FlexiFold: Sensor-Based Automatic Shirt Folding Machine with Dynamic Size Adjustment

Sairia Faith Cadiz, Jonathan Tungal, Apple Joy Tamayo, Mary Ruth Paja

Cor Jesu College Inc. Philippines
Correspondence Email: sairiafaithcadiz@g.cjc.edu.ph

Folding t-shirts manually is a known time-consuming chore. In recent times, automation has played a crucial role in boosting productivity, cutting down manual efforts, and enhancing overall efficiency. Automated folding machines have surfaced as a result. This paper aims to create a Sensor-Based Automatic Shirt Folding Machine with Dynamic Size Adjustment. The study utilizes sensors, motors, and a microcontroller to efficiently fold t-shirts of different sizes, categorized as kid's, adult's, and plus size. The machine uses a mechanism called feedback and control to ensure successful folding. The machine's process includes the evaluation of sensors, an adjustment mechanism, folding, and stacking. Performance evaluation of the machine was conducted, focusing on folded shirt accuracy in terms of output dimensions and the time taken for folding. The results indicate a 5% error rate in achieving the desired dimensions and an average folding speed of 8.67 seconds per shirt. This project holds promise for further improvement and potential use in the clothing industry.

Keywords: adjustable, motor, sensor, t-shirt folding machine.

1. Introduction

The increasing demand for automated solutions and machinery has been evident in various industries, aiming to boost output, minimize manual involvement, and enhance overall effectiveness [1]. Among the many time-consuming household chores, folding clothes is a commonly regarded task that becomes tiresome and uninteresting after washing and drying. On average, it takes a person approximately 10 to 20 seconds to fold a single t-shirt [2], [3], [5]. Properly folded garments are crucial for compact storage [2]. This task extends beyond households and is also pertinent to businesses like laundry services, which often handle a large volume of clothes requiring folding within specific time constraints, occasionally facing challenges in meeting customer delivery timelines due to workload [3]. To address these challenges, automated folding machines have been developed.

Wankhede et al. [4] conducted research on a t-shirt folding machine powered by DC motors.

The folding process is initiated by pressing a button, reducing folding time by almost half compared to manual methods. However, manual activation through the button remains a necessity for folding.

Similarly, Divya et al. [5] utilized DC motors and rotary motions in their device for folding t-shirts. They incorporated ultrasonic sensors to automate the process, resulting in a 50% increase in efficiency compared to manual folding. In the study by Silitonga et al. [6], titled "Design and Simulation of Automatic Folders," an automatic fabric folding tool was developed using ultrasonic sensors and an Arduino Uno microcontroller. Servo motors were employed to fold clothes and pants. Despite sensor integration in these devices, manual initiation via buttons was still required; the folding process did not start automatically.

Li et al. [7] introduced an autonomous cloth folding machine that automatically initiates the folding process upon placing clothes on the machine. Machine's onboard light sensors detect clothing presence, and an infrared sensor recognizes hand and arm movements of human. Testing confirmed the machine's successful cloth detection and automatic folding. Unlike the prior studies, Li et al. eliminated the need for button activation, as the folding process commences automatically upon placing clothes on the machine. However, similar to other research, their devices lacked sensor integration and motor control for adjusting to different t-shirt sizes.

Given the constraints of prior studies, this research endeavors to develop an automated t-shirt folding mechanism without the need for button pressing, alongside a device equipped with sensors and motors to facilitate size adjustments. The main objectives of the study are (1) to design and develop a sensor-based automatic shirt folding machine with dynamic size adjustment; and (2) to test and evaluate the machine's performance in terms of accuracy of folded shirts and folding time.

2. Methodology

This section provides a comprehensive overview of the FlexiFold, an automated shirt folding machine that utilizes sensors for dynamic size adjustment, detailing its development process.

A. Conceptual Framework

Fig. 1 shows the conceptual framework employed in the study. This machine utilizes shirt samples, sensors, and limit switches to determine the presence and size of shirts. These inputs are fed into a microcontroller, serving as the control unit. The control unit processes the signals, enabling it to directly communicate with the motors and motor drivers to initiate precise movements. Consequently, the outcome is a collection of neatly folded shirts, conveniently stacked for easy retrieval. The machine will be designed to handle a range of shirt types specifically t-shirts, sleeveless shirts, and polo shirts, accommodating individuals of various sizes.

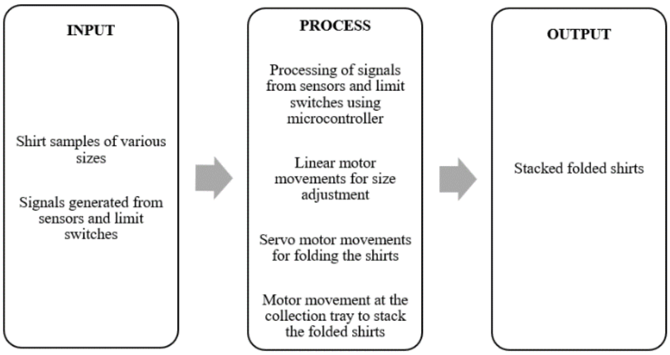

Fig. 1. Conceptual framework of the study

B. Design of the Machine

Fig. 2 illustrates the machine's design, featuring a solid base with intricate electrical wiring and electronic connections inside the base. Five folding boards are included to assist in the folding process. A catch tray is integrated into the design for convenient collection of folded shirts. This catch tray, equipped with a collection basket mounted at the top of the device, offers sufficient space to gather the folded shirts.

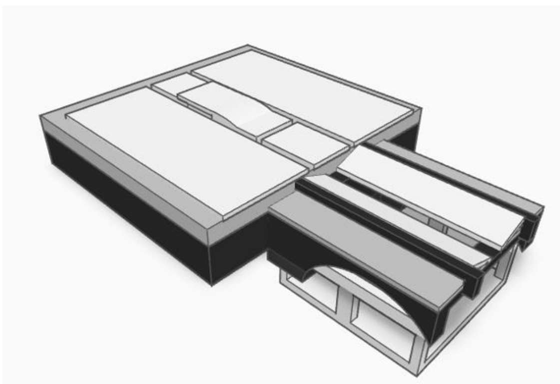

Fig. 2. The Design of the Machine

C. Feedback and Control Diagram

In this research, a feedback and control mechanism, as illustrated in Fig. 3, is employed. The machine is engineered to fold shirts of various sizes, utilizing a feedback and control loop to adapt accordingly to their dimensions.

The machine's input is the shirt itself. When the sensor detects the shirt, the microcontroller transmits input signals instructing the motor situated beneath the folding boards to align the folding boards according to the shirt's size.

Once the adjustment phase is completed, the folding and stacking mechanism is initiated, involving the activation of the motors.

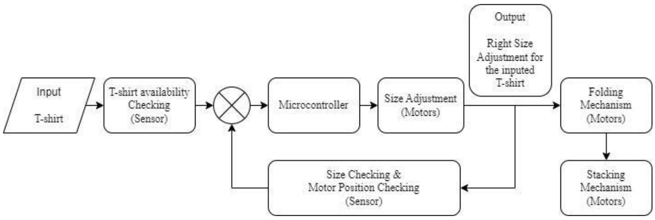

Fig. 3. Feedback and Control mechanism of the system

D. Schematic Diagram

Fig. 4 depicts the schematic diagram of the system design. The machine consists of five motors dedicated for the mechanism for folding the shirts, four motor drivers are used to regulate the motors, with three responsible for adjusting the position of the folding boards according to the shirt's size, and one for the catch tray mechanism. Furthermore, six sensors are utilized for detecting shirt presence and dimensions, while three limit switches are incorporated for homing the motors. These elements are interconnected and linked to a microcontroller which is the machine’s main control unit.

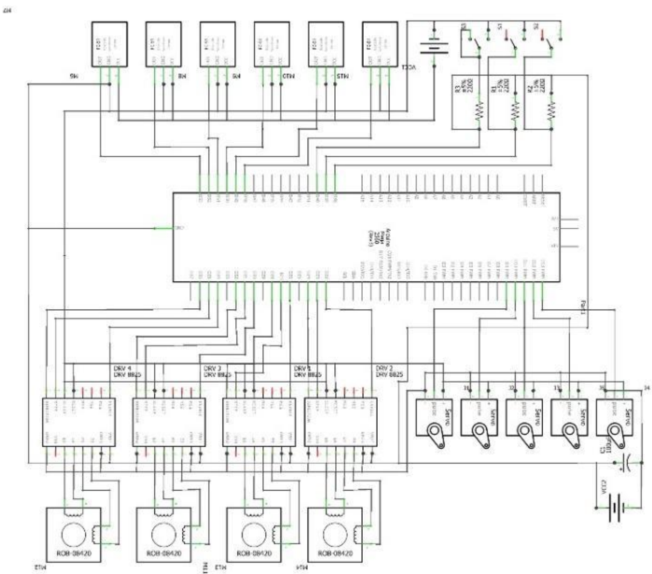

Fig. 4. Schematic Diagram of the machine

E. Mechanism for Size Adjustment

The t- shirts are classified into 3 categories which are kids, adults and plus size. Table I shows the range of the shirts sizes that falls under each category and the corresponding output folding dimensions.

TABLE I. SHIRT SIZES AND ITS CORRESPONDING OUTPUT FOLDING DIMENSIONS

Shirt Category	Shirt Dimension		Output Folding Dimension (inches)
	Width (inches)	Length (inches)	
Kids	13 - 16	18 - 23	6 x 8
Adults	16 - 22	23 - 29	9 x 10
Plus Size	22 - 25	29 - 32	10 x 11

Fig. 5 displays the placement of the sensors. Size adjustment involves five sensors: Sensor 1 positioned in folding board A, Sensors 2 and 3 in folding board C, and Sensors 4 and 5 in folding board D. Sensor 1 is specifically designated for shirt availability detection, while Sensors 2 to 5 are utilized for size identification.

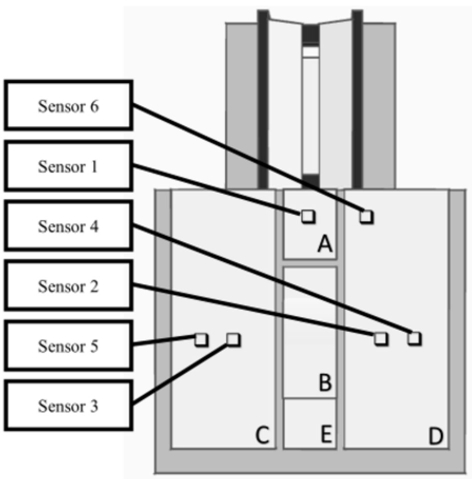

Fig. 5. Location of sensors

Fig. 6 depicts the motion of the folding boards to accommodate different sizes, facilitated by the linear motors attached underneath. The actions include extension of the folding boards, reversing and halting.

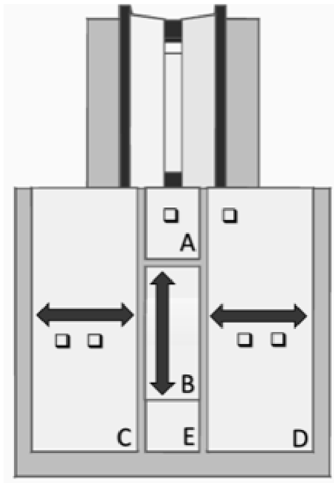

Fig. 6. Size Adjustment Movements of the Folding Board

The device activation is triggered by Sensor 1. When a shirt covers Sensor 1, signaling its presence on the device, the control unit initiates the size checking process. Once sensors are covered, their state is marked as true.

Shirt evaluation relies on Sensors 2 to 5. If Sensors 2 to 5 are not covered, indicating a kids' size shirt, folding boards B, C, and D move to their initial positions. If only Sensors 2 and 3 are covered, suggesting an adult-sized shirt, folding boards C and D move 1.5 inches from their initial positions, while folding board B moves 2 inches. When all Sensors 2 to 5 are covered, indicating a plus-sized shirt, folding boards C and D move 2 inches from their initial positions, and folding board B moves 3 inches. Once the adjustment mechanism is done, the folding process initiated. If none of these conditions are met, the folding process does not start, prompting realignment of the t-shirt.

This logical sequence and the corresponding movement of the linear motors beneath the folding board are depicted in Fig. 7.

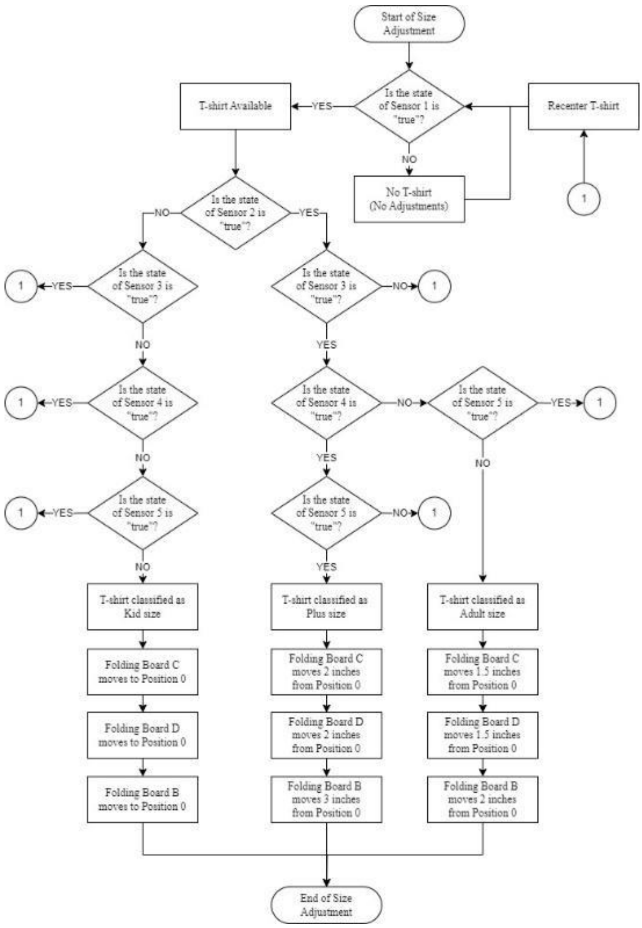

Fig. 7. Flowchart of the Size Adjustment Mechanism

F. Mechanism for Folding Shirts

Fig. 8 displays the positions of the motors responsible for the folding mechanism. Folding board A is controlled by Motor, folding board B by Motor 2, folding board C by Motor 3, folding board D by Motor 4, and folding board E by Motor 5.

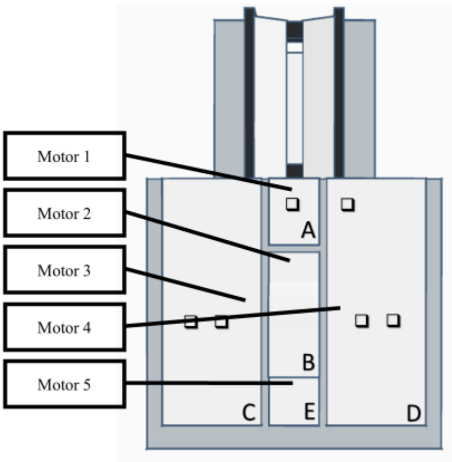

Fig. 8 Location of the Motors

The logic of the folding mechanism and the sequence of motor movements are illustrated in Fig. 9. Once size adjustment is completed, Motor 4 and Motor 3 activate to fold the left and right sides of the shirt at folding boards C and D. Subsequently, Sensor 6 is assessed to determine if there is excess sleeve requiring Motor 4 to engage again at folding board D. If not, the sequence continues with Motor 5, then Motor 2, and finally Motor 1, completing the folding process.

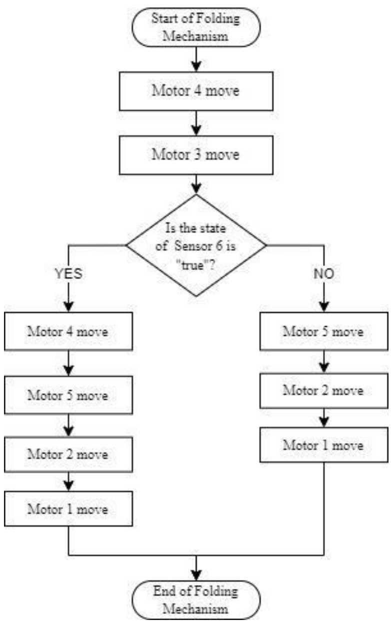

Fig. 9. Flowchart of the Logical Application of the folding mechanism

G. Mechanism for Stacking the Folded Shirts

The mechanism for stacking folded shirts, shown in Fig. 10, is included to the machine to streamline the process of organizing and retrieving folded shirts. It consists of several components, including a microcontroller and stepper motor, which work together to automate the stacking process.

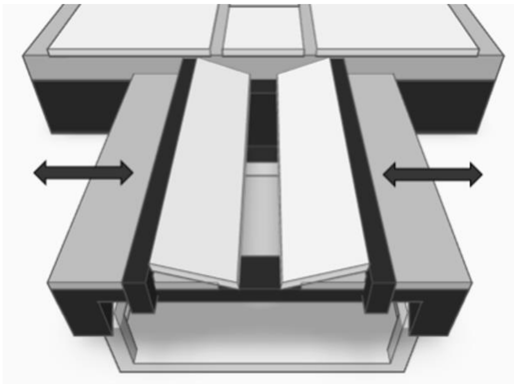

Fig. 10. Mechanism for stacking folded shirts

The stacking mechanism starts automatically as the folding mechanism ends and arrange the folded shirts in a neat and organized manner. The folding board A flips the folded shirt towards the catch tray then the catch tray opens making the shirt falls towards the collection basket below the catch tray with the help of stepper motor. It ensures that each shirt is placed on top of the previous one, creating a stable stack. This enables easy retrieval of shirts without disturbing the rest of the stack.

3. Results And Discussion

A. Developed Sensor-based Automatic Shirt Folding Machine

Fig. 11 depicts the outer facade of the machine having five folding boards, constructed using plexiglass, and incorporating a catch tray. This material is used due to plexiglass's lightweight and transparent properties, facilitating sensor functionality. The device's base is crafted from wood, ensuring stability for the entire setup. Sensor holes are strategically placed in the base, enabling accurate evaluation of the t-shirt's edge position. However, if a folding board unintentionally displaces the sensors from their intended positions, the plexiglass is perceived as a t-shirt.

Fig. 11. Developed shirt folding machine

Fig. 12 illustrates the internal of the device, showcasing the electronic connections and mechanical components involved in facilitating size adjustment movements.

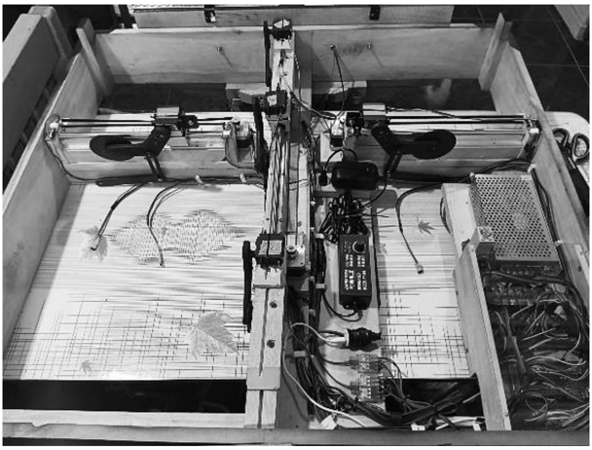

Fig. 12. Inside of the Developed shirt folding machine

a. Working Procedure of the Developed Sensor-based Automatic Shirt Folding Machine

The T-shirt folding process is illustrated in Fig. 13, outlining steps from laying down the shirt to completing the fold. The mechanism incorporates motors' torque and a specially designed arm engineered to support the weight of both the folding board and the shirt. Fig. 14 showcases the stacked shirts in the collection basket beneath the catch tray.

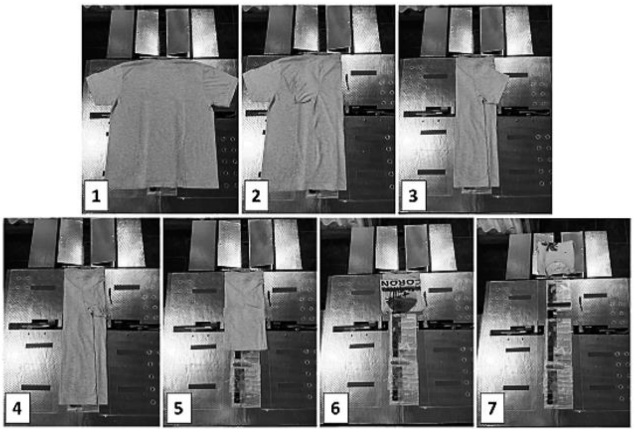

Fig. 13. Folding Sequence of the T-shirt

Fig. 14. Stacked Folded T-shirt

b. Performance Evaluation

There is a total of 20 trials for each shirt category namely kid size, adult size and plus size, having a total of 60 trials.

Table II shows the recorded resulting dimensions of the folded shirts. And it shows an error rate about 5% to the desired corresponding output folding dimensions for each category.

TABLE II. RECORDED RESULTING DIMENSIONS OF THE FOLDED SHIRTS

T-shirt Category	Width of the Folded Shirt (inches)		Length of the Folded Shirt (inches)	
		Percent Deviation		Percent Deviation
Kid Size	6.0 -	5 %	8.0 –	3.8%

	6.3		8.3	
Adult Size	9.0 - 9.4	4.4 %	10.0-10.5	5 %
Plus Size	10.0-10.4	4 %	11.-11.5	5.5 %

Table III shows the average folding time of the t-shirt using the developed shirt folding machine. The attained average folding time of the t-shirt is 8.67 secs. And the average time of the entire process, which includes placing of the shirt, adjustment, folding ang stacking, revealed to be 10.31 secs.

TABLE III. SPEED OF THE FOLDING T-SHIRTS USING THE DEVELOPED SENSOR-BASED AUTOMATIC SHIRT FOLDING MACHINE WITH DYNAMIC SIZE ADJUSTMENT

T-shirt Category	Average folding time of the t-shirt	Overall Average folding time of the t-shirt
Kid Size	8.38 secs	8.67 secs
Adult Size	8.76 secs	
Plus Size	8.89 secs	

Table IV presents a comparative analysis of the average human folding time reported in various published research documents [2], [3], [5] alongside the performance of the Developed Sensor-Based Automatic Shirt Folding Machine with Dynamic Size Adjustment. An independent t-test was employed to determine if a significant difference exists between human folding time, as reported in each published study, and the folding time of the developed machine.

Upon examination of the results, in the studies conducted by Divya et al. [5], Khairulmaini et al. [3] and Ahsan et al. [2], the calculated p-values were all less than 0.0001, indicating an extremely statistically significant difference. Yet, the folding time per shirt in the developed machine was found to be considerably faster than the reported human time in these studies.

TABLE IV. COMPARISON BETWEEN RECORDED HUMAN AND DEVELOPED SENSOR-BASED AUTOMATIC SHIRT FOLDING MACHINE'S FOLDING TIME FOR T-SHIRT

	Human			Developed Sensor-Based Automatic Shirt Folding Machine with Dynamic Size Adjustment
	Divya et. Al.	Khairulmaini et. Al.	Ahsan et. Al	
Folding Time per shirt (Sec)	10.0	20.47	12.0	8.67

4. Conclusion

This study Sensor-Based Automatic Shirt Folding Machine with Dynamic Size Adjustment is successfully developed. Through testing, the machine effectively folds shirts of various sizes using sensors and motor control, significantly reducing the time needed compared to manual folding. It shows a 5% error rate in achieving the desired folding dimensions for different shirt categories. This research and the developed machine address the practical need for efficient t-shirt folding.

The findings have significant implications for scientific understanding and real-world applications, especially in the clothing sector and related industries that involve folding of garments specifically t-shirts. For future research, the researcher suggests looking into other sensors, including computer vision technology, to identify sizes and expand folding capabilities to cover various garments beyond t-shirts. Additionally, the researchers recommend comparing the machine's performance with experts in t-shirt folding and find other ways like improving the mechanisms and motors to further reduce its time and the accuracy of the folded shirt dimensions. These research paths seek to enhance and optimize the procedure on automated folding to align with the changing industry needs.

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