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Research Article

Automated Sorting Conveyor Using Pneumatic Actuators for Industrial Applications at Morowali Metal Industry Polytechnic

Angga Tegar Setiawan[1], Suwandi [2], Hendi Lilih Wijayanto [3], Abdul Wahid Arohman [4]

[1,2,3] Morowali Metal Industry Polytechnic, Padabaho Village, Morowali 94974, Central Sulawesi, Indonesia
[4] Polytechnic STMI Jakarta, Jl. Letjen Suprapto No. 26, Cempaka Putih 10510, Central Jakarta, Indonesia

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CORRESPONDENCE

E-mail Corresponding Author:
angga@pilm.ac.id

ABSTRACT

The use of automatic sorting systems in industry plays a crucial role in saving time and reducing manual labor through automation. The main challenges are the high error rate and slow manual sorting processes. This research aims to design and develop an automatic sorting conveyor system using Arduino technology and pneumatic actuators to enhance sorting efficiency and accuracy. The proposed solution is a system capable of detecting and sorting objects based on size with meager error rates, thereby increasing productivity and reducing human error. The methodology includes the design, implementation, and testing of an automatic sorting conveyor system using Arduino technology and pneumatic actuators. The design steps involve creating 3D models for components such as the conveyor frame, belt, motor, pneumatic actuators, and sensors, and integrating all these components into a complete system. Implementation involves using Arduino to control the conveyor operations and pneumatic actuators, counting install sensors to detect the size of the objects to be sorted. Testing is constrained by passing seven test objects of different sizes through the conveyor belt. The system's performance is then evaluated based on its ability to detect and sort objects by size and height. The research results demonstrate that the developed automatic sorting conveyor system effectively sorts objects with high accuracy. The system can detect and sort objects based on size with a 0% error rate, reducing the time required for the sorting process compared to manual methods. Those pneumatic actuators and appropriate sensors ensure consistent and reliable system performance. The developed automatic sorting conveyor system successfully improves the efficiency and accuracy of the sorting process in industry.

INTRODUCTION

The use of sorting systems in the industry significantly contributes to time savings and reduces human effort through automation. These systems enhance the efficiency of the sorting process by minimizing sorting errors and accelerating the overall process (Ananthi et al., 2021; Sughashini et al., 2021; Xie & Zhang, 2019). Furthermore, the utilization of sorting machines is considered highly practical as they can sort components based on metal, non-metal, and color categories (Prasad et al., 2020). Automatic sorting systems are vital components in the supply chain, encompassing tasks from baggage handling to packaging distribution, and are capable of addressing various decision-making challenges in their design and operation (Boysen et al., 2019). The production rate of the manufacturing industry has seen a surge since the implementation of automated sorting systems, which have replaced human resources (Dabade & Chumble, 2015). These automated sorting machines reduce manual effort and human errors in product sorting, thereby enhancing efficiency and the industrial distribution center (Krishnan et al., 2016; Sughashini et al., 2021). Automated sorting systems come with their intricacies. They are capable of controlling conveyors, pneumatic cylinders, solenoids, motors, and sensors through programming, enabling their operation within industrial systems (Khaing et al., 2023). Automation on sorting conveyors can also boost production speed, reduce labor costs, and minimize the risk of workplace injuries or accidents (Kamboj & Diwan, 2019; Yadav et al., 2020). The use of automatic sorting machines employing pneumatic systems significantly enhances industrial productivity by sorting based on size (Prasad et al., 2020; Xie & Zhang, 2019). Among various automation technologies, pneumatic actuators stand out due to their reliability, quick response time, and precision in handling diverse industrial tasks. Pneumatic systems are highly beneficial in the context of shape sorting due to their robustness, cost-effectiveness, and efficiency (Boyko & Weber, 2024; Dezaki et al., 2022; Shrivastava et al., 2023; Xavier et al., 2022). Color and size are crucial features for accurate product classification and sorting, which can be achieved using optical sensors or image analysis. Color sorting machines are utilized in mass food processing and other industries, separating items based on their color and redirecting mismatched items using mechanical or pneumatic ejection devices (Thike et al., 2019).

Effectively developed automatic sorting machines can separate metal, non-metal, and plastic items using capacitive distance sensors, thereby enhancing efficiency and productivity in industrial and educational settings (Oladapo et al., 2016). The deployment of sensors and pneumatic cylinders facilitates the sorting of items into appropriate containers (Ananthi et al., 2021). Additionally, the use of sensors and belt conveyors as hardware has proven effective in implementing product-sorting strategies (Shrivastava et al., 2023). Conveyor sorting systems employing ultrasonic sensors and Arduino Uno have demonstrated a 92% success rate in selecting items with a maximum weight of 200 grams and a high variation of 1-6 cm (Sahara et al., 2021).

Automation in conveyor transportation systems is crucial in today's world. This project demonstrates how sorting automation can be achieved using hardware and software components, particularly the Arduino platform. The system efficiently sorts and arranges products based on their height, reducing the time required for manual sorting and minimizing human errors (Prabhakar et al., 2020). Automatic color sorting utilizing Arduino offers a practical and efficient solution in the industry for classifying products based on color and size. By leveraging optical sensors and a simple robotic arm equipped with a servo motor, this system accurately sorts objects on a conveyor belt controlled by a DC motor (Thike et al., 2019). The project is made using an Arduino UNO and various components. Some of these include a proximity sensor, a light sensor, a conveyor belt, a power supply, and a color sensor. The results of a test revealed that the machine has a high accuracy of over 90%. It can be utilized in the apple processing industry to improve efficiency and reduce labor costs (Haque et al., 2023).

Utilizing belt conveyors can reduce manual effort in sorting metal and non-ferrous materials with varying shapes and sizes, automatically moving them toward bins with the assistance of distance sensors (Hashimi et al., 2020). Automated sorting machines using belt conveyors help prevent size damage in production machinery, increase production rates, and prevent accidents in manufacturing industries (Dabade & Chumble, 2015). The automated sorting process with belt conveyors enhances speed and accuracy in sorting products based on specific parameters such as height, color, or weight (Kamboj & Diwan, 2019). Automating the sorting process on belt conveyors can reduce production time, labor costs, and processing complexity. Leveraging components like belt conveyors, motors, sensors, and Arduino has successfully identified, separated, and collected objects effectively and efficiently (Nuva et al., 2022; Paranjpe, 2021). The design and development of an automated sorting machine is a complex process that involves many steps. This system needs to be able to meet the needs of the manufacturing industry. This project is an industrial automation application that shows the concept of a normal conveyor belt. It can also be called an intelligent conveyor belt due to its ability to sort different-sized objects (Prakash Dabade et al., 2015).

In this research, Arduino technology was chosen due to its ease of use, low cost, and flexibility in prototype development. Arduino boasts a broad ecosystem with numerous compatible sensors and actuators, as well as strong community support, which facilitates the development process and troubleshooting. It was employed to control the conveyor system's operations, including reading inputs from sensors and regulating outputs to pneumatic actuators, using the efficient and comprehensible Arduino C programming language. Despite its limitations in processing power and memory, Arduino's advantages in small-scale prototype development make it an ideal choice (Jackvony & Jouaneh, 2024; Jayastri & Ambikapathy, 2022; Mingyou et al., 2021). Pneumatic actuators were selected for their reliability in industrial applications, rapid response, and ability to deliver substantial force with high precision, while being resilient to harsh industrial environments. These actuators drive the mechanical components of the conveyor system, such as belt drives and sorting mechanisms, under precise control from Arduino. Although they require a suitable air compressor system and proper pressure regulation, their reliability and quick response make them an optimal choice for this application (Boyko & Weber, 2024; Dezaki et al., 2022; Sughashini et al., 2021; Xavier et al., 2022). These sensors were chosen for their accuracy, response speed, and compatibility with Arduino. Positioned along the conveyor path, they measure the dimensions of passing objects and transmit data to Arduino for sorting processes. While these sensors can be affected by environmental conditions, regular calibration and maintenance can ensure consistent performance (Auliya et al., 2023; Oladapo et al., 2016).

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Designing automated material sorting systems is a complex process presenting various challenges. These systems must be designed to meet the evolving demands of the industry, aiming to enhance efficiency and accuracy in object sorting (Hashimi et al., 2020). Morowali Metal Industry Polytechnic faces unique challenges in its quest to improve efficiency and productivity in the metal industry. Key challenges include high manual error rates in the sorting process of metal components, slow process speeds, limited human resources, and high occupational safety risks. The use of manual sorting systems not only led to high errors but also slowed down the overall production process. In addition, the limited number and skills of the workforce further exacerbated the situation, while the risk of occupational accidents remained a serious concern. In the ever-evolving landscape of industrial manufacturing, efficiency and precision are paramount. Morowali Metal Industry Polytechnic, an institution in metal production, continuously seeks innovative solutions to enhance its production processes. One crucial aspect of this industry is sorting metal components based on their shape and size. Automation presents an intriguing solution by integrating advanced technology, allowing industries to achieve greater accuracy, speed, and consistency in production unit operations. Therefore, this research involves the design and development of an automatic sorting conveyor using Arduino microcontrollers implemented in the production unit. The main objective is to design a system that not only enhances sorting efficiency but also improves the accuracy and reliability of the sorting process. By leveraging pneumatic technology, this research aims to address the limitations of existing manual sorting methods and contribute to the broader field of industrial automation.

METHOD

Design of Automatic Sorting Conveyor

The analysis and identification of requirements are conducted to enhance the effectiveness and accuracy of metal shape sorting. This analysis includes a literature study and benchmarking to comprehend existing automated conveyor technology, the components used, and their respective strengths and weaknesses. Designing the tool is crucial in the development process as it provides a 3D model representation of the conveyor system, including all its components. It also aids in understanding how each part will work together, proving invaluable in optimizing the design and addressing potential issues before production (Isiramen, 2018).

The 3D modeling process begins with creating models of individual components such as the conveyor frame, belt, motor, pneumatic actuator, and sensors, detailing each component according to technical specifications, including dimensions, materials, and connection points. Once all individual components are modeled, the next step involves integrating these components into a cohesive system. During the assembly stage in the CAD software, special attention is given to the placement and orientation of components to ensure the system functions effectively. Pneumatic actuators are strategically positioned along the conveyor to ensure that each metal item can be sorted into the appropriate container based on its shape and size. Sensors are positioned at the input of the conveyor to detect the metal shapes as they enter the system, while proximity sensors are used to detect the presence of metal and send signals to the Arduino microcontroller. The 3D design of the automatic sorting conveyor is shown in Fig 1. In the air pressure section, the air is directed to the solenoid valve. Subsequently, the compressed air is trapped and enters the open valve hole leading to the pneumatic cylinder, pushing the sorting arm after receiving a command from the control panel. The design of this sorting system is shown in Fig 2.

The sorting conveyor designed for the automatic sorting system is equipped with technical specifications that have been meticulously developed to meet operational needs and adapt to the working environment. Each component of the conveyor is engineered with precision to ensure optimal and efficient performance. The technical specifications of the sorting conveyor are presented in Table 1.

Table 1. Technical Specifications of The Sorting Conveyor

Component Name	Specification	Description
Frame	Mild Steel, 1600 x 400 x 600 mm	The dimensions are tailored to the operational space and the type of objects being sorted, ensuring that the conveyor can accommodate and move items smoothly (Frangeul & Loizeau, 2022).
Belt Conveyor	PVC, 330 x 3300 x 5 mm	PVC was selected for its durability, flexibility, and abrasion resistance, making it suitable for various loads and working environments (Ghobashy, 2024).
Roller	Galvanized Steel Ø50 mm x 200 mm	The roller dimensions are designed to effectively transport objects that match the size of the sorted items (Wibowo & Gunanto, 2023).
Gearbox Motor	90W	This drive motor provides sufficient power to ensure

Component Name	Specification	Description
		stable conveyor operation and allows for speed adjustments according to specific requirements (Gebler et al., 2018).
Connection Points	M10 Bolt Connection with Welding on the Main Frame	The connection points use M10 bolts for easy assembly and disassembly, while the welding on the main frame ensures the structural stability of the conveyor (Wang et al., 2022).
Pneumatic Actuator	Ø50 mm, 6 bar Pressure	The actuator controls the sorting movement, offering quick and precise responses to direct objects to the correct sorting path (Falcao Carneiro et al., 2020).
Sorting Sensor	Ultrasonic Sensor, ±1 mm Accuracy	This sensor is employed to detect the size of objects with high accuracy, ensuring that items are sorted correctly according to predefined criteria (Zhao & Li, 2022).

Electrical and Control System

The control system of the automatic sorting conveyor consists of several supporting components. The main component is the Power Supply, which converts the power source from 220V to 5V 5A and then transfers it to the microcontroller. The Arduino Uno serves as the microcontroller, responsible for controlling the overall process and managing the input and output data of the device. Ultrasonic sensors are placed in several areas: the top functions as a height-based item detector, while the side serves as a length-based item detector for objects passing through the conveyor. The I2C LCD provides information on the dimensions of the passing workpiece. The 1-Channel Relay Module on the right activates the Solenoid Valve, while the one on the left controls the stopping of the single-phase AC Motor. The Solenoid Valve acts as the driver for the cylinder component, and the Pneumatic Cylinder serves as a barrier in the middle for item sorting. A single-phase AC Motor is used as the driving force on the conveyor track. The diagram of the control system for the automatic sorting conveyor is shown in Fig 3.

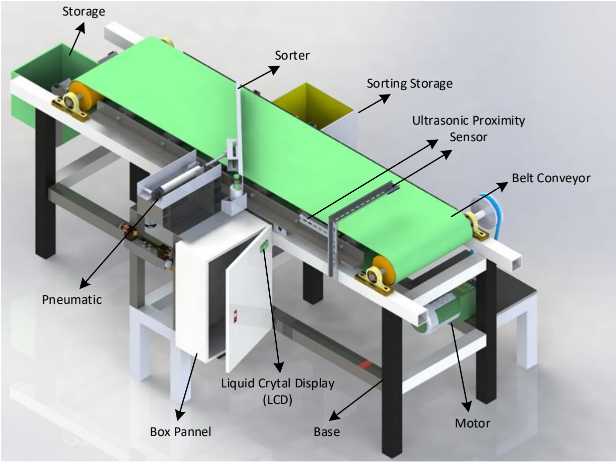

Fig. 1. 3D Design Automatic Sorting Conveyor

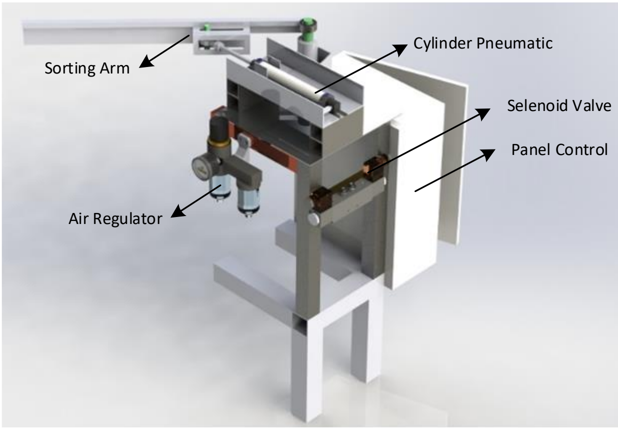

Fig. 2. 3D Design Pneumatic Sorting Arm

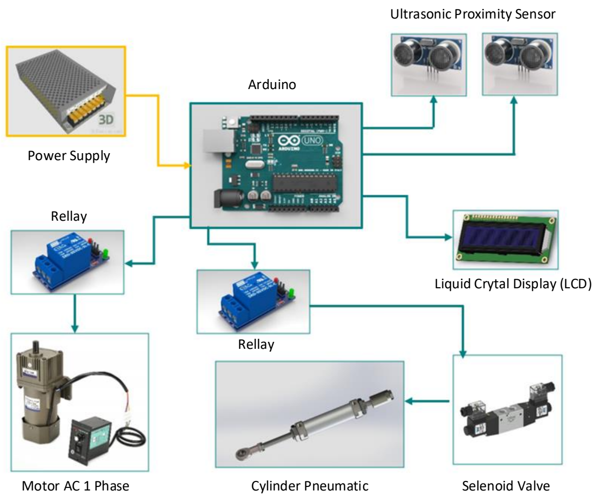

Fig. 3. System Control Diagram

The electrical circuitry of the automatic metal sorting conveyor is designed with the integration of several key components to ensure efficiency and accuracy in the sorting process. This system utilizes the Arduino microcontroller as the central controller, regulating operations based on input from sensors. Sensors are positioned at the input of the conveyor to detect the shape of metal objects, while proximity sensors detect the

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presence of objects and send signals to the Arduino. Data from the sensors is processed using processing algorithms to determine the object's shape and decide the sorting action. Pneumatic actuators are controlled by relays connected to the Arduino's digital pins, receiving a 12V power supply to operate the solenoid valve. A variable-speed DC motor, controlled through a motor driver that receives signals from the Arduino, drives the conveyor belt. A 5V power supply is utilized for the Arduino and sensors, while a 12V power supply is used for the motor and relays. The entire system is designed to ensure stable operation. This design enables the conveyor to sort metal with high accuracy and optimal operational efficiency automatically. The electrical circuitry of the metal sorting equipment is shown in Fig 4.

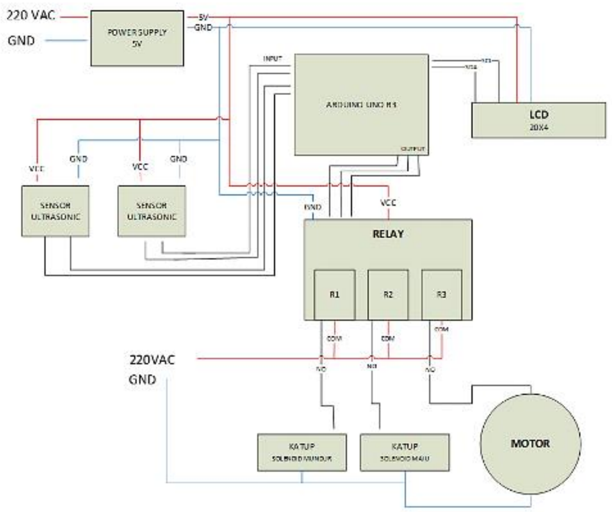


Fig. 4 Electrical Circuit

Sorting System

The design of the automatic sorting arm is intended to optimize the metal sorting process based on shape and size. This arm consists of a pneumatic actuator linked to an Arduino microcontroller system. The actuator provides precise linear motion to push the metal items onto the appropriate sorting track. At the end of the arm, there is a metal-pushing mechanism with various shapes and sizes without damaging the material.

The operation of the automatic sorting arm begins with a sensor that identifies the shape of the metal. This data is sent to the Arduino, which processes the information and determines the correct sorting path. The Arduino activates the pneumatic actuator through a relay, causing the sorting arm to move to the proper position to sort the metal into the designated container or track. This process is fast and efficient, ensuring that each metal item is sorted with high accuracy. The integration of the sensor, controller, and actuator in this design allows the system to work automatically and reduces the need for manual intervention, thereby improving production efficiency and the quality of the final output.

The primary function of the automatic sorting arm is to pick up the detected and identified metal items and move them to predetermined locations based on programmed sorting criteria. The sensor detects the shape and size of the metal as it passes the conveyor and confirms the presence of the metal, sending a signal to the Arduino. The Arduino then processes this data and activates the pneumatic actuator, which moves the arm to sort the metal. The block diagram and electrical circuit of the two-cylinder pneumatic system with dual solenoid valves are shown in Fig 5 and Fig 6.

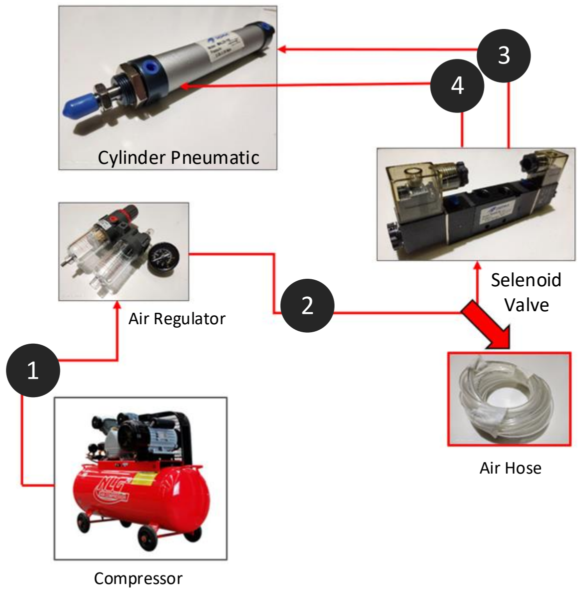


Fig. 5. Two-cylinder Pneumatic Block Diagram

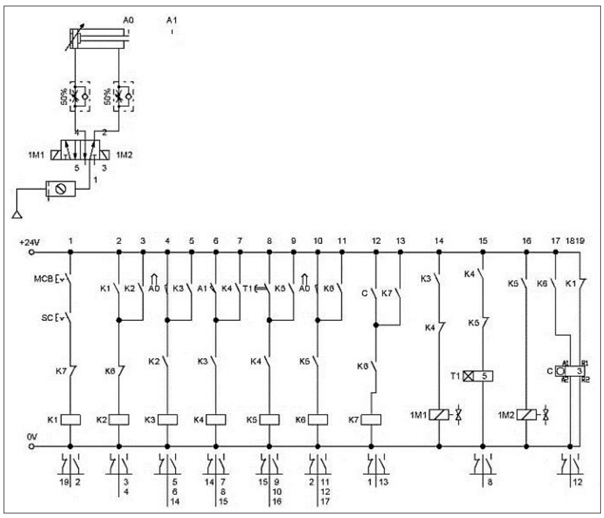


Fig. 6. Two-Cylinder Pneumatic Electrical Circuit

Experimental Set-Up

The automatic sorting conveyor was tested on several metal samples. The metal dimensions were varied to test the sorting system's success on the equipment. The testing involved 7 different-sized box-shaped metals. In addition to sorting based on dimensions, the sorting system was also designed to detect the height of the items. The test materials were made in several sizes as indicated in Table 2. The input and output voltage of the components were tested by measuring the voltage of each component using a multimeter. The results of these voltage measurements are shown in Table 3. This table includes the input and output voltage data for each tested component, providing a clear picture of each component's performance in the circuit. This information is crucial for analyzing the overall device performance and ensuring that each part functions according to the expected specifications. Testing the input and output voltage of the electrical components serves to ensure proper performance, identify faults or failures, and guarantee system reliability (Hidayat & Oktasendra, 2020; Shenil & George, 2019).

Table 2. Object Trial for Sorting Conveyor

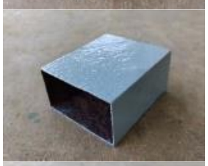
Object Trial	Picture	Dimension	
		Length (cm)	Height (cm)
A		12	1,5
B		13	2,5
C		10	2,6
D		15	3
E		9,5	4,8
F		10,5	5,2
G		10,4	7,1

Table 3. Component Input and Output Voltage Testing

Component Name	Input Voltage	Output Voltage
Power Supply	220 VAC	5 VDC
Arduino Uno	5 VDC	5 VC
Sensor Ultrasonic	5 VDC	-
Liquid Crystal Display	5 VDC	-
Solenoid Valve	220 VAC	-
Relay	5 VDC	12 VDC

The ultrasonic sensor detection test was conducted by measuring the range of the ultrasonic sensor with a ruler (actual distance) and observing the distance displayed on the LCD screen. After obtaining the comparative data between the distance read by the ultrasonic sensor and the distance on the measuring instrument, data analysis techniques are required to determine the percentage error in measurements using the ultrasonic sensor. The percentage error can be determined using Eq. (1), where α_f is the true value of the measuring instrument and α_i is the value obtained during the measurement (Auliya et al., 2023; Sahoo & Udgata, 2020).

$$\%\, error = \frac{\alpha_f - \alpha_i}{\alpha_f} x\ 100\% \qquad (1)$$

Therefore, the key performance indicators for evaluating the success of the automatic conveyor sorting system include the system's error rate in the sorting process. The accuracy of the device in measuring the height of objects is also assessed. Additionally, the system's ability to issue stop commands for transferring items that do not meet the required size is evaluated.

The proposed automatic sorting system is compared with the current manual and automatic sorting systems in terms of efficiency, accuracy, and reliability. The comparison between manual and automatic sorting can be shown in Table 4.

Table 4. Comparison of Manual Sorter and Automatic Sorter

Aspect	Manual Sorter	Automatic Sorter
Efficiency	Generally slower due to human limitations and susceptibility to fatigue, resulting in lower overall productivity (Ji et al., 2023).	Typically, faster compared to manual sorting (Ji et al., 2023).
Accuracy	Higher error rates due to human error (Ji et al., 2023).	Generally, has lower error rates, though it depends on the sophistication of the technology (Ji et al., 2023).

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Aspect	Manual Sorter	Automatic Sorter
Reliability	Reliable in terms of operation but inconsistent in performance due to human factors (Satav et al., 2023).	More advanced systems tend to have higher reliability but may be prone to technical failures (Satav et al., 2023).

RESULT AND DISCUSSION

Design Results

The design of the automatic sorting conveyor frame uses steel. The type of steel used is ST37 hollow steel because of its strong, durable, and resistant characteristics, making it suitable for the sorting system. The size of the leg frame used is 330 mm in length and 200 mm in width. The top frame is 240 mm in length, and the connecting frame is 140 mm long. These dimensions are tailored to the construction size of the sorting frame. The sorting frame is then cut using a handheld grinding machine with a cutting grinder, and then the frame is connected using a welding machine. The conveyor frame functions as the main support structure that carries all conveyor components such as belts, rollers, motors, and other components. Without a strong and stable frame, the conveyor system will not be able to operate efficiently and safely. The belt conveyor is used for continuous material transfer from one point to another. With a flat and flexible surface, the belt conveyor can transport materials of various shapes and sizes. The roller conveyor serves as the support for the belt conveyor. Additionally, the roller can support and move objects stably and safely.

The sorting arms are designed using plate steel and are adjusted to the sorter. Furthermore, the plate steel serves as a pusher for sorted objects based on its characteristics. The dimensions to be used are 500 mm in length for the arm and 500 mm in length for the arm support frame. These dimensions are tailored to the construction size of the sorting arm. The sorting arm is connected with a bearing at the end using a welding machine and will then be attached to the top of the sorting frame support. The cylinder support uses angle steel. The dimensions to be used for the angle steel are 230 mm, 30 mm for the inner angle steel, and the retaining shaft is 45 mm in length, with a diameter of 10 mm and 6 mm. Furthermore, the cylinder support is connected to a pneumatic cylinder at the top. The result of the automatic sorting conveyor design is shown in Fig 7.

Fig. 7. Automatic Sorting Conveyor

The type of panel used in this study is a lender-type panel with dimensions of 25x35x12mm. This panel is chosen for its lightweight and strong characteristics, and its spacious interior makes electrical control installation more convenient and easier. The Control Panel will be installed on the side of the sorting frame using bolts. The design result of the automatic sorting conveyor panel is shown in Fig 8.

Fig. 8. Automatic Sorting Conveyor Panels

Conveyor Test Results

The sensor testing is conducted by passing the prepared test objects over the belt conveyor. The testing is performed on 3 standard metal sizes and 4 non-standard metal sizes. In the first stage, the sensor is used to measure the height of the object. The sensor readings are then displayed on the LCD. When the sensor is tested on the conveyor not traversed by an object, it shows a reading of 0 cm for the object's height. Subsequently, when the sensor is traversed by an object with a height of 2.5 cm, the sensor displays the correct measurement. Therefore, the sensor for detecting object height functions well and successfully detects the metal sizes. The sensor's test results display the items' height and quantity of items sorted. The sensor testing for object height is shown in Fig 9 and Fig 10.

Fig. 9. Measurements Without Objects

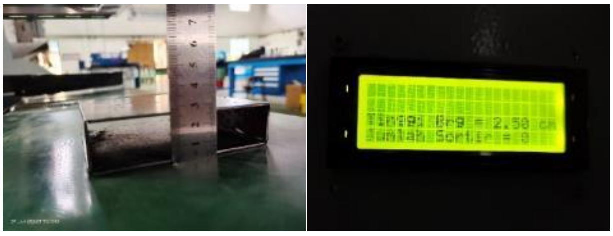

Fig. 10. Measurement With Objects

Subsequently, testing was conducted on 7 test objects to assess the performance of the automatic sorting conveyor. At this stage, the testing aimed to sort objects that fit the specified size criteria and those that did not. The test results demonstrated that the automatic sorting conveyor worked effectively in categorizing the items. In Table 5, the testing was carried out by inputting standard object dimensions within the range of Length 10-14 cm and Height 1-4 cm. If the test object did not meet these standard dimensions, the solenoid valve would be activated, pushing the sorting arm to direct the sorted object into container 1. For objects that met the standard dimensions, the solenoid valve would not be activated, allowing the sorting arm to remain stationary, and the object would proceed over the conveyor to container 2.

Table 5. Standard Test Data for Object Sizes

Object Trial	Size (cm)	Sorted	Unsorted	Error (%)
A	12x1,5		√	0
B	13x2,5		√	0
C	10x2,6		√	0
D	15x3	√		0
E	9,5x4,8	√		0
F	10,5x5,2	√		0
G	10,4x7,1	√		0

The results of the testing were also conducted to evaluate the automatic sorting conveyor's ability to issue a stop command for the transfer of items if any non-conforming items are detected. This mechanism is implemented to halt the transfer process from one stage to the next if a significant number of products of the wrong size are found. The drive motor will stop if the sensor detects three consecutive non-conforming products. Table 6 displays the test results for the motor drive function. The testing involved passing both conforming and non-conforming products. Tests 1, 3, and 5 indicate that the implemented system is functioning as intended. The drive motor remains active even when there is one non-conforming product. In tests 2 and 4, the motor stops when the sensor detects 3 non-conforming products passing through. Therefore, in this trial, the automatic sorting conveyor operates following the design.

Table 6 Drive Motor Detection Test Data

Test	Object Trial	Sorted	Unsorted	Motor	
				Active	Stop
	D	√			
1	A		√	√	
	E	√			
	E	√			
2	F	√			√
	E	√			
	A		√		
3	B		√	√	
	F	√			
	G	√			
4	D	√			√
	F	√			
	C		√		
5	A		√	√	
	B		√		

From the results of the error calculation in Table 5, it can be seen that each metal successfully entered the container according to its size dimensions with an error rate of 0% throughout the experiment. After making adjustments to the sensors, sorting arms, and motors used, trials were conducted on several types of metal sizes so that the sorting results were obtained as shown in Fig. 11 and Fig. 12. The type of product that does not match the standard size of the automatic sorting conveyor successfully separates the product in sorting storage. As for products whose size is following the standard, the product is forwarded and accommodated in storage.

CONCLUSION

The automatic sorting conveyor is designed to automatically sort items based on sizes. It is equipped with a frame, rollers, storage, belt conveyor, sorting arm, sensors, transmission, and drive motor. All components of the automatic sorting conveyor function effectively. The sensors used successfully detect object height with high accuracy, providing accurate readings when tested with objects of specific heights. A trial was conducted with seven test objects to evaluate the conveyor system's performance in sorting objects according to specified size criteria. The results of the test demonstrate that the automatic sorting conveyor effectively sorts objects into the appropriate categories.

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The system operates in line with its design, capable of stopping the drive motor upon detecting three consecutive non-compliant products. The error rate in sorting metal objects is 0% during the experiments, indicating the high accuracy of the designed system. This research indicates that the automatic conveyor system has significant potential to enhance efficiency and production speed in industries by reducing human error. The study recommends further adjustments to the sensors, sorting arm, and motor to further enhance the system's performance in real industrial applications.

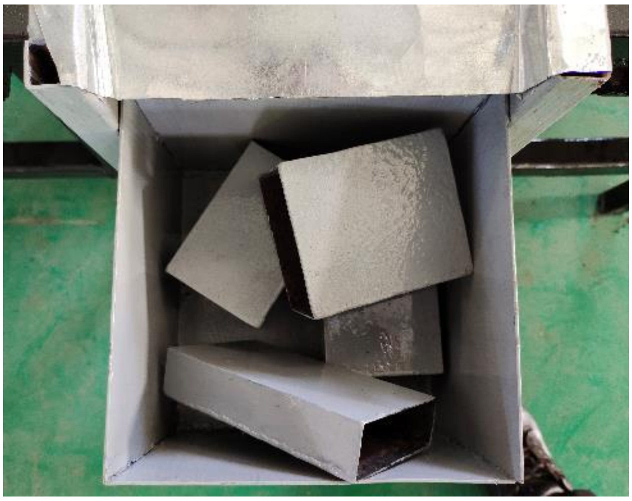

Fig. 11. Sorting Storage

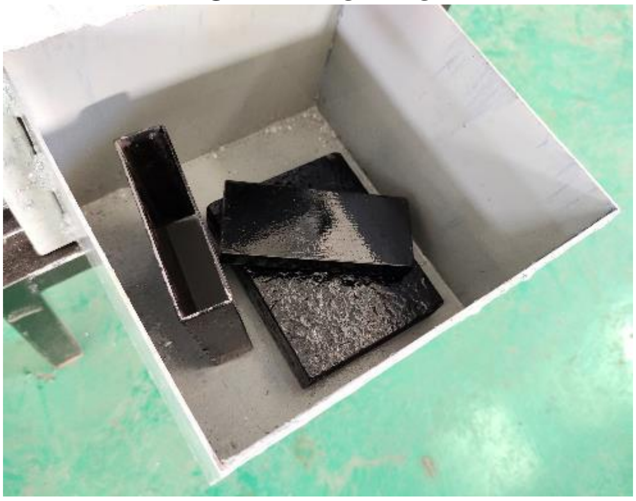

Fig. 12. Storage

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NOMENCLATUR

α_f	definition from true value
α_i	definition from value obtained

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