX1650ti Computing Specs

Memory	
Memory Size:	4 GB
Memory Type:	GDDR6
Memory Bus:	128 bit
Bandwidth:	192.0 GB/s

Figure 2.21: GTX1650ti Memory Specs

In addition, it is worth mentioning that we plan to rent a more powerful server for training. So in this section, we do not consider whether the system can successfully train the model.

2.5 Requirements and Verification

2.5.1 Grabbing System

- **Stable Grasping Capability**
 - *Requirement:* The mechanical claw must reliably grasp garments without dropping them.
 - *Verification:* Perform a series of 100 grasp-and-lift tests with garments of varying sizes and weights. Each test involves the claw grasping a garment placed at random orientations on a flat surface, lifting it to a height of 1 meter, and holding it for 10 seconds. The success rate is recorded as the percentage of successful grasps.
- **Shoulder Identification Accuracy**
 - *Requirement:* The vision module should identify the garment's shoulder region within a tolerance of 0.3cm to 0.8cm.
 - *Verification:* Garments with marked shoulder regions will be presented to the system in various orientations. The vision module's identification accuracy is measured by comparing the detected position to the marked position using a high-precision digital caliper in 50 tests.
- **Efficient Identification Speed**
 - *Requirement:* Identification of garments by the vision module must be completed within 1.5 seconds.
 - *Verification:* Time the identification process using a stopwatch for 50 different garments, recording the time taken for each garment to ensure speed requirements are met.
- **Consistent Transport Speed**
 - *Requirement:* Garments must be transported at 10cm/s to 20cm/s over a 2m distance.
 - *Verification:* Use a motion capture system to measure the transport speed of garments over a 2m distance in 30 trials, ensuring the speed remains within the specified range.
- **Accurate Garment Placement**
 - *Requirement:* Garments must be placed accurately at the folding board's center, with collars oriented uniformly.
 - *Verification:* A grid on the folding board will be used to check the placement accuracy in 50 trials. The garment's position and collar orientation are measured using a ruler and visually inspected for uniformity.
- **Continuous Operation**

- *Requirement:* The system must sustainably grasp multiple garments over an extended period without performance loss.
- *Verification:* Operate the system continuously for 2 hours, grasping a garment every 30-45 seconds. The performance, including grasp success rate and identification accuracy, is monitored and recorded throughout the test duration.

- **Flattening and Smooth Transportation**

- *Requirement:* The system must flatten garments and maintain smoothness throughout transportation.
- *Verification:* Evaluate the smoothness of garments before and after transportation using a standard scale in 50 tests. A panel of three judges will assess each garment's condition based on predefined smoothness criteria to determine if the standard has been met.

2.5.2 Folding System

- **Synchronization with Grabbing System**

- *Requirement:* Folding must only begin once a garment is fully laid flat on the board, in sync with the grabbing system.
- *Verification:* Test inter-system communication for 100 cycles using a real-time monitoring system to confirm synchronization accuracy between grabbing and folding actions.

- **Minimal Visible Wrinkles**

- *Requirement:* Folded garments should exhibit minimal visible wrinkles, meeting quality standards.
- *Verification:* Assess the appearance of 50 folded garments using a wrinkle visibility scale, focusing on various fabric types. The standard for "minimal visible wrinkles" is defined by less than 5% of the garment surface showing wrinkles when inspected under standardized lighting conditions.

- **Stable Removal and Accurate Stacking**

- *Requirement:* After folding, garments must be stably removed from the board and stacked accurately.
- *Verification:* Conduct a stacking test with 50 folded garments. Each garment's stability and alignment are evaluated with a level tool and visual inspection to analyze stack stability and alignment accuracy.

Chapter 3

Cost and Schedule

3.1 Cost

We have purchased most of the parts that we need, since the building and assembling process are not completed, there might be new items that we need to purchase. Table 3.1 shows the estimated cost table for this project.

Category	Item	Price(CNY)	Quantity	Total
Control	XPS15 9500 Laptop(Used)	2390	1	2390
Control	Arduino UNO Developer Set	199	3	597
Control	5v 12A DC Power	35	3	105
Control	DC 5.5*2.5 Power Plug	10.5	1	10.5
Control	RV Power Wire	19.8	2	39.6
Control	USB Extension for Laptop	33.15	1	33.15
Folding	Foldable Table	72.9	2	145.8
Folding	CNC Carbon-fiber folding board	820	1	820
Folding	M6 Screw-Nut Set	7.35	1	7.35
Folding	Custom Wood Board	82	1	82
Folding	L-bar	5.7	1	5.7
Folding	M4 Self-tapping screws	14.04	1	14.04
Folding	Metal Hinge	2.89	8	23.12
Folding	DS3218 Servo	115	4	460
Folding	DS3218 Servo Support	8	4	32
Folding	Servo Extension Wire	2.2	30	66
Folding	Custom Arm for Servo	90	4	360
Grabbing	6-axis Manipulator	388	2	776
Grabbing	Smart 6-axis Manipulator	1350	2	2700
Grabbing	Transport Slides Module	3000	1	3000
Grabbing	Support for Slides	500	1	500
Grabbing	400W 24V DC Power	92	1	92
Grabbing	Long Roller Tube	30	1	30
Grabbing	Roller Stand	15	2	30
Grabbing	Clamps (to fix roller)	6.8	4	27.2
Grabbing	Guide Rail Chain	24	4	96
Grabbing	DC Extension wire (for smart robot arm)	9.8	2	19.6
Manpower	Man Power for 4 ZJUI students*	8000	4	32000
Vision	Camera	400	2	800
Vision	Server Rent	500	1	500
Total				45762.06

Table 3.1: Total Estimated Cost for FoldBot

* Note that we count the manpower as a full time Teaching Assistance salary for one semester in ZJUI, which is 8000 yuan per semester.

3.2 Schedule

	Week 3/18	Week 3/25	Week 4/1
Grabbing system (hardware)	Mechanical gripper completed design Complete the design of the guide rail	Starting procurement of guide rails	Complete the assembly of the guide rail; Robot arms starting to purchase
Folding system (hardware)	Complete the design of the folding board; The design of the folding board drive device has been completed; Folding board base completed design	The folding board base has been manufactured; Folding board completed manufacturing	Purchase of folding board drive device started
Control System	Continue to design the folding board control system; Design of grasping system control begins	The same as previous week	The same as previous week
Vision Device & ML	/	/	/
Qianqi Liu(ME)	Mechanical gripper completed design Complete the design of the guide rail; Complete the design of the folding board; The design of the folding board drive device has been completed; Folding board base completed design	The folding board base has been manufactured; Folding board completed manufacturing	Complete the assembly of the guide rail; Purchase of folding board drive device started
Jiadong Hong(EE)	Start component procurement	Starting procurement of guide rails	Robot arms starting to purchase
Jialin Shang(ECE)	Continue to design the folding board control system; Design of grasping system control begins	The same as previous week	The same as previous week
Weijie Liang (ECE)	Continue to design the folding board control system; Design of grasping system control begins	The same as previous week	The same as previous week

Figure 3.1: Schedule

	Week 4/8	Week 4/15	Week 4/22
Grabbing system (hardware)	Mechanical arm installation completed	The hardware of the grabbing system has been fully assembled	Building aluminum profile brackets
Folding system (hardware)	The folding device has been fully assembled (except for the motor)	The folding system has been fully assembled	Building aluminum profile brackets
Control System	The control system has basically completed its design and all control systems have been purchased in place	Folding system control works successfully	The guide rail runs successfully; The robotic arm has initially been successfully operated
Vision Device & ML	/	/	Start designing visual system
Qianqi Liu(ME)	The folding device has been fully assembled (except for the motor)	The hardware of the grabbing system has been fully assembled	Building aluminum profile brackets
Jiadong Hong(EE)	Mechanical arm installation completed	The folding system has been fully assembled	Building aluminum profile brackets
Jialin Shang(ECE)	The control system has basically completed its design and all control systems have been purchased in place	Folding system control works successfully	Start designing visual system
Weijie Liang (ECE)	The control system has basically completed its design and all control systems have been purchased in place	Folding system control works successfully	The guide rail runs successfully; The robotic arm has initially been successfully operated

Figure 3.2: Schedule

	Week 4/29	Week 5/6	Week 5/13 (Final Pre)
Grabbing system (hardware)	All working properly	Successfully working together with other subsystems	Prepare for Final pre
Folding system (hardware)	All working properly	Successfully working together with other subsystems	Prepare for Final pre
Control System	The robotic arm can successfully grasp and transport clothes; The folding board can be successfully folded	Successfully working together with other subsystems	Prepare for Final pre
Vision Device & ML	Visual system completion training	Successfully working together with other subsystems	Prepare for Final pre
			Prepare for Final pre
Qianqi Liu(ME)	The robotic arm can successfully grasp and transport clothes; The folding board can be successfully folded	Perform final maintenance and testing on mechanical components	Prepare for Final pre
Jiadong Hong(EE)	The robotic arm can successfully grasp and transport clothes; The folding board can be successfully folded	Perform final calibration on the guide rail and folding board	Prepare for Final pre
Jialin Shang(ECE)	Visual system completion training	Perform final testing and calibration on the mechanical gripper	Prepare for Final pre
Weijie Liang (ECE)	Visual system completion training	Perform final testing on the visual system	Prepare for Final pre

Figure 3.3: Schedule

Chapter 4

Ethics and Safety

4.1 Ethics

In alignment with the principles outlined in both the IEEE (6) and ACM (7) Codes of Ethics, our project rigorously addresses the following ethical concerns:

Social Responsibility: Our project is committed to evaluating and mitigating its impact on society, encompassing social, economic, and environmental dimensions. We pledge to assess not just the immediate advantages of our work but to anticipate and plan for potential long-term effects on the community and environment.

Fairness and Equity: We guarantee that our project operations and outcomes will adhere to the highest standards of fairness and justice, ensuring no discrimination against individuals or groups based on ethnicity, gender identity, sexual orientation, religion, or national origin. Acknowledging the potential for inherent biases, we are dedicated to identifying and rectifying these biases through conscious design and implementation strategies.

Integrity and Transparency: Our team commits to upholding the utmost levels of honesty and transparency throughout the project life cycle. This includes clear communication regarding the project's progress, and any associated risks, uncertainties, or conflicts of interest to all stakeholders, including team members, instructors, and the broader community. This commitment ensures accountability and fosters trust in our project and its outcomes.

4.2 Safety

Our project's development and implementation strictly adhere to the safety guidelines specified on the course website and relevant regulatory standards. We emphasize the following areas:

4.2.1 Electrical Safety

Given our project's reliance on electrical components, we prioritize electrical safety to prevent risks such as electrocution or fires. Our measures include:

- *Insulation and Grounding:* All electrical wiring will be insulated with materials rated for twice the maximum operational voltage. Grounding systems will maintain a resistance of less than 1 ohm, verified by quarterly resistance testing according to IEEE Standard 142.
- *Circuit Protection:* Circuit breakers and fuses will be sized for 125% of the maximum expected current to accommodate peak loads, with compliance verified through initial installation checks and annual load testing.
- *Safety Equipment:* Electrical safety equipment, including insulated gloves and tools, will be provided to all teammates.

4.2.2 Mechanical Safety

To prevent accidents from mechanical components:

- *Secure Installation:* Mechanical installations will use vibration-resistant fasteners, with torque specifications verified to within a 5% tolerance using calibrated torque wrenches during initial setup and biannual reviews.
- *Guarding Moving Parts:* All moving parts will have physical barriers compliant with ANSI/RIA R15.06 standards.
- *Safety Protocols:* Comprehensive safety protocols will be implemented for the operation and maintenance of mechanical systems.

4.2.3 Laboratory Safety

Our development process involves stringent measures:

- *Comprehensive Safety Training:* Mandatory safety training sessions will be held by lab manager of ZJUI at project initiation.
- *Protective Gear:* Usage of protective gear such as goggles, gloves, and lab coats will be mandatory.
- *Controlled Environment:* All experiments will be conducted within environments that comply with OSHA regulations for laboratory safety. Environmental safety compliance will be verified through biannual environmental audits, ensuring adherence to all applicable standards.

Chapter 5

Appendix

5.1 Inverse Calculation for Robot Arm

```

import math
import numpy as np
from scipy.optimize import fsolve
import time
from Arm_Lib import Arm_Device

Arm = Arm_Device()
time.sleep(.1)

def normalize_angle(angle):
    return angle % 360

def solve_equations(dest, L1, L2, L3, L4, theta2=30):

    theta2 = 30
    def equation(theta):
        return [
            L1+L2*math.cos(math.radians(theta2))+
            L3*math.cos(math.radians(theta2+theta[0]))+
            L4*math.cos(math.radians(theta2+theta[0]+theta[1])),
            L2*math.sin(math.radians(theta2))+
            L3*math.sin(math.radians(theta2+theta[0]))+
            L4*math.sin(math.radians(theta2+theta[0]+theta[1])) - dest
        ]

    while True:
        solution = root(equation,[30,30]).x
        theta3_normalized = normalize_angle(solution[0])
        theta4_normalized = normalize_angle(solution[1])

        if all(0 <= theta <= 90 for theta in
            (theta3_normalized, theta4_normalized)):
            return theta2, theta3_normalized, theta4_normalized
        else:
            theta2 += 1
            if theta2 > 90:
                theta2 = 0

L1 = 122.85
L2 = 80.5
L3 = 80.5
L4 = 180.6
x = 140

```



```
y = 130
theta1 = math.atan(x/y)*180/math.pi
dest = math.sqrt(x**2+y**2)
theta2, theta3, theta4 = solve_equations(dest, L1, L2, L3, L4)
```

```
Arm.Arm_serial_servo_write6(90-theta1,90-theta2,
90-theta3,90-theta4,90, 180, 500)
```

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