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Senior Design Project

Smart Laundry FoldBot

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Chapter 1

Introduction

1.1 Problem

In response to the growing demand for household automation, this project focuses on the development of an intelligent T-shirt folding machine capable of efficiently handling scattered clothes. While existing solutions can only fold flattened garments, our objective is to bridge the gap by creating a system that can retrieve T-shirts from a basket, identify the shape of T-shirts, automatically flatten them, and apply specific folding methods to handle them. Our machine can automatically grasp, flatten and fold clothes, liberating people from tedious steps. Compared to existing solutions on the market. So, the machine possesses strong competitiveness compared to other machines on current markets.

1.2 Solution

Our proposed solution involves the development of an automatic T-shirt folding machine equipped with advanced vision algorithms and robotic manipulation techniques. By leveraging vision models, the system will be able to recognize the shape of the T-shirts and flatten the clothing according to its shape. The mechanical design will incorporate flexible gripping mechanisms and folding boards capable of adapting to different T-shirt dimensions and materials. Through iterative testing and refinement, we aim to create a reliable and efficient solution that streamlines the T-shirt folding process, ultimately saving time and effort for users. A brief figure depicting our system for visual aid is shown in Figure 1.1.

1.3 High-Level Requirements

1. Visual Model Technology: Our visual model employs deep learning algorithms to achieve an 85% accuracy rate in feature recognition and 90% in image segmentation accuracy. Posture analysis maintains an error margin within ± 2 degrees, significantly enhancing the finesse and accuracy of complex object form analysis.

2. Robust Reinforcement Learning Algorithm: Our reinforcement learning algorithm simulates main environmental disturbance factors (Variability in Garment Types and Materials,

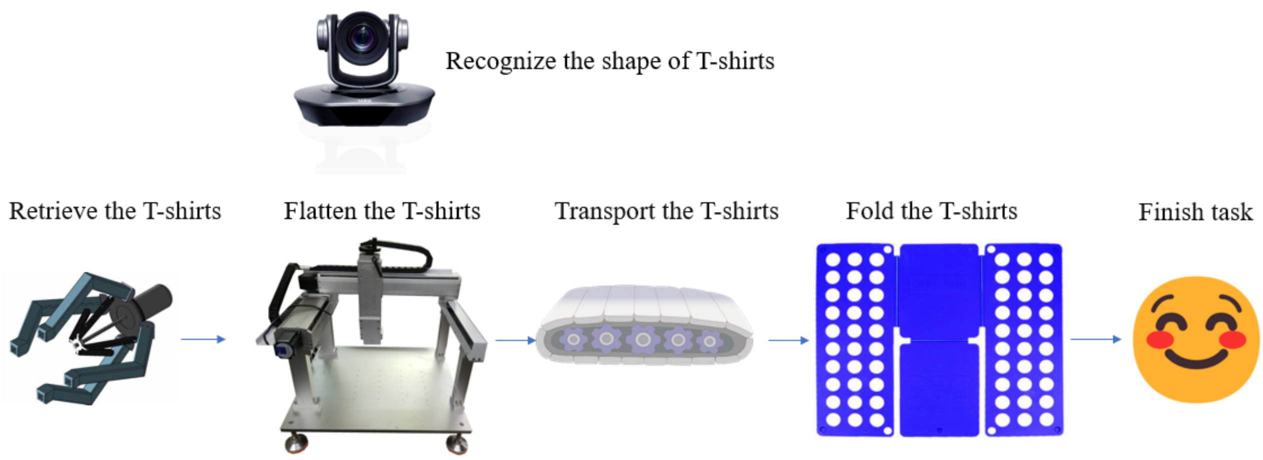

Figure 1.1: Control System Flowchart

and unpredictable Garment Positions and Conditions) and integrates these into the source environment model for simulation, enhancing strategy transfer robustness and reducing operational error rates by 10-15% compared to before optimization. Particularly in garment handling, the algorithm ensures effective prevention of new creases in most operational scenarios, improving efficiency and the quality of treatment.

3. Robust Integrated Mechanical and Electronic Control System: The control system achieves precise response times of less than 10 milliseconds and ensures performance deviation remains below 1% during extended operations (such as continuous operation for 3 hours). This system is especially suitable for tasks requiring high precision control, like garment folding, significantly reducing the likelihood of creases during operation and markedly enhancing operational accuracy and efficiency.

Chapter 2

Design

2.1 Block Diagram

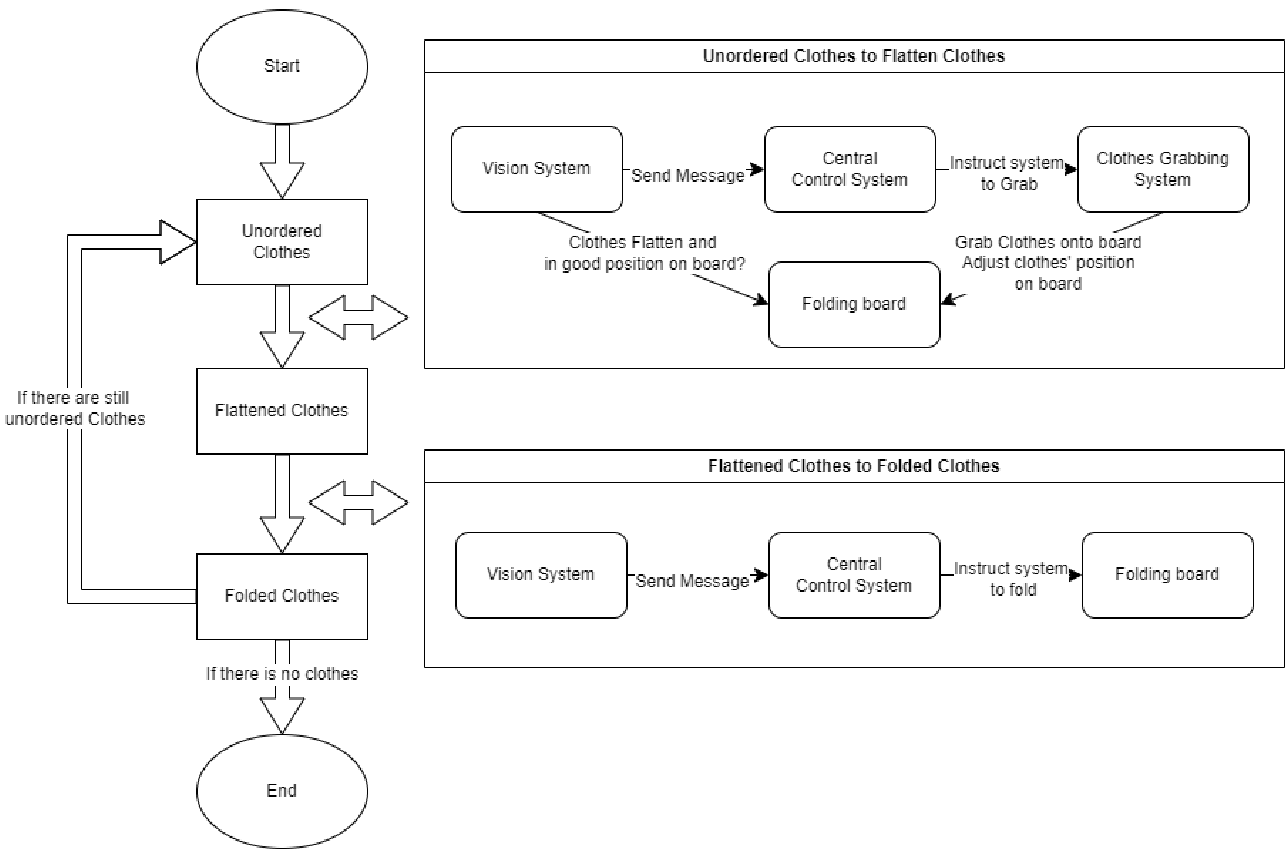

Figure 2.1: System Functionality Illustration

2.2 Subsystem Overview

2.2.1 Subsystem 1: Grabbing System

Purpose and Components: 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 neural network's capability for clothes detection.

The first subsystem is designed to grab loose clothing from a clothes basket and transport it to the second subsystem, the folding system. The fetching system comprises an XYZ three-axis manipulator and a visual recognition device. The visual recognition device can automatically identify the shoulder of each piece of clothing. Subsequently, the robot accurately grabs the clothes' shoulders and transports them to the folding system.

Operation and Interaction: The clothes picked up by the robot will pass over a long roller device located in front of the folding system. The long roller device will ensure that when the robot arm places the clothes on the folding system, the clothes will always remain flat (not curled); when the robot arm releases the clothes, the clothes will be flat on the folding plate.

2.2.2 Subsystem 2: Folding System

Purpose and Components: This subsystem automatically identifies the clothing size and folds them according to the preset parameters. It consists of core boards and expansion plates. There are existing folding machines like FoldiMate (4), which is an innovative implementation of folding a well-arranged T-shirt. But there is no implementation for a randomly arranged T-shirt. The Folding and Stacking system is functionally the same as the FoldiMate.

Core Boards

The primary folding mechanism includes four specialized boards, each powered by an electric motor, designed to fold 180 degrees to facilitate sequential folding of clothing. These are:

- **Left Core Board:** Positioned on the left side, folds 180 degrees to the right, folding the left portion of the clothing.
- **Right Core Board:** Located on the right side, folds 180 degrees to the left, mirroring the action of the left core board.
- **Center Lower Core Board:** Situated below the central part of the clothing, folds upwards 180 degrees, folding the lower part of the garment.
- **Center Upper Core Board:** Located above the central part of the clothing, also folds upwards 180 degrees, completing the fold by folding the upper portion of the garment.

Expansion Plates

This part consists of three adjustable plates to provide flexibility for handling various clothing sizes and types:

- **Left Expansion Plate:** Adjacent to the left core board, extends or retracts to accommodate different clothing sizes.
- **Right Expansion Plate:** Positioned next to the right core board, adjusts for the parts of the clothing that exceed the right core board.
- **Lower Expansion Plate:** Located below the central lower core board, ensures a complete and neat fold by adjusting for clothing parts that extend beyond the board.

Conclusion: These two subsystems enable our automated folding device to perform its function in an efficient and hassle-free manner. The Cloth Grabbing System ensures clothes are prepared for folding, while the Folding System adapts to various clothing sizes for precise folding.

2.3 Subsystem Requirements

2.3.1 Requirements for Grabbing System

For a randomly placed T-shirt taken out of the dryer, we need to design a mechanical claw mechanism. The function of this mechanism is to fetch and flatten a randomly placed T-shirt, and finally place the T-shirt on the folding mechanism.

- **Fetching Role:**
  - **Requirements:**
    - Stable grasping capability. It should be able to grasp T-shirt with maximal speed of 10cm/s moving in area of 2 meters long and the T-shirt never drops.
    - Visual recognition mechanism for determining T-shirt posture and grabbing at precise position. The difference of grabbing point and target point should not exceed 1 cm.
- **Flattening and Placing Role:**
  - **Requirements:**
    - Ability to flatten T-shirt. No obvious wrinkles should be seen after flattening step.
  - **Methods:**
    - Design of mechanical mechanism.
    - Deployment of a reinforcement learning algorithm for clothing flattening.

2.3.2 Requirements for Folding System

For clothes that have been placed correctly, we need to design an electric folding mechanism based on a fixed plate. This mechanism mainly performs two steps: folding T-shirts and stacking folded T-shirts.

- **Folding Clothes:**
  - Requirements:
    - Sufficient force and response speed. It should have enough power to hold T-shirts and rotate at speed of 0.5 rad/s to 1.0 rad/s.
  - Mechanism: Electro-mechanical motion control mechanism.
- **Stacking Clothes:**
  - Requirements:
    - Avoidance of skewness in stacked clothes. The T-shirts at higher level should fully cover the T-shirts at lower level, with necklines pointing to the same directions.
  - Purpose: Maintain alignment of stacked clothes.

2.4 Tolerance Analysis

2.4.1 Grabbing System Tolerance Analysis

We choose an xyz-3D crane to transport and flatten clothes onto the folding board.

Assumption for Analysis

We need to grab the clothes from the ground and place them onto the folding plate. So we need a relatively large crane system to transport the clothes. At least we should have a height of 80cm so that the T-shirt can be naturally flattened through gravity. Then we designed a 110cm × 140cm plane to grab any clothes for this region.

Figure 2.2: 3D Grabbing Crane Size

2.4.2 Folding System Tolerance Analysis

The folding plates are powered by steering engines and should be able to fold clothes on the plates. We aim to design four plates. Two big plates have size of 80cm × 30cm and two small plates have size of 40cm × 30cm. They can match the size of clothes. We choose DS3218 steering engines and they have enough power to fold plates and clothes. Parameters of the engines are listed below.

Operating Voltage	5V	6.8V
Idle current(at stopped)	4mA	5mA
Operating speed (at no load)	0.16 sec/60°	0.14sec/60°
Stall torque (at locked)	18 kg-cm	21.5 kg-cm
Stall current (at locked)	1.8A	2.2A

Figure 2.3: Steering Motor Electrical Specification

2.4.3 Vision System Tolerance Analysis

The VRT is crucial for the system's ability to identify the position and orientation of clothing accurately. It is defined by the system's resolution and its error margin in recognizing clothing features.

Assumptions for Analysis

- The visual recognition system can decode video images of 1920*1080p at 30fps
- The system can identify clothing positions and do AI inference for $1920 * 1080 * 30 * (4byte) = 248.83200\text{MB/s}$ computational output.

The table below lists the NVIDIA Jetson Nano specs. As we can see, Jetson Nano is capable of CV development and AI inference.

Table 2.1: Jetson Nano AI Performance and Video Codec Capabilities

Feature	Specification
AI Performance	
GPU	128-core Maxwell CUDA core
GFLOPS	472
CPU	Quad-core A57
Clock speed	1.43 GHz
Video Codec Capabilities	
H.264	Encode and decode up to 4K at 30 FPS
H.265	Encode and decode up to 4K at 30 FPS
VP8	Encode and decode up to 1080p at 30 FPS
VP9	Encode and decode up to 1080p at 30 FPS

Chapter 3

Ethics and Safety

3.1 Ethics

In alignment with the principles outlined in both the IEEE (5) and ACM (6) 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.

3.2 Safety

Our project's development and implementation strictly adhere to the safety guidelines specified on the course website and relevant regulatory standards, emphasizing:

Electrical Safety: Given our project's reliance on electrical components, we prioritize electrical safety to prevent risks such as electrocution or fires. This involves ensuring proper insulation and grounding of wires, correct sizing and protection of circuits, and the provision of necessary safety equipment for electrical component handling.

Mechanical Safety: For projects involving mechanical elements, we ensure that all machinery, such as motors, is securely installed and that moving parts are safeguarded to prevent accidents. This includes implementing physical barriers and safety protocols to protect users and equipment from harm.

Laboratory Safety: Our project's development process includes stringent laboratory safety measures to protect project members from potential hazards associated with tools, equipment, and materials used. This encompasses comprehensive safety training for all project participants, availability of appropriate protective gear, and conducting all experimental activities within a controlled laboratory setting.

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