

## Design and Fabrication of an Automatic Cloth Folding Machine

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### ABSTRACT

Over the past two decades, the influence of automation and technological advancements on our societies has grown significantly. These innovations have alleviated us from mundane domestic tasks, enhancing convenience and providing more time for important matters. These developments have impacted considerably everyday household activities like meal preparation, cleaning, laundry, and grocery shopping. Thanks to technology, autonomous machines can now handle most of these tasks. However, despite numerous attempts to create practical clothes-folding devices, folding clothes remains laborious and tiresome. Existing clothes-folding gadgets are not commercially available. In addition to that, most of the prototypes produced in various research are limited to folding rectangle-shaped items like towels due to their simple design. Moreover, as household devices, safety concerns arise when these gadgets operate close to children and pets, potentially causing accidents. Additionally, larger and more advanced clothes-folding machines can be inconvenient and less portable. In response to these challenges, this project was undertaken to design and fabricate an automatic machine for folding t-shirts. The other objective is to compare the time taken to fold 30 shirts manually versus autonomously. Utilising SolidWorks software, the device was carefully designed and brought to life using a prototype of the combination of an HC-SR04 ultrasonic sensor, an Arduino Mega microprocessor and three MG996R servomotors. The Weighted Decision Matrix method evaluated four concept ideas, selecting the most promising concept for further development. After successful implementation, the clothes-folding machine underwent testing to assess whether it achieved the second study's goals. Its performance was evaluated by comparing the time taken for automatic folding versus manual labour. The results demonstrated a significant time reduction of 121.54 seconds for folding 30 t-shirts, or 34.77% in time efficiency when using the automated clothes-folding mechanism compared to manual folding.

## 1. Introduction

Automation technologies have led or dominated many aspects of modern life, such as industrial machinery, military and defence arms and ammunition, entertainment, sports, and, most importantly, our daily activities. The technology of automated, mechanised devices relieves us of many routine domestic tasks to provide enhanced convenience and more time for other essential things [1]. Household chores are daily tasks that everyone performs, such as meal preparation,

cleaning, laundry, and grocery shopping. Even in developed nations, household members devote significant time to these mundane duties. In 26 industrialised countries, the average time dedicated to household chores surpasses 50% of the time invested in jobs and education in 21 countries, primarily for those aged 15 to 65 [2]. Thanks to technological advancement, automated machines can handle most of these tasks. Cleaning, for example, can be performed by a robot vacuum cleaner. Online shopping applications, which are frequently even integrated with home delivery services, have taken the grocery shopping experience to the next level. Rice cookers and washing machines are found practically in every home.

However, despite numerous innovations in washing and drying, folding clothes remains a physical and notoriously tedious task. Seven Dreamers, the company that invented The Laundroid, touted as the world's first automatic laundry folding robot, estimated that the average household comprising four people spends nearly 18,000 hours in a lifetime on laundry. Out of 18000 hours, organising, folding, and transferring the clothes to the various drawers and wardrobes took about 9000 hours [3]. Besides that, according to a study, women spend more than twice the time men spend on domestic chores. Despite working almost the same day job hours, women bore more responsibility for household chores than men. After most of the day at work, doing household tasks will tire humans out. For a task performed nearly every day, folding clothes takes too long when the time spent could be used for another purpose. Therefore, this manual task consumes much time and energy; consequently, boredom, tiredness and fatigue occur.

Furthermore, despite multiple endeavours to create practical machines for folding clothes, there are currently no commercially accessible alternatives to effectively folding intricate or non-uniform textiles such as t-shirts. Due to their simpler form, most gadgets in the market are limited to folding rectangular items, such as towels. Advanced clothes-folding machines tend to be bulky, making them less portable and convenient for domestic use. On top of that, safety is a critical concern, as these devices operate near children and pets in households. Children's natural curiosity may lead them to put their hands in the machine, potentially resulting in injuries.

The automatic cloth folding machine is in increasing demand in our daily lives. Therefore, this project was developed and designed to eliminate the tedious cloth folding. The objectives are to design and fabricate an effective mechanism for folding cloth using a few electronic devices. Then, to compare the timing of folding cloth manually and autonomously. In summary, this research paper is about improving the cloth folding tool to provide improved features such as reducing folding time, saving physical energy while folding many cloths, and overcoming challenges in handling the device if it is complicated.

### *1.1 Literature Review*

Despite numerous attempts to develop functional clothes-folding devices, commercially available solutions must be designed to fold shirts. Nonetheless, notable inventions in this domain are relevant to this research endeavour. By delving into the existing literature and examining these inventions, the study aims to advance cloth-folding technology and address the pressing need for an efficient and accessible device to fold shirts and simplify users' lives.

The Laundroid is a prototype cloth-folding machine revealed during the 2017 Consumer Electronics Show (CES), an annual trade show organised by the Consumer Technology Association, where breakthrough technologies or innovations related to the consumer electronics industry are presented. It is a joint invention of the leading corporations of Japan, namely Panasonic, Daiwa House, and Seven Dreamers. The cloth-folding machine is rectangular, about the size of an enlarged refrigerator. At less than 35 decibels, its operating noise is equivalent to a running air conditioner.

The Laundroid has two modes of operation; the first mode categorises the laundry depending on its type (shirt, pants, towel). In the second option, the device sorts by family members, placing each clothes in a designated spot after registering each piece of clothing through an application, allowing the bot to determine whose. Image processing, robotic systems, and artificial intelligence (AI) are technologies utilised in the Laundroid operation. Identifying each cloth, interacting with a centralised server over Wi-Fi, and folding each item takes approximately 5 to 10 minutes. Users will be required to perform some tasks, such as partially buttoning shirts and checking that the clothes are not inside out. The technology of the Laundroid seems promising at first until it fails to recognise dark-coloured garments. Having a hefty price tag of \$16,000 certainly does not help either. The developing company, the Seven Dreamers, was declared bankrupt in 2019, failing to sell a single device. It turns out that the complexity of getting AI, image processing, and robotic arms to function simultaneously made the problem too difficult to tackle [4].

The FoldiMate prototype, another emerging innovation with a considerably lower price tag of \$1000, was unveiled at the Consumer Electronics Show (CES) in 2018. According to its creators, it can fold a laundry of around 25 items in less than 4 minutes. Furthermore, the equipment emits noise comparable to that of a large printer. The built-in tray can accommodate 10 to 15 shirts, depending on the thickness of the garment [5]. To use, the consumer or user must attach a piece of clothing to two hooks that draw it into the machine. A series of rollers and arms then move to flatten and fold it. FoldiMate can fold shirts, buttoned-up blouses, and pants in sizes ranging from children to adults [6]. The newest model can now fold towels and pillowcases, but complex-shaped clothes such as socks and underwear remain on-limits. The folded items are returned to the machine in a stack via a window at the machine base. The FoldiMate is ideal for use in the living room or bedroom and is designed to be around the size of a standard washing machine. The FoldiMate is considered an up-and-coming invention due to its considerably cheaper price than the Laundroid. However, according to the reviewers at the CES, the FoldiMate cannot fold non-medium-sized items, such as bedsheets or baby clothes. The FoldiMate, aimed initially to have anti-wrinkling technology and fragrance features, was redesigned into a simple cloth-folding machine. The prototype, however, failed to enter the market as its founding company, the Seven Dreamers, filed for bankruptcy in 2019.

Another prototype by Hata et al. (2009) [7] has successfully developed an experimental cloth-handling robot system composed of an image processor, two handling robots, a precision vision, a slider, a vision phase conveyer belt, a cloth adjuster, a mounting frame, utilising clean and dried towels as experimental garments. The robot has two cameras, a pattern projector, and an LED lighting system. The pattern projector's image reflects a mesh motif with dots on the towel. The mesh design allows for the extraction of accurate towel shapes, whereas dot patterns are required for rough pattern recognition, which is necessary to evade mesh pattern mismatching. Although the device was satisfactorily produced, additional modifications are required as the overall efficiency is 80%, which is risky if this technology is implemented in laundromat factories or other places requiring higher precision and accuracy.

An ultrasonic sensor is a device that utilises ultrasonic sound waves to calculate the distance to an item. The HC-SR04 ultrasonic sensor employs SONAR technology to measure the length of an object precisely. This highly effective sensor provides reliable non-contact range detection with exceptional accuracy, covering distances from 2 cm to 400 cm. Notably, its functionality remains unaffected by sunlight or black surfaces. However, it may encounter challenges when detecting soft materials like cloth due to acoustic properties [8]. Comprising an ultrasonic transmitter and receiver module, the HC-SR04 sensor is thoughtfully designed for effortless integration and user-friendly operation. As a result, it has gained widespread popularity among embedded system developers due to its accessibility, seamless integration capabilities, and affordability [9].

Another popular method is Arduino IDE software, ultrasonic sensor and gear servo. In the study by Irawan et al. [10], a garment-folding gadget was designed to address issues by folding clothing quickly and neatly without having to fold them manually. A low-cost, Android-based folding gadget for apparel has been created using a similar approach [11]. The single-board microcontrollers and microcontroller setups for producing computerised gadgets are developed and produced by Arduino, an open-source technology and software platform. The boards have an ATMEL microprocessor, RAM, flash storage, and input and output cable stations, thus having the same framework as standard personal computers. Regardless of its simplicity and modest cost, the Arduino, according to Schubert et al. [12], can act as a competent microcontroller for experimentation scenarios. A study additionally demonstrated that the duration and latency of signal produced by an Arduino were regularly constant [13]. The same research also discovered that standard input and output combinations were executed with extraordinary precision and accuracy, often with standard deviations of barely microseconds, demonstrating how an Arduino may substitute more complex devices as an independent controller. The Arduino also consists of software, Arduino Integrated Development Environment (IDE), which incorporates the C programming language, the most popular programming tool. Table 1 shows a summary of frequently used Arduino Microcontrollers.

**Table 1**  
 Summary of frequently used Arduino Microcontrollers

References	Description	Findings
Kondaveeti et al., [14]	Arduino LilyPad	<ul style="list-style-type: none"> <li>• Suitable for e-textiles or wearables</li> <li>• Can be sewed to the fabric as well as jointed power supply, sensors, and actuators</li> </ul>
Ben, n.d. [15]	SparkFun Qwiic Pro Micro	<ul style="list-style-type: none"> <li>• Can be supported by battery or AC to DC adapter</li> <li>• Can handle up to 6VDC thanks to the voltage regulator</li> <li>• Can be reset without requiring the removal of wires</li> <li>• Transfer data at a faster pace via USB-C</li> </ul>
Arduino Mega 2560 Rev3 — Arduino Official Store, n.d. [16]	Arduino Mega	<ul style="list-style-type: none"> <li>• Can be powered via USB cable, power outlet or its Vin pin</li> <li>• Can be reset without requiring the removal of wires</li> <li>• Resettable poly fused protects against overheating</li> <li>• Two voltage regulators, a 5V and 3.3V</li> </ul>

A servomotor is a highly efficient and precise actuator, enabling control over rotational or linear position, velocity, and acceleration. It consists of a motor connected to a position feedback sensor and requires a powerful controller, often a specialised module explicitly designed for servomotor use. A closed-loop system includes a control circuit, servo motor, shaft, potentiometer, drive gears, amplifier, and an encoder or resolver. Servo motors use conventional and positional feedback sensors to achieve precise control. The MG996R servo motor represents an improved version of the MG995 servo, featuring notable enhancements in performance and accuracy. A new PCB and IC control system delivers greater precision in its movements. Upgrades to its internal gearing and motor enhance dead bandwidth and centring, resulting in smoother and more accurate operation [17]. A distinguishing feature of the MG996R is its metal gear construction, providing enhanced durability and resistance to wear. With an impressive maximum stall torque of 11 kg/cm, the motor can sustain a total full load of 11kg when suspended at 1cm, making it capable of handling higher loads and providing increased force. Similar to other servos, the MG996R's motor can rotate within a range of 0 to 180 degrees based on the duty cycle of the supplied PWM (Pulse Width Modulation) wave to its signal pin. This precise control mechanism makes it well-suited for various applications. In the context of this project, the MG996R servomotor will be employed to automate the cloth-folding board, allowing for efficient and accurate cloth-folding operations.

Based on the insights gained from the literature review, the HC-SR04 ultrasonic sensor, Arduino Mega microcontroller and the MG996R servomotors have been chosen for this study due to their advantages and capabilities. These selected components are highly suitable for the research objectives, ensuring efficiency and precision in the cloth-folding process.

## 2. Methodology

The flowchart in Figure 1 visualises the sequential process adopted in the research project to design and construct an efficient clothes-folding device. Firstly, extensive research was conducted to explore the existing cloth-folding technologies available in the market, and relevant information was gathered from research papers and academic studies. Product Design Specifications (PDS) were carefully formulated and tabulated to guide development. Four concept ideas were generated to meet the criteria laid out in the PDS. These concepts were evaluated using a Weighted Decision Matrix, resulting in selecting the most promising idea for further development. The prototype was designed using SolidWorks software. The project involves designing and constructing an efficient device for folding shirts, utilising electronic components such as ultrasonic sensors, servomotors and an Arduino Mega microcontroller. After the fabrication, the clothes-folding machine underwent a thorough evaluation to determine whether the project's aims and objectives were successfully achieved. The device's ability to fold clothes, mainly shirts, was a critical benchmark of success. Moreover, the time to autonomously fold thirty pieces of clothing was observed and compared against manual labour. The ultimate goal was to reduce the time required for folding clothes significantly.

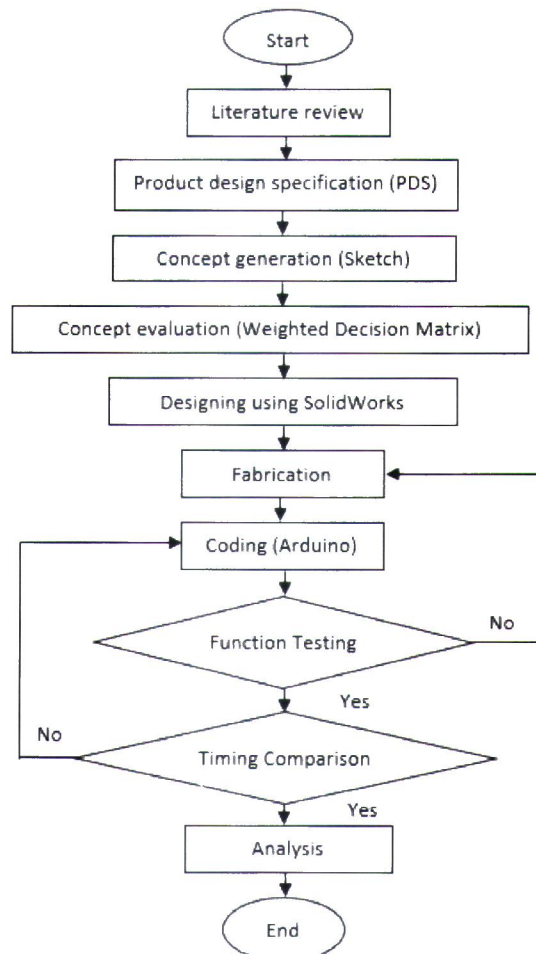


Fig. 1. Flowchart depicting the research flow

## 2.1 Potential Difficulties, Challenges and Proposed Solutions

The cloth folding machine is expected to encounter some difficulties during the design and fabrication. Therefore, the potential challenges are listed and proposed solutions to counter the problems shown in Table 2:

**Table 2**

Potential difficulties, challenges and proposed solutions

Potential Challenges/Difficulties	Effect on the cloth folding machine	Proposed solution
Material of the folding tools	Clothes slipping from the tools	Material with a rough surface
Detection of the clothes	The servomotor fails to detect the clothes and cannot fold in the correct mechanism.	Servomotor placement testing
Folding mechanism	The cloth folding machine may fail to fold complex-shaped clothes	Further consideration of the folding mechanism

## 2.2 Product Design Specifications (PDS)

The primary objective of this Product Design Specifications (PDS) is to serve as a guiding framework during the entire development process, as shown in Table 3. The specification is crucial in transforming abstract ideas from the initial design phase into well-defined and concrete requirements. Adhering to the PDS ensures the successful design and fabrication of the cloth folding machine.

**Table 3**

Product Design Specifications (PDS)

General Requirements	Specific Requirements	Acceptable Performance
Automatic	Able to fold the clothes automatically	Arduino Integrated Development Environment (IDE) is utilised to write codes and communicate with the hardware.
Safety	Safe for usage in a household (close to children and pets)	The cloth folding of the machine is designed with no sharp edges, and the electrical components are placed inside a cover/compartament
Portability	Easy to be moved	Tyres or other moving mechanism is added
Sustainability	Economic costs	Inexpensive life-cycle cost
Maintenance-friendly	Non-complex design	The electronic parts should be easy to remove for repair or maintenance work.

## 2.3 Conceptual Design

Four distinct concepts are sketched based on the insights derived from the mind map to meet the requirements outlined in the Product Design Specifications (PDS). These sketches present various design ideas and configurations that explore different approaches to developing the cloth-folding machine, as shown in Figure 2. Each concept aims to address specific aspects and functionalities specified in the PDS, ensuring that the final design aligns with the desired objectives of the project. The sketches serve as a visual representation of the creative exploration and innovative thinking undertaken to achieve an efficient and practical cloth-folding device.

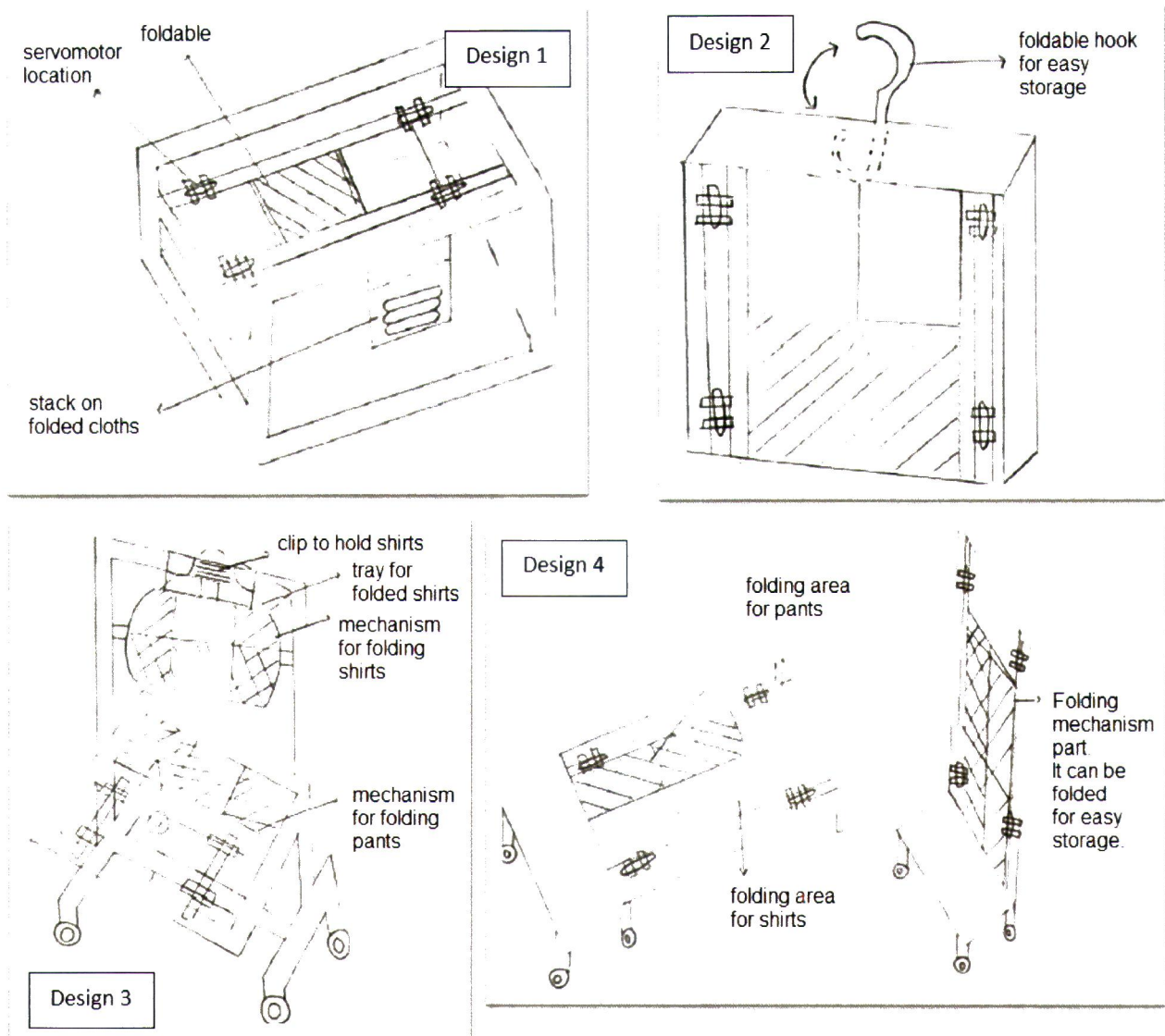


Fig. 2. Four Design Concepts

Design Concept 1 adopts a cuboid shape, positioning the servomotor and folding board on the top side. A practical feature in this concept is a designated section for stacked folded items, enhancing user convenience during garment collection. However, this design approach poses a safety concern for households with children or pets, as the electrical components are exposed at the machine's top, increasing the risk of potential injuries. Another drawback of this concept is its large size, making it less suitable for easy storage and requiring additional storage space. Additionally, the absence of wheels or tires limits its mobility, hindering the ease of transportation to different locations.

Design Concept 2 shares the same structural and electronic components as Design Concept 1 but incorporates a design inspired by a fabric hanger. Including a hanger-like hook facilitates convenient storage of the cloth-folding machine when not in use. By positioning it at a higher level, this design feature enhances safety, reducing the risk of potential physical harm to children or pets who might otherwise interact with the machine. However, a potential disadvantage of this approach is that when the machine is suspended in the air, it may not achieve the same level of precision in folding garments as when placed on a stable surface. This consideration underscores the importance of balancing improved safety features and the machine's folding performance.

Design Concept 3 introduces the integration of tires, enhancing portability and ease of transportation for the cloth-folding machine between storage and utilisation for folding garments. It stands apart from the other design ideas by featuring a dedicated folding area for shirts, aiming to improve efficiency by allowing the simultaneous folding of two items. However, one setback with this design is the higher procurement cost, which necessitates twice as many mechanical and electrical components. Moreover, separating the folding regions may pose challenges when conducting maintenance or repairs, potentially making addressing any issues more complex and time-consuming. Balancing the benefits of enhanced portability and efficiency with the increased cost and maintenance considerations will be crucial in evaluating the overall feasibility and practicality of Design Concept 3.

Design Concept 4 similarly incorporates tires to improve portability and utilises a bedside table design. It provides enhanced stability, essential for precise and accurate cloth-folding operations. The flat and firm surface of the table ensures that the machine remains steady during the folding process, minimising any unwanted movements that could affect the folding precision. Moreover, the table design allows for better ergonomics and user accessibility. Users can easily approach the table and interact with the cloth-folding machine comfortably, reducing strain and fatigue during operation. Secondly, space efficiency is critical in household settings where the cloth-folding machine is likely to be utilised. The table design offers a more compact and space-saving solution. This clever design ensures easier storage, requiring less space when not in use. Moreover, placing the components within a secure cover provides added safety measures, safeguarding children and pets from potential harm. This thoughtful consideration addresses the concerns raised in previous design ideas regarding safety. By combining enhanced portability, efficient storage, and improved safety features, Design Concept 4 offers a comprehensive and user-friendly solution for the cloth-folding machine. Integrating these beneficial elements enhances the practicality and usability of the device in various domestic settings.

## 2.4 Concept Evaluation

During the concept-generation stage, four viable model solutions for the Cloth-folding machine design were identified and represented through drawings. A thorough assessment of these concepts is essential to determine the most suitable design concept that aligns with the Product Design Specifications (PDS).

**Table 4**

Weighted Decision Matrix

Parameters	Design Concepts							
	1		2		3		4	
	Rank	Weighted Score	Rank	Weighted Score	Rank	Weighted Score	Rank	Weighted Score
Portability (10%)	1	0.1	3	0.3	2	0.2	2	0.2
Storability (10%)	1	0.1	3	0.3	2	0.2	3	0.3
Automatic (30%)	3	0.9	1	0.3	3	0.9	3	0.9
Safety (20%)	1	0.2	1	0.2	1	0.2	1	0.2
Costs (15%)	3	0.45	3	0.45	1	0.15	3	0.45
Maintenance-Friendly (15%)	3	0.45	3	0.45	1	0.15	3	0.45
Total	12	2.2	14	2.0	10	1.8	15	2.5
Rank	2		3		4		1	
Decision	No		No		No		Yes	

The Weighted Decision Matrix, as shown in Table 4, also known as the prioritising matrix, facilitates comparing and evaluating the generated design concepts. This technique allows for a systematic comparison of different approaches, assigning varied weightage to each parameter based on its significance to the product. Unlike the Pugh Concept Selection method, which assumes equal importance for all factors, the Weighted Decision Matrix allows for a more flexible and nuanced evaluation of the design concepts [18].

Given the varying levels of importance for different aspects of the cloth-folding machine, the Weighted Decision Matrix was deemed the appropriate method for conducting the assessment. By utilising this technique, the project can objectively and comprehensively evaluate each design concept, ultimately aiding in selecting the most suitable and feasible solution that best fulfils the Product Design Specifications (PDS).

In the context of electromechanical systems, the function algorithm is a valuable tool for describing product functions in detail by breaking down the main product into smaller, manageable problems. In order to gain a deeper understanding of the working principle of the automatic cloth-folding machine, the functions of the whole product, subassemblies, and functions of individual components are segregated. This hierarchical approach that allows for a comprehensive analysis of the device's functions and their interconnections is displayed in Figure 3.

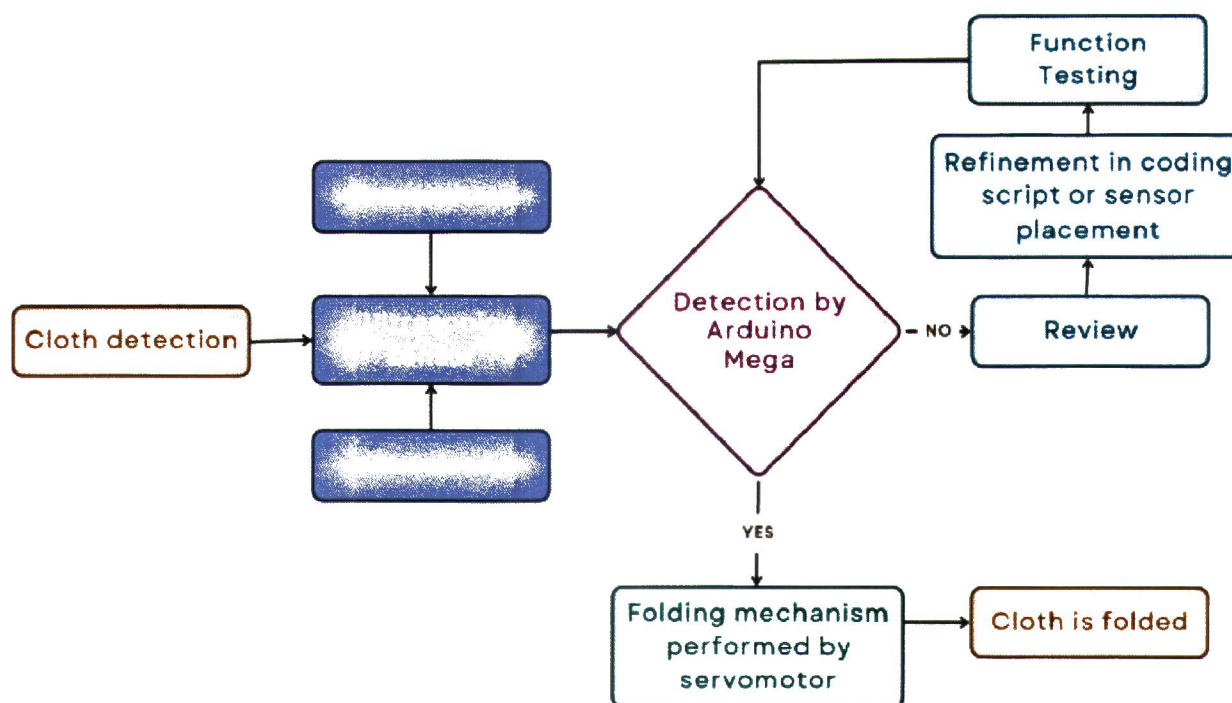


Fig. 3. Algorithm of the Function

### 3. Results

The selected concept has undergone development, leading to the successful creation of a clothes-folding machine specifically designed for efficiently folding shirts. The design process involved using Solidworks software, which facilitated the integration of essential components, including the HC-RS04 ultrasonic sensor and three MG996R servomotors, all precisely controlled by an Arduino Mega microcontroller.

### 3.1 Modifications Made to the Selected Design

After careful consideration, the decision has been made to shift the design direction from a cart to a table. This is done by retaining and matching the parameters to select the most suitable design. An automated cloth folding machine incorporating an adjustable table with wheels, as shown in Figure 4, provides numerous advantages over a traditional cart design.



**Fig. 4.** The Adjustable Table with Wheels

Firstly, the flexibility in height and size afforded by the adjustable table gives the machine ergonomic benefits. Operators can set the table at the optimal height, reducing strain and fatigue during the loading and unloading of clothes. This improved ergonomics increases worker productivity and creates a more comfortable working environment, leading to a more efficient and contented workforce. Including wheels in the design adds to the machine's mobility, allowing it to move quickly within the workspace. This feature is particularly useful in dynamic environments where the machine may need to be relocated frequently or shared among different workstations. Moving the machine around effortlessly enhances the overall workflow and operational flexibility.

Space efficiency is another crucial advantage of adopting an adjustable table with wheels. When not in use, the table can be conveniently stored or tucked away, optimising floor space in the facility. On the other hand, a fixed cart may require a designated area for storage, limiting the workspace's flexibility and potentially cluttering the area when not in operation. The stability and security the adjustable table design offers are crucial for achieving consistent and precise folding results. Unlike carts, which might be more prone to shifting during folding, an adjustable table provides a stable platform, ensuring that clothes remain in position and the folding operation proceeds smoothly.

In conclusion, adopting an automated cloth folding machine with an adjustable table and wheels brings many benefits. It offers flexibility, ergonomic advantages, mobility, space efficiency, stability, customisation, and integration. It is superior to a traditional cart design for cloth folding operations in various work environments.

### 3.2 Full Assembly of the Solid Works Design

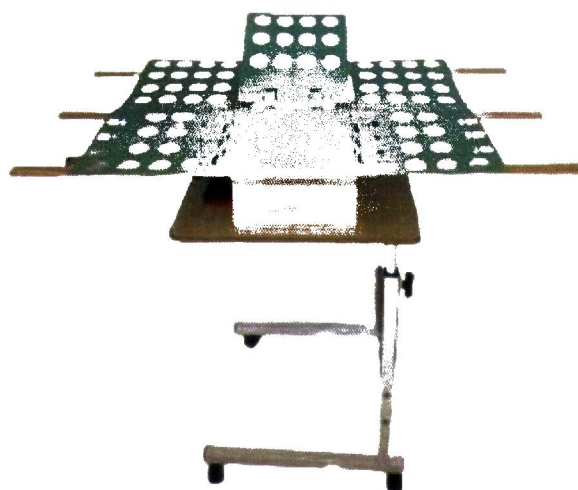
The entire assembly of the selected design concept of the cloth-folding machine was meticulously constructed using the detailed 3D models designed in SolidWorks, as shown in Figure 5. The assembly process involved integrating various components, including the HC-RS04 ultrasonic sensors, three MG996R servomotors, and the Arduino Mega microcontroller. Each component was carefully positioned and secured to ensure optimal functionality and performance.



**Fig. 5.** The SolidWorks Design

### *3.3 Production of Prototype*

The production of the cloth-folding machine prototype, as shown in Figure 6, commenced after the final concept was selected and refined using SolidWorks software. The prototype was meticulously fabricated, ensuring all components were assembled according to the design specifications. The manufacturing process involved precision machining and joining techniques to achieve a high-quality and reliable prototype. During the production phase, integrating the HC-RS04 ultrasonic sensor, three MG996R servomotors, and the Arduino Mega microcontroller was carefully executed to ensure seamless communication and precise control of the cloth-folding mechanism. Each component was tested for functionality and compatibility, and any necessary adjustments were made to guarantee optimal performance. The successful production of the cloth-folding machine prototype marked a significant milestone in the project, demonstrating the feasibility and potential of the innovative design.



**Fig. 6.** The Full Assembly of the fabricated prototype

As part of the assembly process, the MG996R servomotors were strategically extended in length by attaching them to plastic chopsticks. This modification was implemented to enhance the reach and functionality of the servomotors, enabling them to handle larger and heavier garments during the folding process effectively. Using plastic chopsticks as extensions provided a lightweight and durable solution, ensuring smooth and reliable operation of the servomotors in the cloth-folding machine. This innovative approach contributed to the overall efficiency and performance of the device, allowing it to fold shirts with precision and ease effectively. Figure 7 shows The folding sequence of the T-shirt.

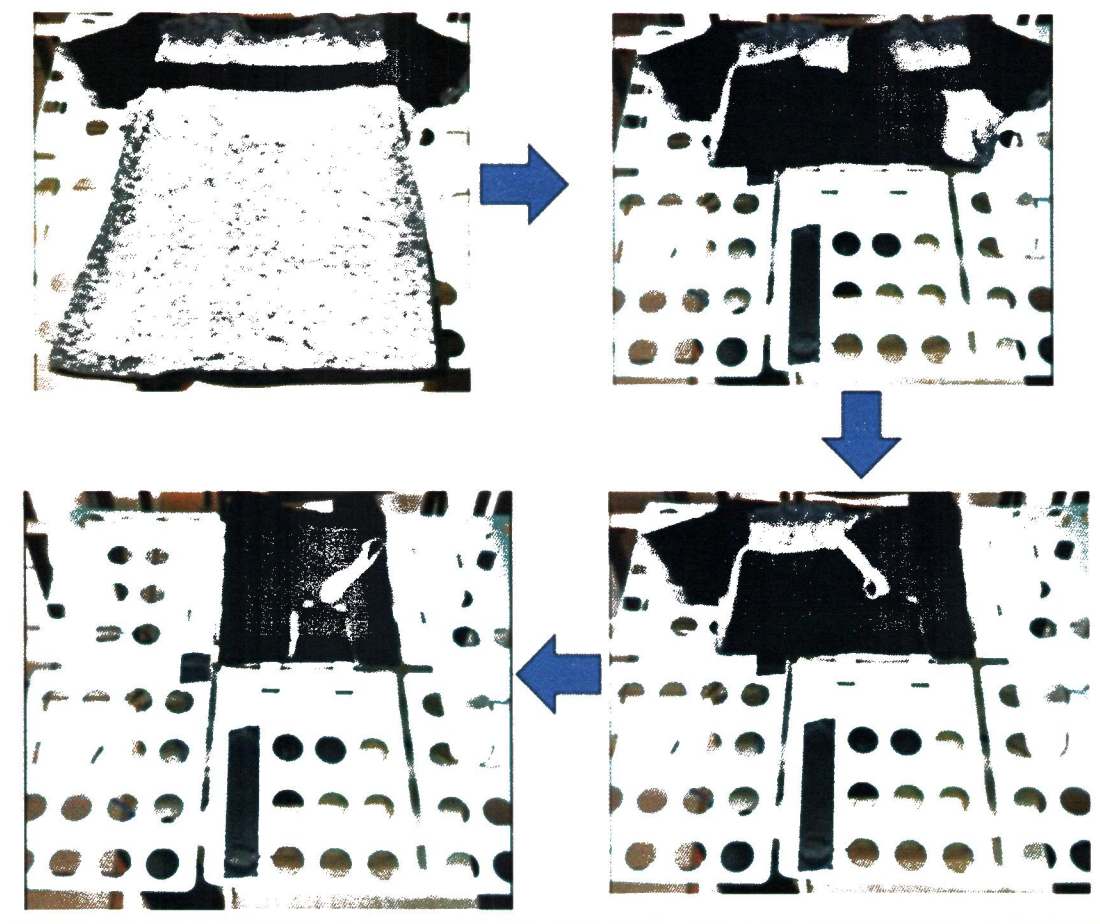
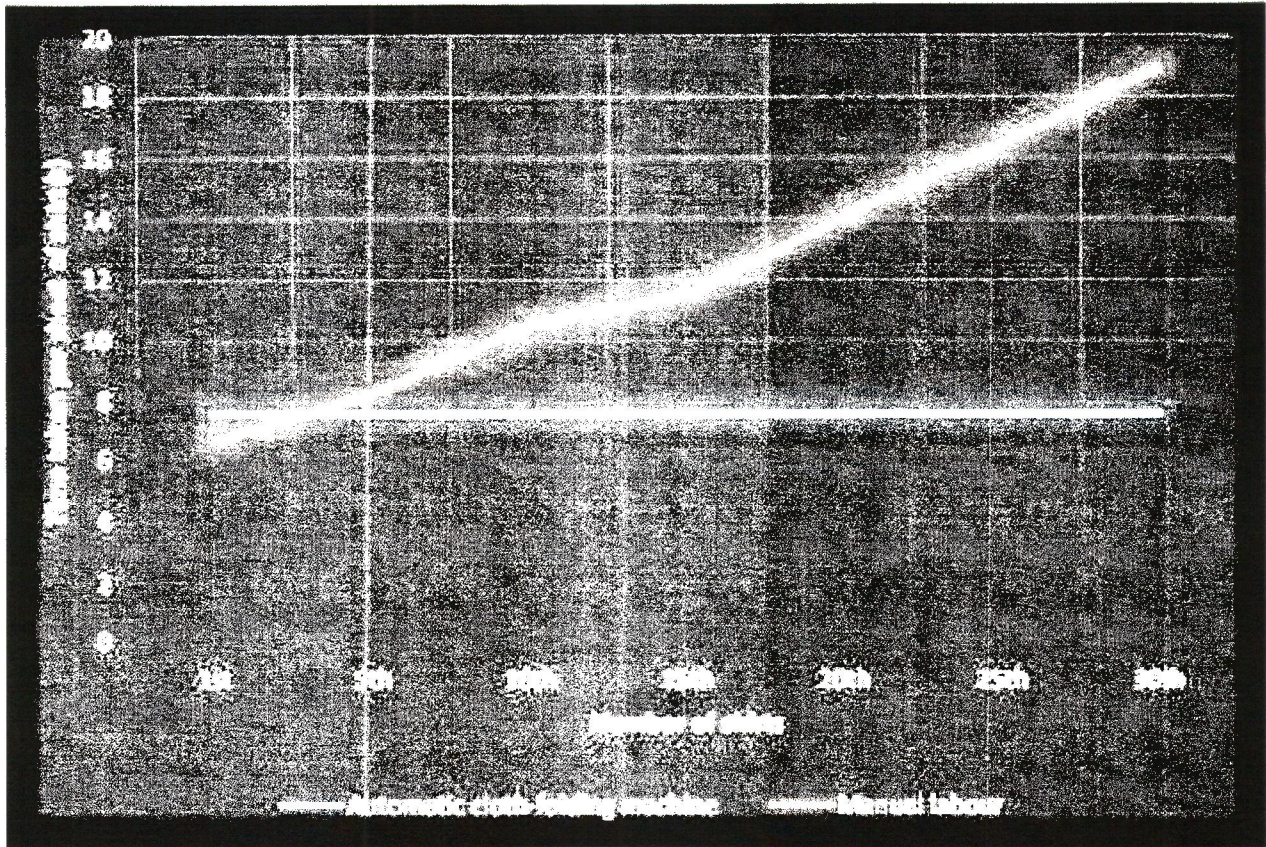


Fig. 7. The folding sequence of the T-shirt

### 3.4 Timing Comparison

The performance evaluation of the developed clothes-folding machine involved a comparative analysis of the time taken for automatic folding versus manual folding by human labour. For this evaluation, 30 shirts were utilised as the standard measurement. To ensure accuracy and reliability, the folding process for both the automatic and manual methods was conducted under controlled conditions, with consistent folding techniques employed for each shirt. The time taken for the cloth folding machine to fold the 30 shirts autonomously was recorded. The efficiency and effectiveness of the cloth-folding machine were evaluated by comparing the time taken for automatic folding with the time taken for manual labour. The data obtained from this performance assessment served as a crucial metric to gauge the success of the machine in reducing the time and effort required for folding clothes, thus validating the benefits of automation in this context.

Based on the recorded data, it is evident that the manual folding of the 30 clothes took an average of 349.54 seconds, while the automatic folding using the developed clothes-folding machine took an average of 228.00 seconds. Figure 8 indicates that the designed machine outperformed manual labour regarding time comparison. The cloth-folding machine demonstrated significantly faster and more efficient folding capabilities, reducing the time required to fold the same number of shirts compared to manual folding. This time-saving aspect highlights the successful implementation of the automated system, providing users with a practical and time-efficient solution for folding clothes. On average, it could fold the shirts approximately 121.54 seconds faster for 30 sheets than manual folding, resulting in about 34.77% time savings.



**Fig. 8.** The Full Assembly of the fabricated prototype

The automated folding device achieves a shorter folding time due to its consistent and precise folding mechanism, ensuring uniform and accurate folds for each garment [13]. This eliminates the variability introduced by manual folding, resulting in a more efficient process. Integrating ultrasonic sensors and servomotors enables rapid and accurate garment detection and folding actions. The sensor detects the presence and dimensions of each garment, allowing the device to adapt its folding mechanism accordingly. In contrast, manual-folding involves visual inspection and manual manipulation, which is time-consuming and prone to errors.

#### **4. Conclusions**

The development of this clothes-folding machine signifies a significant advancement in domestic automation, providing users with a practical and time-saving solution for the laborious task of folding clothes. The technology enhances convenience and the overall user experience by reducing the effort and time required for this routine household chore. Indeed, the research has effectively accomplished its primary objectives of designing and fabricating an automatic cloth-folding machine and conducting a comparative analysis of the time taken for autonomous and manual folding. Developing the efficient clothes-folding device, utilising electronic components such as three MG996R servomotors, HC-SR04 ultrasonic sensors, and an Arduino Mega microcontroller, represents a significant advancement in household automation technology. Besides, the developed clothes-folding machine has proven its superiority over manual labour in terms of time efficiency. According to the recorded data, the machine folded 30 shirts approximately 121.54 seconds faster than manual folding, resulting in a substantial time saving of about 34.77%. The success of the automated folding device can be attributed to its consistent and precise folding mechanism, ensuring uniform and accurate folds for each garment.

## 5. Recommendation for Future Research

In terms of future research, several key areas can be explored to maximise the potential of this project. Firstly, there is room to investigate the machine's compatibility with other clothing items, such as pants, skirts, or socks. This expansion in functionality would greatly broaden its applicability and usefulness in various household tasks. Secondly, incorporating advanced sensors and algorithms can improve the machine's folding accuracy and adaptability. This enhancement would allow for more precise and reliable folding performance, as the machine would be better equipped to identify and understand the unique characteristics and folding requirements of different garments.

Additionally, optimising the folding speed is an important aspect to consider. This can involve refining the movements of the servo motors, exploring alternative folding techniques, or even implementing parallelisation to fold multiple garments simultaneously. The machine can further enhance its efficiency and convenience by reducing the time required for folding. Furthermore, gathering user feedback and conducting thorough usability studies would be instrumental in refining the machine's design and integration. By actively involving users in the development process, their valuable insights can help identify areas for improvement and ensure a more user-friendly experience. Additionally, exploring integration options with smart home systems or mobile applications could enhance the machine's accessibility and convenience for users.

On top of that, it would be valuable to explore the potential of the cloth-folding device in alleviating musculoskeletal pain. Musculoskeletal disorders (MSDs) are closely associated with the intensity and severity of work, even in seemingly lighter activities like housework or exercise [19]. One specific condition related to muscular imbalances is Upper Crossed Syndrome (UCS), which results from weakness in certain muscle groups and tightness in others. This syndrome is primarily caused by the imbalance between weak and tonic muscles, leading to deep neck flexor weakness and tightness in the pectorals and sternocleidomastoid muscles. According to research, Laundry workers who perform tasks like sorting, washing, drying, ironing, and potentially folding clothes are particularly susceptible to developing musculoskeletal problems, including Upper Crossed Syndrome [20]. Their work's repetitive and physically demanding nature can contribute to the development of muscular imbalances, leading to discomfort and pain in the neck, shoulders, and upper back. While the current research mainly focuses on sorting, washing, drying, and ironing tasks, it is essential to recognise that folding clothes could contribute to musculoskeletal issues.

Further investigation into the impact of folding on musculoskeletal health is warranted to gain a comprehensive understanding of potential risks and develop strategies to mitigate any adverse effects. The project can reach its maximum potential by focusing on these areas of future research. Ultimately, these efforts will contribute to a highly efficient and versatile clothes-folding machine.

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