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Ergonomic Assessment in Designing a Semi-Automatic Silk Screen Printing Machine: A RULA Analysis for Reducing Repetitive Strain in SMEs

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ABSTRACT

The silk screen printing process remains widely used due to its versatility and ability to deliver high-quality prints. However, the conventional manual approach is characterized by repetitive strain, inconsistent print quality, and slow production. This study focuses on the design and development of a semi-automatic silk screen printing machine to address these challenges while emphasizing ergonomic improvements. Field testing compared manual and semi-automatic methods in terms of production time, print consistency, and ergonomic outcomes, assessed using the Rapid Upper Limb Assessment (RULA). Results show that the machine reduced printing time per shirt from 25 seconds to 12 seconds, and steps required decreased from 10 to 6. Ergonomic assessment confirmed reduced strain and musculoskeletal risks for operators. Although the 24V stepper motor caused slower squeegee movement and minor ink blockage, the overall performance demonstrated significant improvements in productivity, ergonomic safety, and consistency. The semi-automatic machine provides an effective solution for small and medium enterprises (SMEs), offering a foundation for further optimization in ergonomic industrial design.

Keywords: Ergonomic Assessment**,** Rapid Upper Limb Assessment (RULA), Silk Screen Printing

1. INTRODUCTION

Screen printing is one of the most widely adopted techniques for fabric and material printing, offering durability, versatility, and low-cost implementation. Manual screen printing, while effective, demands high levels of physical effort and repetitive movement, which may lead to musculoskeletal disorders (MSDs) among workers. With the growing focus on productivity and occupational health, semi-automatic machines present a balanced solution between efficiency and affordability.

Previous studies [1][2] have highlighted the potential of integrating servo systems, linear guides, and optimized squeegee mechanisms to enhance printing accuracy and repeatability. From an ergonomic perspective, minimizing repetitive strain while ensuring machine usability is central to improving worker well-being and sustaining productivity in small and medium-sized enterprises (SMEs).

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1.1 Printing Accuracy and Repeatability

To recurring the problem of the quality print is a major issue in printing, the other technology makes a lot of progress for all printing. Stenciling screen printing is non-automatic, and the succeeding steps are applying emulsion and in return, the image obtained is of an ink patch. These uncertainties can generate unsatisfactory designs or images where the original ones get replaced by other versions. These characteristics will decide whether the product is premium quality or standard one, and thus, will affect the uniformity of the product.

1.2 Repetitive Strain and Discomfort

Repetitive strain and discomfort in screen printing therefore stems from the repetitiveness of the motions carried out while screen printing. This problem often happens when workers make the same movements for many times, like pressing the screen, aligning designs, or handling some materials. In the long term, such movements cause physical stress and pains, thus affecting the productivity of the workers. Over time, pressure causes carpal tunnel syndrome or general pain that becomes chronic in nature. The consequences of this problem are that people may lose productivity or even be forced to quit working due to the pain and injuries that they suffer.

1.3 Hindering Productivity

Challenges in productivity that relate to screen printing involve attaining the level of quality of the hand printed work but using automatic equipment that require dozens or hundreds of pieces at a go. The issue arises because manual screen printing involves complex slow movements which causes a problem when automating the process, resulting in slowed down production. This issue hinders products from being manufactured at the expected time according to the number of units required [3]. In traditional screen printing, lifting and moving of increased frames proved difficult and risky as it led to more cases of human error and potential injuries. These problems are solved with the help of automation since printing itself is performed without the direct participation of the worker, thus, the resulting output contains fewer errors, and the likelihood of the worker being injured is minimized.

2. MATERIAL AND METHODS

Afterwards, the screen is prepared for screen printing on a screen printing press [4]. Many designs are used to support the screen and enable it to be aligned properly for the ink to be applied meticulously. Small scale production often employs the manual presses while the automatic presses are commonly used in large scale production due to the speed factor. There are steps that are followed in the application of the ink and one of them is to put the T-shirt on a flat board that has capacity of holding the T-shirt. The screen is then placed and lowered to cover the shirt. Figure 1 shows the ink is distributed across the screen with a squeegee, which applies pressure that is employed to drive the ink to the mesh's open areas and deposit it onto the article of clothing [5]. The optimum pressure is supposed to be applied when printing to make it more long lasting.

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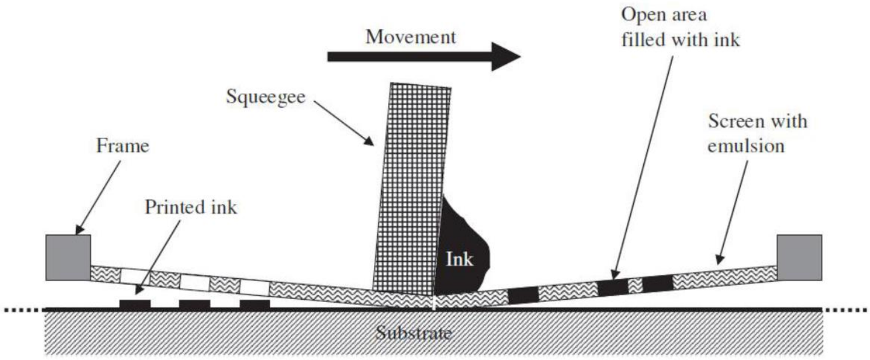

Figure 1. Illustration of screen printing process [5].

2.1 User Needs Identification

This section specifically focuses on problems articulated by user through interview sessions, which were crucial for identifying and listing user needs to guide the final product specification. The main data was collected through interview with individuals who have many experiences in fabric printing as shown in Figure 2.

Figure 2. Interview sessions with experienced people.

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The interviewees share their issue and opinion regarding to the silk screen printing. Data for this project was primarily gathered through five interview sessions. These sessions aimed to identify the existing screen printing processes and pinpoint the specific problems encountered with manual screen printing methods. The details of the interviewee is tabulated in Table 1.

Table 1. Interviewee background.

No.	Interviewee	Position and Company Name	Year (s) of Experience
1	Mr. Hassan bin Ahmad 61 years old	Manager SAM Kreatif Dinamik Sdn. Bhd	30 years experiences
2	Mrs. Suria binti Abu Salim 52 years old	Assistant Manager SAM Kreatif Dinamik Sdn. Bhd	25 years experiences
3	Mr. Muhammad Amirul Mukminin bin Hassan 27 years old	Worker SAM Kreatif Dinamik Sdn. Bhd	4 years experiences
4	Mrs. Musryfah binti Mansor 27 years old	Worker SAM Kreatif Dinamik Sdn. Bhd	3 years experiences
5	Mr. Mahazani bin Omar 48 years old	Screen Printer MBO Utara Enterprise	16 years experiences

Experienced personnel from SAM Kreatif Dinamik Sdn. Bhd. and MBO Utara Enterprise provided critical insights into the challenges of silk screen printing, highlighting the urgent need for improvements. The manual nature of the process consistently led to physical strain, with repetitive movements and prolonged standing causing discomfort in the wrist, hand, leg, and back. The time-consuming setup process hindered productivity, while uneven ink distribution and improper squeegee angles resulted in inconsistent prints. The diversity of printing materials further complicated operations, as each required specific inks, angles, and techniques.

Production capacities varied significantly, ranging from 100 to 300 units per hour, depending on job complexity and workforce size (typically one to five workers), with most tasks limited to single-colour prints. To overcome these challenges, interviewees strongly suggested integrating automation, such as robotic arms, motorized squeegees, or ink pushers, to enhance efficiency, alleviate physical strain, and ensure consistent ink application. A compact machine design was also deemed beneficial for small workshops, and addressing issues like ink blockage, setup time, and ink distribution was crucial for overall productivity and quality.

In conclusion, these interviews underscored the demand for a semi-automatic silk screen printing machine equipped with features to overcome the limitations of manual processes. Such a machine, by automating repetitive tasks, optimizing space, and addressing key operational challenges, would significantly improve productivity, reduce physical strain, and ensure consistent, high-quality prints, thereby effectively meeting the operational needs of screen printing professionals.

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2.2 Concept Development

Raw data collected from the interviews was meticulously interpreted to derive meaningful insights and formulate specific user needs. This process involved analysing the data, drawing conclusions from observed relationships, and applying these inferences to define a set of need statements from the users' perspectives or problems faced. Concept generation is the initial phase in engineering design, beginning with the collection of information on customer requirements and target concepts, culminating in a few potential design solutions. This preliminary stage of product development involves the critique and evaluation of sketches, 2D designs, layouts, and 3D models before finalizing the best concept. Table 2 shows SCAMPER technique was applied to generate the concepts of Semi-Automated Silk Screen Printing Machine.

Table 2. SCAMPER in concept generation.

Category	Ideas
Substitute (S)	Replace traditional flat printing bed with a crocodile jaw-inspired design.
Combine (C)	Combine the crocodile mouth mechanism with a stapler-like movement for precise clamping.
Adapt (A)	Adapt a car hood opening mechanism for easy maintenance access. Use on bed cover to make it easy for maintenance.
M (Modify)	Modify the CNC movement to squeegee movement.
P (Put to another use)	Use the adjustable wrench mechanism for gripping and positioning block in it position.
E (Eliminate)	Eliminate manual process on holding squeegee and replace it with automation movement of squeegee.
R (Reverse)	Reverse the clamping mechanism to release after each print cycle.

Figure 3 shows the final concept was selected by concept screening and scoring method. The final concept is made of stainless-steel bed construction that is easily opened and closed via a hydraulic damper mechanism. The bed material selected is foam, providing a secure grip for the printing material. An ABS material cover is integrated to protect the linear guide system from dust and other environmental hazards. The printing sequence is initiated by a push-button. The squeegee mechanism incorporates a stepper motor for movement, supported by a ball screw linear guide, an arrangement designed to ensure easy, precise, and uniform squeegee movements, which are critical for achieving consistent print quality.

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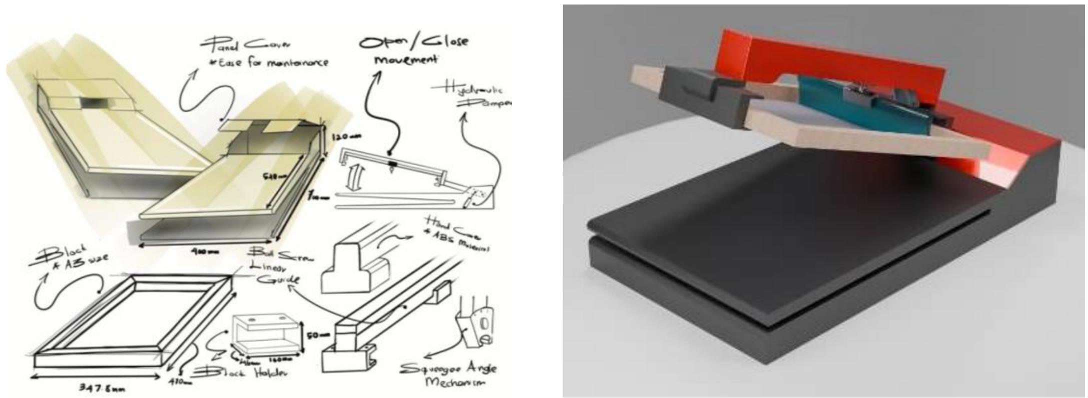

Figure 3. The final concept of Semi-Automatic Silk Screen Printing Machine.

3. RESULTS AND DISCUSSION

The results and findings obtained from the development of the semi-automatic silk screen printing machine. It covers aspects of the fabrication process, including 3D modelling, material selection, and assembly, and explains the device's functionality and maintenance procedures. Furthermore, it details the machine's performance comparison against traditional manual methods.

3.1 Result of Product Testing

Product testing is a critical phase in the development of the semi-automatic silk screen printing machine, essential for verifying that the design meets its intended performance, reliability, and usability standards. This stage focuses on evaluating the machine's functionality under real-world conditions, with particular emphasis on operational speed, print quality, and ergonomic improvements. The semi-automated silk screen printing machine only required six steps to operate the machine and detail result can be find in Table 3.

Table 3. Process breakdown for semi-automated silk screen printing machine.

Aspect	By using semi-automated method
Number of steps	6 (initial) / 5 (subsequent)
Step Involved	1. Slot in block into block holder (initial only). 2. Slot in the shirt. 3. Spread ink into block. 4. Print cycle 1 (using controller). 5. Lift the block. 6. Take out the shirt.
Block Placement	Block slot into block holder
Time Taken	12 sec (1 shirt)
Squeegee Control	Control squeegee movement using controller
RULA Score	3 (Low Risk)

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3.2 Comparison between Manual Method and by Using Machine

The new silk screen printing machine develop in the Figure 4 was specifically developed to address the problems encountered with the manual method, particularly the physical strain caused by prolonged squeegee holding. The semi-automated method alleviates this strain by replacing manual squeegee control with a controller.

Manual method Using semi-automated machine

Figure 4. Comparison methods.

3.2.1 RULA Analysis

The Rapid Upper Limb Assessment (RULA) analysis was employed during the development of the silk screen printing machine to specifically address ergonomic challenges inherent in manual screen printing. Manual methods often involve repetitive movements, awkward postures, and high physical exertion, which are known to contribute to a high risk of musculoskeletal disorders (MSDs) among operators. RULA analysis enables designers to pinpoint specific physical strain points, such as those affecting the wrists, arms, shoulders, and trunk, that become overstressed during manual tasks. This information is crucial for guiding ergonomic improvements in machine design, such as automating repetitive actions like squeegee movements and minimizing manual adjustments, which significantly reduce operator fatigue and discomfort.

RULA analysis also contributes to mitigating long-term health risks for operators, including chronic back pain and carpal tunnel syndrome, by promoting better posture and reducing repetitive strain. Ergonomically optimized machines not only enhance health outcomes but also boost productivity by enabling operators to work more efficiently and comfortably for longer durations. Furthermore, RULA insights ensure that the machine complies with workplace safety standards, fostering a safer work environment and increasing its attractiveness to industries. Ultimately, a machine designed with operator comfort and health in mind enhances user acceptance and satisfaction, delivering long-term value and reliability.

3.3.2 RULA Analysis on Manual Method

The manual silk screen printing method yielded a RULA score of 7 (High Risk), as illustrated in Figure 5. This score signifies an urgent need for investigation and ergonomic intervention. Contributing factors to this high score included repetitive wrist movements, awkward arm

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postures, elevated trunk angles, and significant muscular force exerted during operation. The manual method required operators to sustain static or repetitive postures, leading to substantial physical fatigue and an increased risk of musculoskeletal disorders over time.

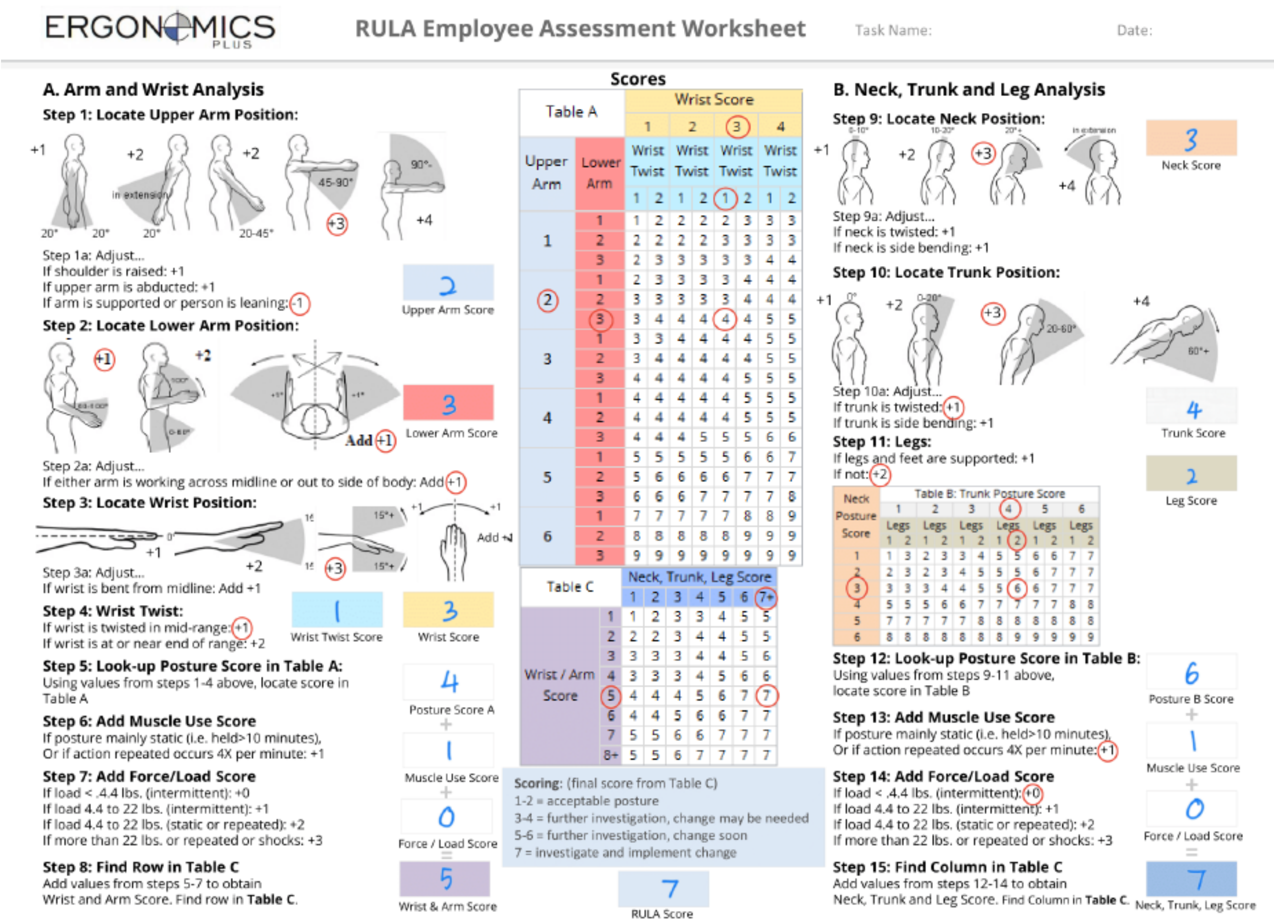

Figure 5. RULA result by using manual method.

3.3.3 RULA Analysis on a Semi-Automatic Silk Screen Printing Machine

In contrast, the semi-automatic machine demonstrated a significant reduction in ergonomic strain, achieving a RULA score of 3 (Low Risk), as shown in Figure 6. This improvement stems from the automation of repetitive movements, such as squeegee handling, which allows operators to maintain a neutral and ergonomic posture with minimal force exertion. The semi-automatic system significantly reduces stress on the upper limbs, trunk, and neck, thereby lowering the risk of work-related injuries by automating force-intensive tasks.

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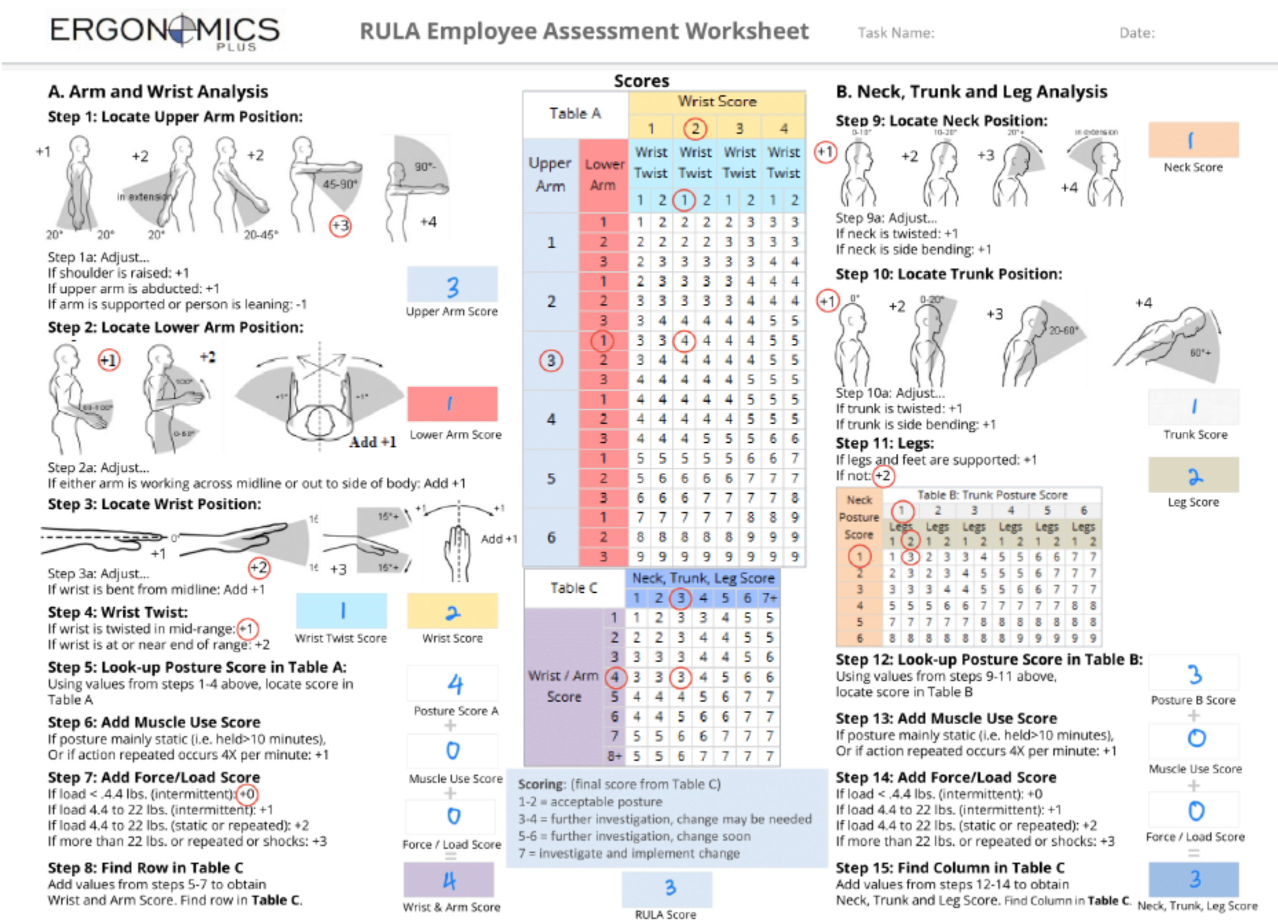

Figure 6. RULA result by using Semi-Automatic Silk Screen Printing Machine

3.3.4 Comparison of RULA Scores

Table 4 clearly demonstrates that the semi-automatic silk screen printing machine substantially improves ergonomics and mitigates the risks associated with manual methods, thus providing a safer and more efficient working environment. The RULA score decreased from 7 (High Risk) for the manual method to 3 (Low Risk) for the semi-automatic machine, indicating a significant reduction in physical strain and an improved safety level for users. This translates to reduced operator fatigue, better posture, less muscular effort, enhanced productivity, and a lower long-term health risk.

Table 4. RULA comparison.

Aspect	Manual Method	Semi Auto Silk Screen Printing Machine	Difference
RULA Score	7 (High Risk)	3 (Low Risk)	Significant reduction in physical strain
Risk Level	Immediate ergonomic intervention needed	Acceptable, no immediate action required	Improved safety for users

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Physical Strain	High due to repetitive and forceful tasks	Minimal due to automated operations	Reduced user fatigue
Posture	Awkward wrist, arm, and trunk positions	Neutral and ergonomic posture	Better operator comfort
Muscle Effort	High repetitive force exertion required	Low tasks are automated	Less muscular fatigue
Efficiency	Lower due to operator fatigue	Higher due to reduced physical strain	Enhanced productivity
Long-Term Health Risk	High risk of musculoskeletal disorders	Low risk due to improved ergonomics	Safer for extended use

3.4 Result of Field Testing

Field testing was conducted to compare the semi-automatic silk screen printing machine's performance against the traditional manual method. Two types of shirts, cotton t-shirts and jerseys, were used to evaluate the machine's adaptability to different fabric types and printing requirements. Mr. Mahazani, an experienced manual screen printer, performed identical tasks using both methods, manual and semi-automatic. Key metrics, including production speed, print consistency, and ergonomic impact, were analyzed.

The results showed a significant improvement in production speed with the semi-automatic machine. While the manual method required 25 seconds to complete a single print, the semi-automatic machine reduced this time to 12 seconds, effectively doubling the output rate. Additionally, the number of printing steps was reduced from 10 in the manual method to 6 with the semi-automatic machine, simplifying the workflow and shortening setup and execution times. However, a limitation was observed in achieving consistent print quality: the 24V stepper motor's speed was insufficient to prevent ink blockages on the printing block. This issue was particularly evident with larger designs requiring continuous ink flow, leading to printing flaws as shown in Figure 7. Despite this challenge, the semi-automatic machine still delivered substantial benefits in reducing operator fatigue and increasing productivity compared to the manual method, highlighting its efficiency gains while also identifying areas for improvement in motor speed for consistent print quality.

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Figure 7. Printing flaws.

User feedback was instrumental in evaluating the semi-automatic silk screen printing machine, providing insights into how well it meets user needs and expectations compared to traditional manual methods. Operators with practical experience in manual screen printing provided feedback on overall satisfaction, identifying the machine's strengths and weaknesses for optimization in real-world applications and user-friendly operation. Table 5 shows the user feedback.

Table 5. User feedback.

Feedback Category	Manual Method	Semi-Automatic Machine	Comments from User
Ease of Use	Difficult to align screens manually	Simple setup with automated steps	"Much easier to operate with fewer steps, especially during alignment."
Ergonomic Impact	High physical strain	Reduced physical effort	"Significantly less tiring, particularly for long printing sessions."
Production Speed	25 seconds per print	12 seconds per print	"The machine cuts production time in half, allowing faster completion of tasks."
Overall Satisfaction	Moderate	High	"The machine saves time and reduces fatigue, making the process more enjoyable."

A key limitation identified for the semi-automatic silk screen printing machine is the performance of the 24V stepper motor used for squeegee movement. The slower speed of this motor negatively impacts the ink distribution process, causing ink to block on the printing block as shown in Figure 8 and resulting in occasional flaws in the printed designs. This limitation was particularly evident

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in prints requiring continuous ink flow over larger areas, where a consistent and faster squeegee movement is essential for maintaining print quality.

Figure 8. Slow squeegee movement cause ink blockage.

4. CONCLUSION

The developed semi-automatic silk screen printing machine successfully addressed the primary challenges inherent in manual screen printing, including repetitive strain, production inefficiencies, and inconsistent print quality. Through the automation of squeegee movement and optimization of the printing process, the machine demonstrated significant improvements in production speed, reducing printing time per shirt from 25 seconds to 12 seconds. The design also streamlined operations by cutting the number of printing steps from 10 to 6. Crucially, the incorporation of ergonomic features and automation effectively reduced operator fatigue and enhanced usability, as evidenced by a RULA analysis score improvement from 7 (High Risk) for manual methods to 3 (Low Risk) for the semi-automatic machine.

Despite these substantial achievements, a notable limitation was identified: the speed of the 24V stepper motor was occasionally insufficient, leading to ink blockages and minor printing flaws. Nevertheless, the machine largely succeeded in meeting its core objectives, providing small industries with a cost-effective and low-effort solution for printing while maintaining consistent print quality.

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