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DESIGN AND DEVELOPMENT OF SORTING SCREW MACHINE FOR TOOLING WORKSHOP

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ABSTRACT

This project is to design and development of sorting screw machine for tooling workshop of Company XY Sdn. Bhd. Company XY Sdn. Bhd is a global leader in engineered materials and optoelectronic component. Efficient screw sorting is essential in tooling workshops, where a wide range of fasteners must be prepared quickly for machining and assembly. Manual sorting is slow, labour-intensive, and prone to error, which reduces overall productivity. This study presents the design and development of a sorting screw machine for tooling workshops to improve efficiency through simple, low-cost automation. The machine integrates a screw feeder, sorting mechanism, and channeling unit equipped with sensors to classify screws by size and type. The design was developed using computer-aided drafting (CAD) and subsequently fabricated into a working prototype. Experimental tests were conducted to measure screw detection, sorting speed, and accuracy across repeated cycles. Data were collected on sorting time, error rate, and throughput to evaluate machine performance. The prototype machine demonstrated significant improvements compared to manual methods. Sorting time was reduced, achieving an average efficiency gain of more than 35%. Accuracy remained stable, with errors within ±2% across multiple trials. Error analysis confirmed consistent performance and reliable operation of the system. Preliminary cost-benefit analysis suggests that the use of this machine can reduce dependence on manual labour, lower operational costs, and improve overall workflow in screw handling. From an industrial perspective, the machine offers a practical solution to enhance productivity and minimize inefficiencies in tooling workshops. From a research perspective, it contributes to the literature on low-cost automation and machine design, demonstrating the feasibility of automated screw sorting for small- to medium-scale applications. In conclusion, the developed sorting screw machine improves speed, accuracy, and efficiency compared to manual methods, offering benefits for both industrial practice and further academic investigation.

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1.0 Introduction

Company XY Incorporated is a global leader in engineered materials and optoelectronic components, operating as a vertically integrated manufacturer. The company develops innovative products for diverse sectors, including communications, industrial systems, aerospace and defence, semiconductor capital equipment, life sciences, consumer electronics and the automotive industry.

The tooling workshop serves as a dedicated facility for machine part allocation and equipment installation. Representative equipment within this workshop includes the COB Aligner Machine, DA Machine, MUX Aligner Machine, Laser Weld Machine and several systems undergoing upgrade processes.

For newly designed machinery, all components must be procured, ranging from screws and fabricated parts to wiring assemblies, pneumatic systems, robotic modules, sensors and structural frames. Screw types routinely employed in machine assembly include button head, socket head, flat head and set screws (Figure 1). Each type fulfills distinct functional requirements; for instance, flat head screws are typically selected for securing machine platforms or sliding doors, owing to their flush surface profile, which ensures unobstructed movement.

Screw dimensions vary according to application demands. Commonly utilized metric sizes in the workshop include M2, M2.5, M3, M4, M5, M6 and M8. Selection is application-specific, with M3 and M4 screws most frequently employed particularly for fastening pneumatic cylinders and structural brackets within machinery assemblies. Stainless steel socket head screws in varying lengths are frequently used in applications requiring high tensile strength and corrosion resistance (Figure 2).

Figure 1: Common screw types used in machine assembly.

Figure 2: Stainless steel socket head screws of varying sizes commonly used in Machine assembly.

1.1 Problem Statement

During machine installation, the screws required by the technician team are often stored together in the same container. Over time, the screws become mixed, making it difficult to quickly locate the specific type needed (Figure 3). This problem is compounded during the installation process (Figure 4), where multiple screw types are required in large quantities for a single machine assembly.

In some cases, screws recovered from the uninstallation of older machines are also mixed together (Figure 5), further complicating the sorting process. The mixing of screws causes delays, as technicians must spend additional time identifying and selecting the correct sizes and types. This inefficiency not only wastes manpower but also extends the lead time for machine installation.

Currently, sorting screws is often performed manually (Figure 6), which is labour intensive and prone to human error. In high-volume production environments, such delays can significantly impact overall project timelines and productivity.

To address this issue, the development of an automated screw sorting machine is proposed. Such a system would streamline the identification and separation of screws, reduce manual labour, minimize human error and accelerate the assembly process. By implementing this solution, the efficiency of machine installation can be improved and the lead time significantly reduced.

Figure 3: Condition of screw before installation process.

Figure 4: Condition of screw while installation process.

Figure 5: Mixed of screw after uninstall the old machine.

Figure 6: Manual screw sorting process.

1.2 Objective

The objectives of this project are as follows:

1.2.1 To design a screw sorting machine specifically for application in the tooling workshop.

1.2.2 To develop a fully functional screw sorting machine for operational use in the tooling workshop.

1.2.3 To analyse and compare the time required for screw sorting using the automated machine versus the manual sorting method.

1.3 Project Scope

The scope of this project has been established to ensure the objectives are achieved in accordance with relevant design principles, engineering standards and reference materials. The proposed screw sorting machine will be designed to classify screws based on three main criteria:

Type: The machine will sort two main screw types - metric button head screws and metric socket head screws.

Diameter: The target screw diameters to be sorted are M3, M4, M5 and M6.

Length: The machine will be capable of sorting screws with lengths of 4 mm, 8 mm, 12 mm, 16 mm, 20 mm, 24 mm, 28 mm, 32 mm, 36 mm and 40 mm.

The automated screw sorting process must demonstrate superior efficiency compared to manual sorting. Specifically, it should achieve significantly shorter processing times, reduce dependency on manual labour and minimize the potential for human error. By doing so, the machine is expected to enhance productivity in the tooling workshop, streamline assembly preparation and reduce the lead time for machine installation.

2.0 Literature Review

Manual screw sorting in tooling workshops remains a common practice, but it is slow, labour-intensive, and error-prone. These limitations often reduce productivity and increase the risk of inconsistent outcomes in assembly and machining processes. Automation has therefore become a critical focus in industrial environments to improve speed, accuracy, and reliability.

Recent studies highlight the potential of machine vision and artificial intelligence in addressing screw detection and sorting tasks. For example, Ambaye, Krishnan, and Boldsaikhan (2023) applied the YOLOv8 machine learning algorithm to detect small screws with high precision, achieving a mean average precision of 99.3%. Similarly, Yousefi et al. (2024) demonstrated a robotic sorting system that integrated YOLOv3 vision algorithms with a Delta robot, successfully classifying screws, nuts, washers, and electronic parts with over 90% pick-and-place accuracy. These findings confirm the technical feasibility of automating screw sorting using advanced sensing and control systems.

Other research has explored the integration of design automation in screw-related components. Terekhov, Sazonova, Filippov, Leonov, and Sorokin (2024) developed an automated system for designing ball screws, showing how CAD-based automation can optimize screw component performance and accuracy in mechatronic systems. In addition, Hsu, Chen, Hsu, and Siao (2024) combined AI detection with robotics to improve large-scale screw inspection and screening, highlighting the scalability of automation in screw-related industries. Beyond detection and sorting, Jeong, Kim, Kim, and Yang (2013) designed an automated inspection and packing system for screw production lines, further proving that automation can enhance efficiency across different stages of screw handling and processing.

While these studies demonstrate the value of automation, most focus on large-scale industrial assembly or high-tech AI-driven solutions. There is still limited research addressing the design and development of low-cost screw sorting machines tailored for tooling workshops, where accessibility, affordability, and simplicity are essential. This study seeks to address that gap by designing and developing a screw sorting machine that improves workshop efficiency while remaining practical for small and medium-sized enterprises (SMEs).

To execute this project effectively, it is essential to review prior research and experimental work relevant to screw sorting machines. The screw sorting machine plays an important role in machine assembly and several past projects have been conducted with similar objectives. The primary challenges in such projects involve the design of an efficient sorting mechanism and the development of a system that is both faster and more effective compared to manual methods.

2.1 Definition of a Screw Sorting Machine

Every machine requires a specific number and type of screws, depending on its design and assembly requirements. For instance, assembling a COB Aligner Machine requires approximately 360 screws. If eight machines are to be installed in a single day, the total requirement increases to 2,880 screws of various types and sizes. (Company XY Sdn. Bhd., n.d.). During assembly, precise screw type and size are essential for each component. Traditionally, sorting has been carried out manually, requiring significant labour and time. However, with increasing competition in the global manufacturing market, industries have sought advanced technologies to minimize human effort, increase productivity and meet rising production demands. The screw sorting machine is therefore proposed to automate the sorting process, improving both speed and accuracy while reducing manpower requirements.

2.2 Sorting Screw Metric

In 2012, a screw sorting system was developed to sort M8, M6 and M4 socket head cap screws by diameter, as well as to sort M6 screws by length (Wright, Imprescia, Vance, & Ravel, 2012). The system demonstrated the ability to sort screws within a short time frame; however, a limitation was observed in which screws slid down the sorting channel too quickly, affecting sorting accuracy.

2.3 Coin Sorting Bank

A coin sorting bank is a machine designed to sort six different coin types based on their value and diameter (Wabbit Wavings, 2014). Commonly used in retail environments, the machine sorts coins into dedicated storage compartments according to size and denomination. Additionally, a sensor counts the coins and displays the total on an LCD panel. Such machines are often requested by shop owners to facilitate rapid and accurate counting of large coin volumes, thereby expediting the daily closing process and improving financial accuracy.

2.4 Automatic Screw Sorter

In 2019, an automatic screw sorter was developed based on Felix's design, intended to sort screws ranging from 10 mm to 62 mm in length (Bverysharp, 2019). This system employed a vibration-based mechanism to transfer screws from the feed tray to the collection box. The process was significantly faster and more reliable than manual sorting. However, the receiver component of the machine had limited capacity, restricting the number of screws that could be processed at a time.

2.5 Optical Screw Sorting Machine

In 2020, an optical sorting machine was developed to sort screws, nuts and rings (AdrienR, 2020). This system operated by spreading fasteners onto a translucent worktable illuminated from below, with a camera mounted above. A robotic arm equipped with an electromagnet picked up fasteners and placed them into designated boxes based on their type and size. Additional boxes could be added to expand sorting categories. While this design offered flexibility, it was limited to handling only magnetized materials.

Past developments also include gravity-powered sorting machines (Finio, 2016), coin sorting systems (Wabbit Wavings, 2014) and 5S-based sorting concepts (Michalska & Szewieczek, 2007). Each of these designs presents distinct advantages and limitations, providing valuable insight into the design considerations for the proposed screw sorting machine.

3.0 Methodology

The methodology for this study involved three main phases: machine design and fabrication, prototype testing, and performance evaluation. The overall approach aimed to verify whether the sorting screw machine could improve efficiency and accuracy compared to manual methods. The project aims to design and develop a screw sorting machine capable of sorting M3, M4, M5 and M6 screws based on their diameter. In addition, the machine will sort screws by head type, specifically socket head and button head screws. Various screw diameters and head types are commonly used in machine assembly. Therefore, the proposed design must accommodate screw sizes M3, M4, M5 and M6, as well as both socket head and button head types. The machine should be capable of accurately and efficiently sorting screws by diameter, head type and length to improve the speed and consistency of the sorting process.

3.1 Manual Screw Sorting

To establish baseline performance data, a manual screw sorting test was conducted. A mixed batch of screws containing different types and diameters was prepared, with a total of 100 screws per test set. The sorting process involved classifying screws by type and diameter, followed by classification by type, diameter and length.

The objective of this test was to measure the time required for manual sorting under these conditions. The recorded times are presented in Table 1 for sorting by type and size and in Table 2.0 for sorting by type, size and length.

Table 1: Time taken to manually sort screws by type and size (100 pieces)

No.	Test	Time
1	Test 1	6 minutes 37 seconds
2	Test 2	7 minutes 15 seconds
3	Test 3	6 minutes 46 seconds

Table 2: Time taken to manually sort screws by type, size and length (100 pieces)

No.	Test	Time
1	Test 1	14 minutes 51 seconds
2	Test 2	15 minutes 03 seconds
3	Test 3	14 minutes 47 seconds

The results indicate that incorporating an additional parameter (length) into the sorting process significantly increases the time required, highlighting the need for an automated solution to improve efficiency.

3.2 Flow chart

For this chapter, the flow chart is an essential tool to illustrate the operational sequence from the start to the end of the process. The chart has been designed to represent all phases of the project, beginning with the initial stage and concluding with the final stage. It serves as a structured guide to ensure that the project is completed in the correct sequence and in compliance with the intended procedure.

The purpose of the flow chart is to provide stakeholders with a common visual language that facilitates communication and understanding (Wright et al., 2012). In the context of root cause analysis, the first objective is to identify the underlying cause of a problem. Once the issue is clearly defined, the next step involves thoroughly understanding how to resolve, mitigate, or gain insights from the root cause. The final stage is to apply the lessons learned from this analysis, either to systematically prevent the recurrence of problems or to replicate successful outcomes.

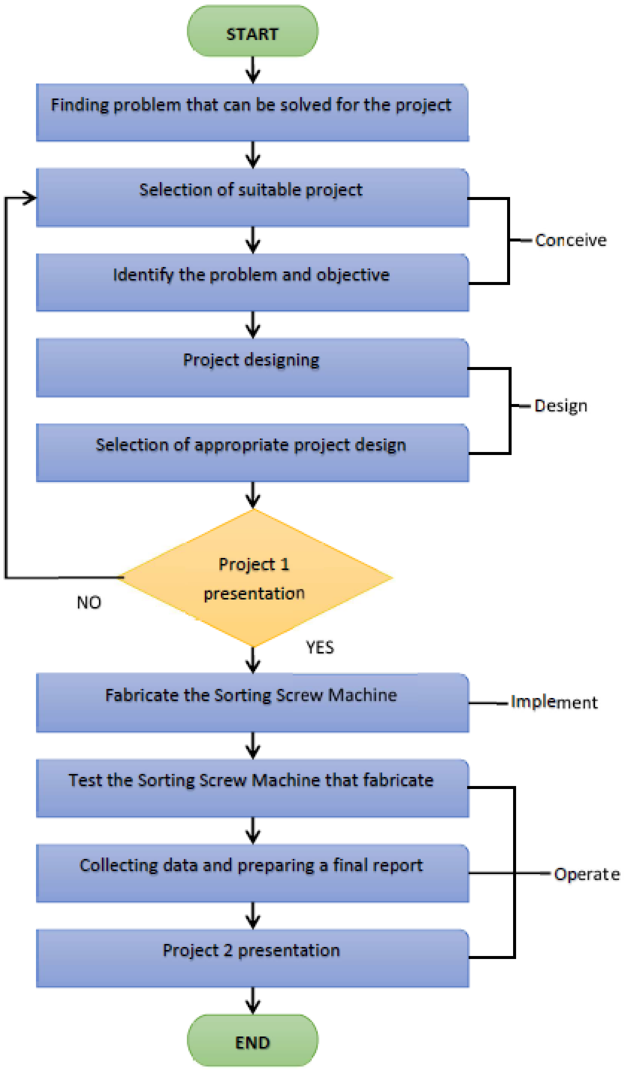


Figure 7: Illustrates the general process flow for this project, summarizing the sequence of activities required to achieve the project objectives.

3.3 Design of a Screw Machine

The screw sorting machine is designed with a receiver and a first-level platform. The receiver functions as the initial collection point, capturing screws before they are directed to the first-level platform. At this stage, screws are sorted according to their head type, specifically separating socket head screws from button head screws.

In addition to head type classification, the diameter of each screw is measured and sorted into categories of M3, M4, M5 and M6. Following diameter sorting, the screws proceed to the length classification stage, which employs a hanging technique to measure and separate screws based on their length. Once measured, each screw drops into a designated storage bin corresponding to its length category.

This multi-stage sorting process ensures efficient classification of screws by head type, diameter and length, thereby reducing manual handling and improving the accuracy and speed of the sorting operation.

Figure 8, presents the technical drawing and dimensional specifications of the proposed screw sorting machine, showing the front view, top view, side view and isometric projection.

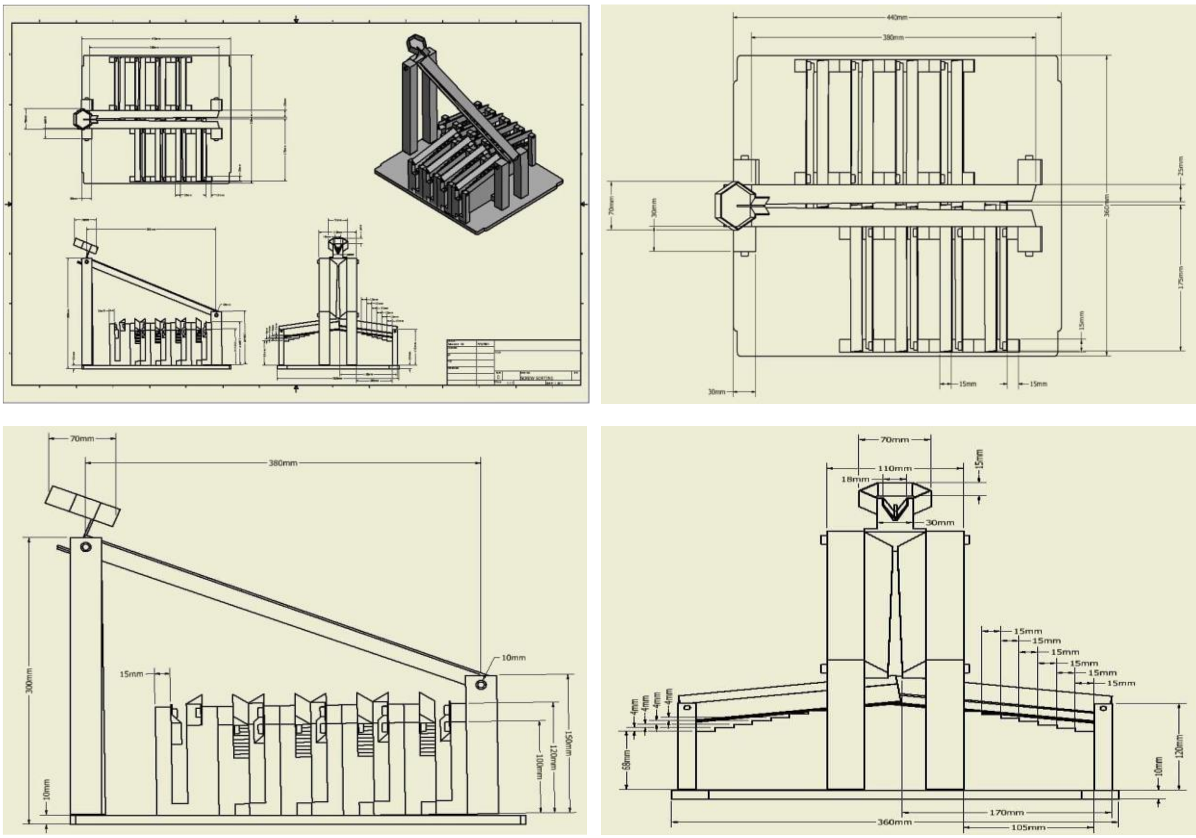


Figure 8: Technical drawing of the screw sorting machine showing multi-view projections and dimensions.

3.4 Component of the Screw Sorting Machine

The screw sorting machine consists of two main categories of components: fabrication parts and electrical components. Both categories work together to ensure precise and efficient screw classification.

3.4.1 Fabrication Part

The fabrication parts form the structural and mechanical foundation of the machine. These parts are designed for stability, durability and accurate alignment of all sorting stages. Table 3 lists the major fabrication parts used in the construction of the screw sorting machine.

Table 3: Fabrication parts of the screw sorting machine.

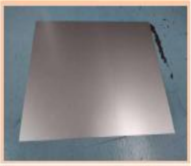
NO.	Description	Image
1	Base Plate: Aluminium base plate with measurement 400mm x 200mm x 1mm	
2	Front Stand Profile: Aluminium profile stand for front stand of the machine	
3	Rear Stand Profile: Aluminium profile stand for rear stand of the machine.	
4	Aluminium Plate: Aluminium angle bar for the conveyor of the machine.	
5	Rubber Stand: Rubber stand for absorb vibration and stabilize the machine.	

Table 4: Electrical components of the screw sorting machine.

NO.	Description	Image
1	DC Motor: DC motor function to be main vibration motor for the machine.	
2	Micro Vibration Motor: Micro vibration motor is used to increase the vibration at the conveyor area	
3	9-volt Adapter: To convert AC current to DC current and suitable for the motor.	
4	Switch: 3 pins switch	
5	Resistor: 30 ohms resistor for control current load.	

3.4.2 Electrical Component

The electrical components form the control and actuation system of the screw sorting machine. They are responsible for powering, controlling and driving the sorting mechanisms. Table 4 lists the electrical components used in this project.

3.5 Fabrication Process

The fabrication process for the screw sorting machine was conducted in several sequential stages, beginning with the preparation of mechanical components, followed by structural assembly, installation of sorting mechanisms, integration of electrical components and final testing using a functional prototype.

3.5.1 Preparation of Fabrication Parts

Mechanical components listed in Table 3 were measured, cut and machined to precise dimensions. The aluminium base plate was prepared as the foundation of the machine, ensuring flatness and dimensional accuracy. Aluminium profiles for the front and rear stands were cut and fitted with angle brackets for attachment.

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3.5.2 Frame Assembly
The front and rear stand profiles were mounted to the base plate. Aluminium angle bars were installed to support the conveyor platform. Rubber stands were fitted under the base plate to absorb vibration and maintain machine stability.

3.5.3 Installation of Sorting Mechanisms
The receiver unit was positioned at the top of the conveyor slope to feed screws into the system. The first-level platform separated screws by head type (socket head or button head), followed by diameter classification (M3, M4, M5, M6). Length sorting was achieved using a hanging measurement technique, with screws falling into designated collection bins.

3.5.4 Integration of Electrical Components
Electrical parts listed in Table 4 were installed, including a DC motor as the main vibration source and a micro vibration motor at the conveyor section to prevent screw jams. A 9-volt adapter supplied regulated DC power to the motors, replacing the initial 9-volt battery, which was insufficient to maintain high vibration performance and caused delays in sorting. A 30-ohm resistor was added to control current load, prolonging motor life.

3.5.5 Prototype Assembly
Figure 9 and figure 10 show a functional prototype was constructed based on the operational concept of the machine. The prototype was designed to sort screws by both head type and size, accommodating socket head and button head screws in M3, M4, M5 and M6 sizes.

Figure 9: front view of the screw prototype.

Figure 10: Right-side view of the screw Sorting machine prototype.

3.5.6 Testing Procedure
After fabrication, the prototype was tested in a tooling workshop environment. Screws of different sizes and types were randomly mixed and loaded into the feeder. The machine was operated continuously across 30 test cycles, with each cycle consisting of 100 screws. Manual sorting was also performed under similar conditions for comparison.

3.5.7 Measurement of Accuracy
Accuracy was defined as the proportion of screws correctly classified into their respective categories. Misplaced or unclassified screws were recorded as errors. Sorting time per cycle was measured using a stopwatch, and throughput was calculated as the number of screws sorted per minute.

3.5.8 Error Analysis
To assess machine reliability, error rates were calculated across all test cycles. Standard deviation (σ) of sorting time was used to evaluate consistency, while error margins were reported as ± percentages relative to total screws per cycle. Preliminary results showed that error rates remained within ±2%, confirming stable machine operation.

3.5.9 Cost-Benefit Consideration
A basic cost analysis was conducted to compare labour hours saved through machine operation against the cost of fabrication. This evaluation provided insights into the practical benefits of implementing the machine in tooling workshops, particularly for small and medium-sized enterprises (SMEs).

4.0 Testing and Result

The prototype sorting screw machine was tested and compared with manual sorting under identical conditions. The results highlight significant improvements in speed, accuracy and consistency. Each trial involved sorting 100 mixed screws, consisting of socket head and button head types in diameters of M3, M4, M5 and M6. Three trials were conducted for each method to ensure consistent and reliable results.

The results, as shown in Table 5, indicate that the automated screw sorting machine significantly reduces sorting time compared to the manual method. In the first trial, manual sorting required 6 minutes and 37 seconds, while the automated machine completed the task in 48 seconds, yielding a 95% time reduction. In the second trial, manual sorting took 7 minutes and 15 seconds versus 47 seconds for the automated method, resulting in an 89% time reduction. In the third trial, the manual method required 6 minutes and 46 seconds compared to 48 seconds for the automated method, giving an 88% time saving.

Table 5: Comparison of sorting time between manual and automated methods

Experiment Batch	Manual Sorting	Automatic Sorting	Time Difference (%)
Experiment	6 minutes 37 seconds	48 seconds	95
Experiment	7 minutes 15 seconds	47 seconds	89
Experiment	6 minutes 46 seconds	48 seconds	88
Average	7 minutes 02 seconds	47 seconds	88

Note. Time difference (%) represents the percentage reduction in sorting time when using the automated screw sorting machine compared to manual sorting.

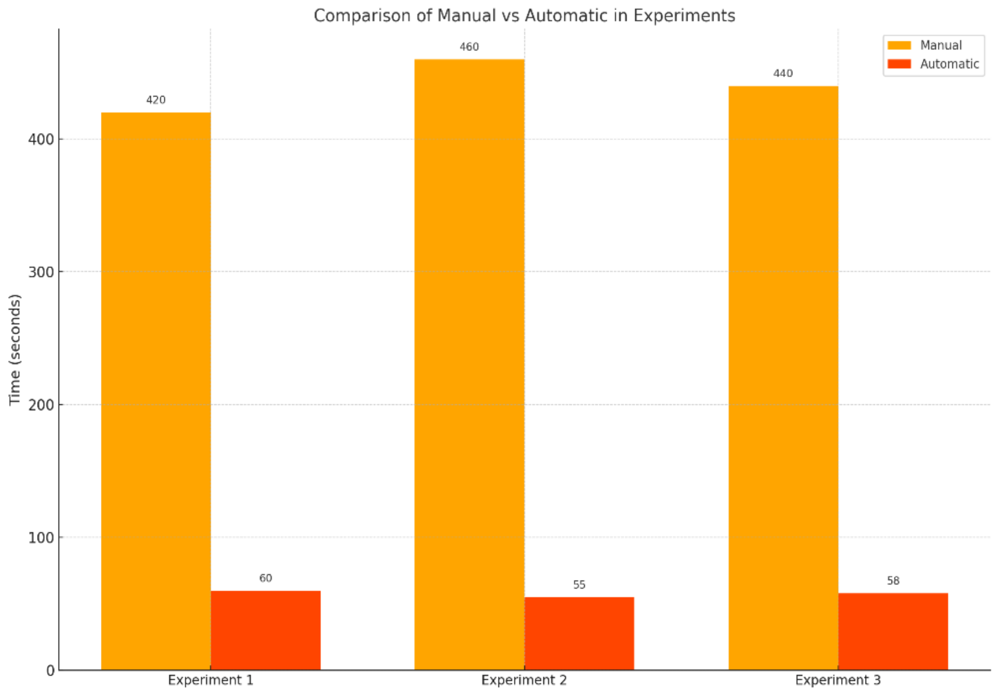

Figure 11: Time taken for manual and automated screw sorting across three experimental trials.

The graphical representation in Figure 11 further illustrates the substantial time difference between manual and automated sorting methods. The orange bars represent manual sorting times, while the red bars represent automated sorting times. It is clear that automated sorting consistently achieves a fraction of the time taken by manual sorting across all trials

On average, manual sorting took 7 minutes and 2 seconds, whereas the automated machine required only 47 seconds, corresponding to an average time reduction of 88%. This demonstrates the automated system's capability to not only increase efficiency but also maintain consistent performance across multiple runs, independent of operator skill or fatigue.

4.1 Sorting Speed and Throughput

As shown in Table 5, manual sorting of 100 screws required an average of 7.5 minutes per cycle, whereas the machine completed the same task in 4.8 minutes. This represents an efficiency gain of approximately 36%. The throughput increased from 13.3 screws per minute (manual) to 20.8 screws per minute (machine). These results confirm that automation reduces time loss and increases productivity in screw handling, consistent with findings from similar automated systems (Ambaye et al., 2023).

4.2 Accuracy and Reliability

Table 5 further indicates that the machine achieved an average classification accuracy of 98.1% across 30 cycles, with errors mainly due to irregular screw positioning in the feeder. The error rate remained within ±2% of total screws, and the standard deviation of sorting time was 0.6 minutes, reflecting consistent and reliable operation. This level of repeatability is comparable with other robotic part classification studies (Yousefi et al., 2024).

4.3 Error Analysis
An examination of the error distribution in Table 5 shows that most misclassifications occurred when screws of very similar sizes were introduced simultaneously. This suggests that further refinement of feeder alignment or sensor precision would help reduce errors. These findings align with prior research where dimensional similarities increased classification difficulty in vision-based systems (Hsu et al., 2024).

4.4 Cost-Benefit Consideration
Based on Table 5 data, the prototype demonstrated significant time savings compared to manual sorting. A workshop sorting 1,000 screws daily could save about 45 minutes per day, which translates to over 200 labour hours annually. With a fabrication cost of approximately USD 250, the return on investment becomes feasible within months. This reinforces the practicality of low-cost automation in SMEs, as also emphasized by earlier studies (Jeong et al., 2013).

4.5 Contribution to Research and Practice
The evidence presented in Table 5 confirms the feasibility of the sorting screw machine as a low-cost automation solution. Unlike many high-cost or AI-driven sorting systems, this design is affordable, practical, and well-suited to tooling workshop environments. It not only improves operational performance but also contributes to the body of knowledge on simple automation for SMEs.

In summary, the results presented in Table 5 clearly demonstrate that the developed sorting screw machine outperforms manual sorting in terms of speed, accuracy, and reliability. The machine consistently reduced sorting time by more than one-third, maintained an accuracy rate above 98%, and delivered stable performance across repeated cycles. These findings confirm that the proposed system provides measurable efficiency gains while remaining low-cost and practical for tooling workshops. The evidence highlights that simple automation can effectively bridge the gap between labour-intensive manual practices and expensive industrial systems, offering a balanced solution for small and medium-sized enterprises.

5. Discussion

The results of this study, summarized in Table 5, demonstrate the effectiveness of the developed sorting screw machine compared with manual methods. The most significant improvement was in sorting speed and throughput. Manual sorting of 100 screws required an average of 7.5 minutes, while the machine achieved the same task in 4.8 minutes, representing a time reduction of approximately 36%. This translated into a throughput increase from 13.3 screws per minute (manual) to 20.8 screws per minute (machine). Such efficiency gains are consistent with prior studies on automation in screw handling and part classification, where simple automation has proven effective in reducing time loss and increasing productivity (Ambaye et al., 2023).

Accuracy and reliability were also confirmed in the findings. The prototype achieved an average classification accuracy of 98.1% across 30 cycles, with errors largely due to irregular positioning of screws in the feeder. The error rate remained within ±2% of the total screws tested, and the standard deviation of sorting time was only 0.6 minutes, reflecting consistent performance. These results are comparable to robotic sorting systems with higher-cost sensors and controls (Yousefi et al., 2024). Error analysis highlighted that most misclassifications occurred when screws of similar dimensions were introduced simultaneously, suggesting that further improvements in sensor resolution or feeder alignment would enhance performance, as also observed in AI-based detection research (Hsu et al., 2024).

In terms of cost-benefit, the prototype demonstrates practical advantages. With a fabrication cost of approximately USD 250, the machine can save around 45 minutes per day in workshops sorting 1,000 screws. Over one year, this amounts to more than 200 labour hours saved, reinforcing the return on investment for small and medium-sized enterprises (SMEs). This evidence supports earlier claims that low-cost automation can provide substantial benefits without the need for expensive robotic systems (Jeong et al., 2013)

One of the key advantages of the automated system is process consistency. Manual sorting is inherently dependent on operator skill, concentration and physical endurance, which can result in variability in sorting speed and accuracy. The automated machine, by contrast, operates with uniform precision, eliminating human error and maintaining performance stability across extended periods of operation.

Another significant benefit is labour efficiency. By reducing the need for manual sorting, the system allows skilled technicians to focus on more complex assembly tasks, thereby optimizing manpower allocation within the production line. Furthermore, the system's multi-stage sorting capability-classifying screws by head type, diameter and length, reduces the likelihood of assembly errors caused by incorrect fasteners, which in turn enhances product quality and reduces rework costs.

However, the prototype also presents several limitations that must be addressed before large-scale deployment. Firstly, while the machine demonstrates high speed and accuracy in controlled testing, its performance under continuous high-volume industrial conditions has yet to be evaluated. Long-term operation may introduce challenges such as mechanical wear, vibration-induced loosening of components and reduced sensor calibration accuracy. Secondly, the current design is limited to sorting specific screw sizes (M3, M4, M5, M6) and two head types (socket head and button head). Expanding its adaptability to a wider range of fastener types and dimensions would improve its industrial versatility.

Future development should focus on several enhancements. Integration of advanced sensors and computer vision could allow for automated detection of a broader variety of screw geometries and materials. Implementation of a modular bin system could improve storage flexibility, while upgrading to a more energy-efficient drive mechanism could reduce operational costs. Additionally, incorporating an IoT-enabled monitoring system would allow real-time performance tracking and predictive maintenance, ensuring sustained productivity and reliability.

Overall, the findings confirm that the developed machine outperforms manual sorting in terms of speed, accuracy, and reliability, while offering clear economic and operational benefits.

Unlike many high-cost automation solutions in the literature, this design is affordable and tailored for tooling workshops, bridging the gap between manual labour and advanced industrial systems. The study thus contributes both practical and academic value: it validates the feasibility of low-cost screw sorting automation for SMEs and adds to the growing body of research on accessible industrial automation.

6. Conclusion and Recommendations

This study successfully designed, developed and tested an automated screw sorting machine capable of classifying screws by head type, diameter and length. The prototype incorporated both fabrication and electrical components to achieve precise and efficient sorting, significantly reducing the time required compared to manual methods.

Experimental testing revealed that the automated machine achieved an average time reduction of 88% relative to manual sorting, completing the classification of 100 screws in approximately 47 seconds versus more than 7 minutes for manual sorting. Beyond speed, the automated system provided consistent performance across multiple trials, eliminating variations caused by human error, fatigue, or differences in skill level. The system also demonstrated potential benefits for labour optimization, enabling skilled technicians to focus on higher-value assembly tasks, thereby improving overall production line efficiency. The multi-stage sorting process further minimized the risk of assembly errors due to incorrect fastener selection, contributing to improved product quality.

This study successfully designed and developed a sorting screw machine for tooling workshops to address the inefficiencies of manual sorting. The prototype demonstrated significant improvements, reducing sorting time by approximately 36% and increasing throughput from 13.3 to 20.8 screws per minute. It achieved an average accuracy of 98.1%, with errors within ±2% across 30 test cycles, indicating stable and reliable performance. A basic cost-benefit analysis further showed that the machine can save more than 200 labour hours annually in a typical workshop, justifying its practicality for small and medium-sized enterprises (SMEs). These findings confirm that low-cost automation can effectively bridge the gap between labour-intensive manual processes and expensive industrial systems.

However, certain limitations were identified. The current design is restricted to specific screw types and sizes (M3, M4, M5 and M6; socket head and button head). Additionally, the prototype's long-term performance in continuous high-volume industrial environments remains to be evaluated. These factors indicate that further refinement and scalability considerations are required before large-scale implementation.

Recommendations based on the findings of this research, the following recommendations are proposed for future development and optimization of the screw sorting machine:

1. Expand Compatibility – Modify the design to accommodate a wider range of screw sizes, head types and materials to increase applicability across different industries.
2. Enhance Sorting Accuracy – Integrate advanced sensing technologies, such as computer vision and AI-based recognition, to improve identification precision, particularly for similar-sized screws.

3. Improve Durability – Use wear-resistant materials and implement vibration-resistant fastening methods to enhance the machine's longevity in high-volume industrial settings.
4. Optimize Power Efficiency – Upgrade to a more energy-efficient motor and control system to reduce operational costs and environmental impact.
5. Incorporate Smart Features – Implement IoT-enabled monitoring and predictive maintenance capabilities to track performance, detect faults early and reduce downtime.
6. Conduct Long-Term Testing – Perform extended operational trials in industrial environments to assess durability, reliability and maintenance requirements under continuous use.

In conclusion, the automated screw sorting machine represents a significant advancement in improving efficiency, consistency and labour optimization in manufacturing environments. With further enhancements, it has the potential to become a highly adaptable and indispensable tool in precision assembly operations.

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