
| RESEARCH ARTICLE

Automated Pick & Stow Robot System for Sorting in an e-Commerce Warehouse

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| ABSTRACT

Technology is an important factor influencing the development of a company. The Industrial Revolution 4.0 is a new era with an independent field of science in the form of data digitization. Reliable technology has the ability of a flexible, customer-oriented control system with the Just in Time (JIT) concept, and can function as a continuous control system process. Problems that often occur in e-commerce warehouses are improper management, lack of inventory control carried out by machines, and lack of integration with operators, so it takes a long time to analyze errors in the logistics process. This study proposes a sorting robot to reduce the workload in a logistics warehouse. The system consists of three main modules, including a six-axis arm and its controller, software, and flexible end-effectors. The robot automates the picking and storing of objects from and to shelves in an e-commerce warehouse. The prototype system can be demonstrated through several simulations and real-world experiments with real robots.

| KEYWORDS

robotic arm, logistics warehouse, sorting robot, robot system integration

| ARTICLE INFORMATION

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1. Introduction

The rise of the e-commerce industry has made the development of the logistics industry a primary demand of society. There is more automated equipment and more scientific management in modern warehouses making the storage of goods and logistics more efficient and flexible (Tan, 2009). Therefore, warehouses play a very important role in modern e-commerce, where automation processes are needed to be more efficient and improve adaptability (Ayat et. al, 2020).

Modern business competition has an impact on changing the focus of competition from between companies to between business networks such as supply chains. Industry and technology have developed very rapidly, especially with automation. Based on a survey conducted by Credit Suisse, the total cost incurred for automation globally in 2016 was 152 billion dollars, while the cost incurred for automation in the food and beverage process sector was 5.8% of the total automation globally (Corke, 2023).

In today's digital era, most people are accustomed to shopping online at e-commerce. Social Research & Monitoring (soclab.com) shows that 77 percent of the 93.4 million internet users in Indonesia are proven to search for product information and shop online. This phenomenon also provides great opportunities for the logistics business. However, it turns out that the logistics business in Indonesia still faces various obstacles that cause low performance. As a result, clients are unsatisfied. The sorting process in an e-commerce warehouse refers to taking goods from the shelves and sending them to the order according to the box. Flexibility, intelligence, and adaptation have become requirements for the development of robotic arms to complete complex operations in the warehouse. In sorting goods and other jobs, robots need to adapt to complex scenes and the diversity of goods. However, in most e-commerce that have warehouses, sorting goods, packaging and other jobs are still mostly done by humans, limiting accuracy and efficiency (George et. al, 2013).

The difficulty in replacing humans with robots for sorting in e-commerce warehouses is to make robots more efficient than humans at the same cost (Craig et. al. 2015). Several studies have tried to combine online real-time sensing technology with industrial robot

control motion [3]. Further realization can be divided into two aspects such as reducing the construction cost and improving the work efficiency. To develop a robot sorting system, this study integrates the robot control system, motion, basic development of the robot arm, sensor development, and final effect design.

Based on the problems and opportunities for the development of robotic systems that can be used as an improvement in planning and control activities in e-commerce warehouses, this study aims to develop a robotic system for pick & stow with a robot arm technology model (armed technology). This study is expected to be useful for the industry, especially e-commerce or warehousing services with logistics and warehousing activities in managing the planning and control of logistics activities.

2. Methods

This study aims to create a simulator of a logistics monitoring information system in a logistics service company (3PL) so that it functions automatically, integrated with RFID sensors and an Artificial Intelligence (AI) system to facilitate the production and warehousing process which researchers will later name Logistics Control Tower (LCT). This system also makes it easier for users such as transportation/logistics operators to monitor incoming/outgoing goods in the warehouse, and update the achievement of inventory results in the warehouse, without having to print reports, or the option to cancel the warehouse operation activity process due to an unwanted incident in the incoming/outgoing goods process in the warehouse.

By providing an Android-based device for each operator and also a display screen in the form of dashboard information, and connecting the incoming/outgoing goods system using a barcode sensor integrated with the RFID (radio frequency identification) system and an Artificial Intelligence (AI) camera, the goods monitoring process in the warehouse will be easily detected. After the operator runs the integrated system, an automatic transportation system will be produced to monitor incoming/outgoing goods in the warehouse. After being validated by the operator, the system will send the data to the available server and display it on the warehouse monitor which will then be sent to all divisions.

2.1 Improvements with the implementation of information technology (IT) systems

Improvements are made by implementing information technology (IT) applications in the form of SCADA software devices connected to RFID and AI systems. The dashboard display system is an information system used to automate business processes in a company to make it easier for companies to centrally manage and control company resources, namely by integrating sales systems, stock management systems, planning systems and controlling stock needs in the warehouse.

2.2 The development of an automated inventory control system (integrated RFID sensor application)

1. Needs Analysis of Integrated Warehouse System

This analysis aims to explore the needs of the inventory system to be built. The industrial inventory information system is developed according to the integrated needs with a stock card monitoring tool. The final result of this analysis is a Software Requirements Specification (SKPL) document.

2. Design of Integrated Logistics System (Logistics Control Tower)

The design of the inventory system aims to obtain a detailed description of the system contained in Software Design Description (DPPL) document.

3. Needs Analysis of Warehouse Control Tower (LCT) System Device

This stage analyzes the system device specifications that produce software requirements specification documents (SKPL). This SKPL will later be used as a technical reference in the simulation of the integrated production process with RFID sensors to help the industry in planning and controlling the incoming/outgoing goods.

(4) HMI (Human Machine Interface) System

With the use of HMI, operators do not need to worry about the incoming/outgoing goods because data will be recorded on the integrated HMI tool.

(5) Warehouse Monitor, Andon, Kanban

The monitor functions as an information provider regarding the incoming/outgoing goods. If there is a problem with the incoming/outgoing goods, the monitor will inform via andon as a sign that an error has occurred. Kanban functions to inform about excess or insufficient stock of goods, so that operators know the stock of goods in the warehouse is needed.

2.3 The development of an automated inventory control system (integrated AI sensor application)

a. Needs Analysis of Integrated Warehouse System

Needs analysis of integrated inventory control systems is carried out to be able to integrate the system with monitoring tools in the form of inventory stock cards.

b. Design of Inventory Control System

The design of the inventory control system aims to obtain a detailed description of the system

c. Needs Analysis of System Software

This stage analyzes the system device specifications that produce software requirements specification documents (SKPL). This SKPL will later be used as a technical reference in the simulation of the integrated production process with RFID sensors and Artificial Intelligence (AI) to help the industry in planning and controlling the logistics activities.

d. Design of Goods Monitoring

HMI can monitor every workstation in the warehouse, especially with RFID, it can manage goods inventory automatically. This technology allows companies to increase agility and speed of processes, thereby reducing the time employees need to perform tasks related to storage, cutting costs, and easily accessing information.

Artificial Intelligence (AI) readers installed at the transport entrance post allow operators to automatically record the parking location and the warehouse to which they are heading. Thus, the AI system proves to be a viable solution that improves processes and brings more reliability to performing tasks.



Figure 1. Transportation Work Station

e. Storage of Goods

The transportation mode is equipped with AI sensor readers and Artificial Intelligence (AI) cameras on the license plate used to identify each item and ensure it is placed in the correct location. Once the transportation mode enters the company, information about the type of item and its storage location is associated with the ID tag number of each item and recorded in the system. This information is forwarded by LAN/Wi-Fi in real time and all data can be easily accessed through a web-based platform.

f. Outgoing of Goods

AI is used to map the storage location of each item through the license plate. Tags are attached to each storage rack to generate warehouse map information. Each item has a bag where a label is placed to identify the type of product. Then, when the goods are picked by the transportation mode, AI automatically reads it by the AI reader and the entire process is automatically sent to the server and reducing the existing stock.

g. Configuration

At this stage, Artificial Intelligence can monitor the mode of transportation and also the driver driving it.



Figure 2. Configuration

3. Result

The robot system uses actuators, Mechanical materials, Sensor, a Microcontroller, a Computing Interface, and Artificial Intelligence (AI). The robot specifications as shown in Figure 4.2 are as follows:

1. Minimum height 120 cm, maximum 150 cm
2. 5-DOF arm system
3. Smart System Artificial Intelligence (AI)
4. Grip System
5. Logistics service solutions

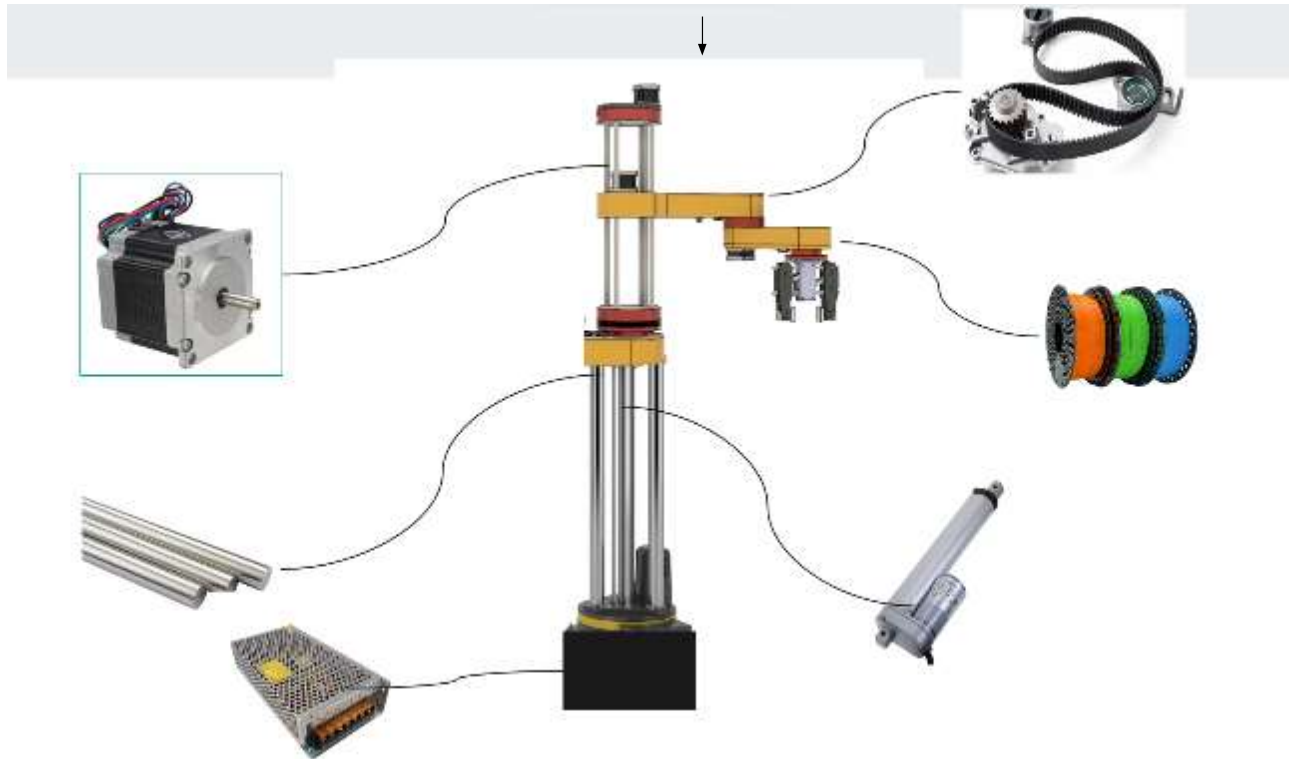


Figure 3. Specifications of the robot system

3.1 Sensor

The robot uses a camera sensor for the implementation of Artificial Intelligence (AI) in addition to its function can also be programmed according to needs. The sensor is used to detect objects so that the robot can provide information according to the programmed commands.

3.2 Microcontroller

The microcontroller used in the robot arm is the Arduino Mega, with the output generated based on the number of ports, making it easier for further development.



Figure 4.3. Arduino Mega

Based on the installed components, a robot can be produced with Artificial Intelligence technology as shown in the following figure.



Figure 4.4. Conceptual Model of Robot

Figure 4.4 shows a conceptual robot model designed with a camera sensor to capture objects in the form of artificial intelligence, Arduino Mega as a controller, a PC as a program processor, and a touchscreen panel to operate the functions produced by the robot arm.

3.3 Microcontroller Program

Commands on the microcontroller are used to provide functions for robot movement such as sensors, actuators, and grippers to pick up goods according to instructions.

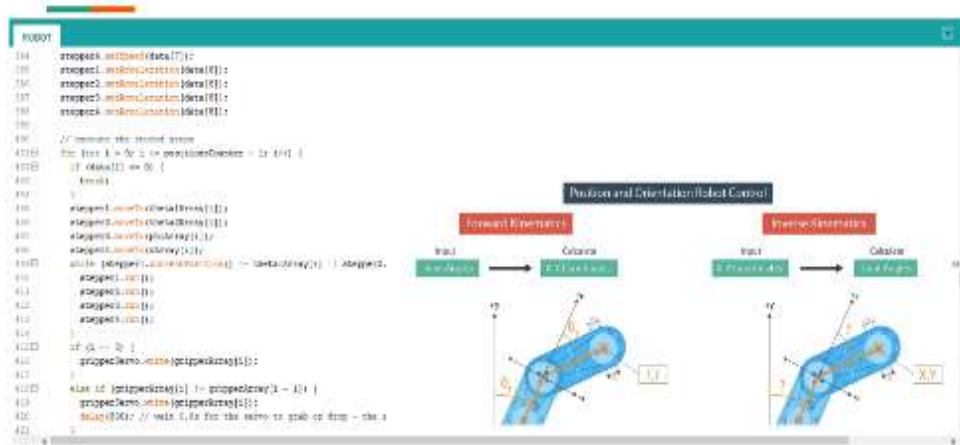


Figure 4. Microcontroller Code

3.4 Artificial Intelligence (AI) Code

Commands on Artificial Intelligence (AI) are given to provide instructions and recognize objects seen by the camera, so that it can detect and carry out commands according to the instructions of the program created. AI code are shown as in Figure 4.6.

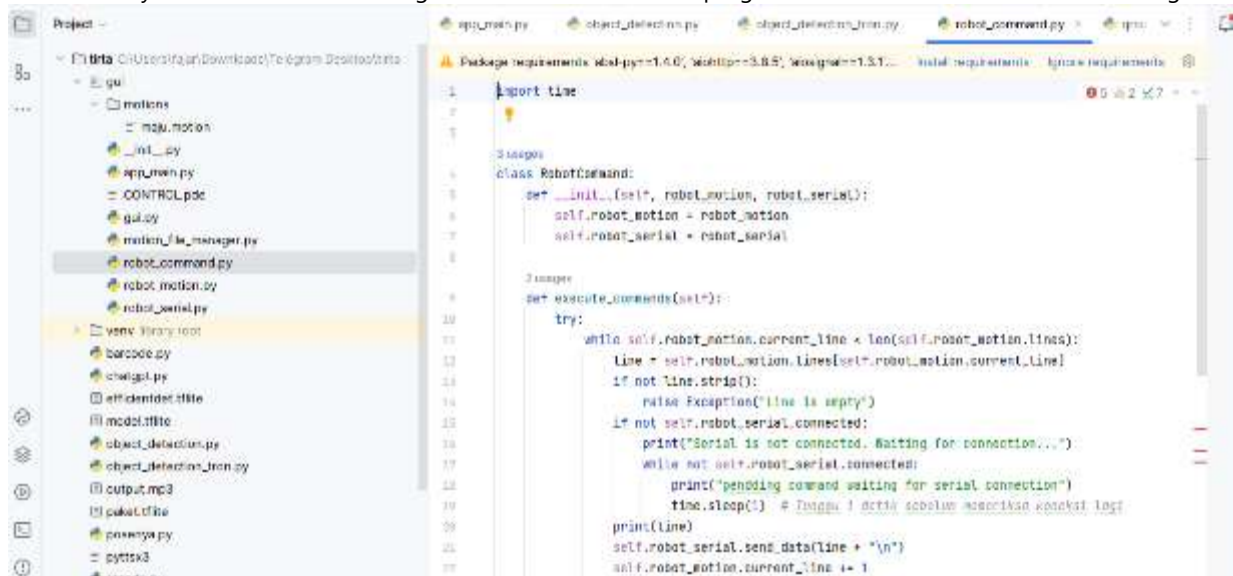
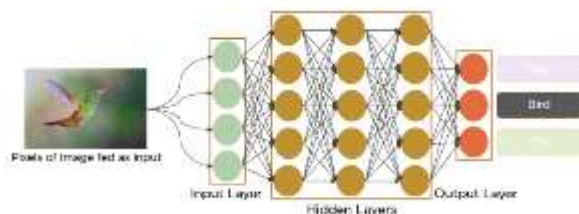
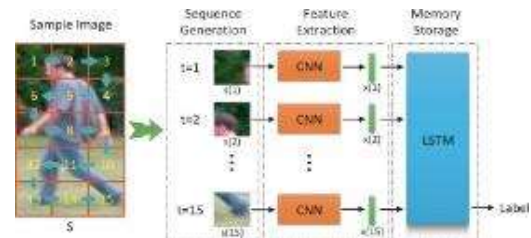


Figure 5. Code for Artificial Intelligence

Through this code, the camera is trained to be able to detect objects, such as color, types of images, movement, voice commands, and QR codes attached to items.



(a). Color



(b) Movement



(c). QR Code

3.5 Robot Schematics

After determining the sensors, actuators, AI programs, and microcontroller programs, the next step is to design a schematic diagram. The robot has 4 axes, namely horizontal movement from right to left and vice versa, then vertical movement from top to bottom and vice versa.

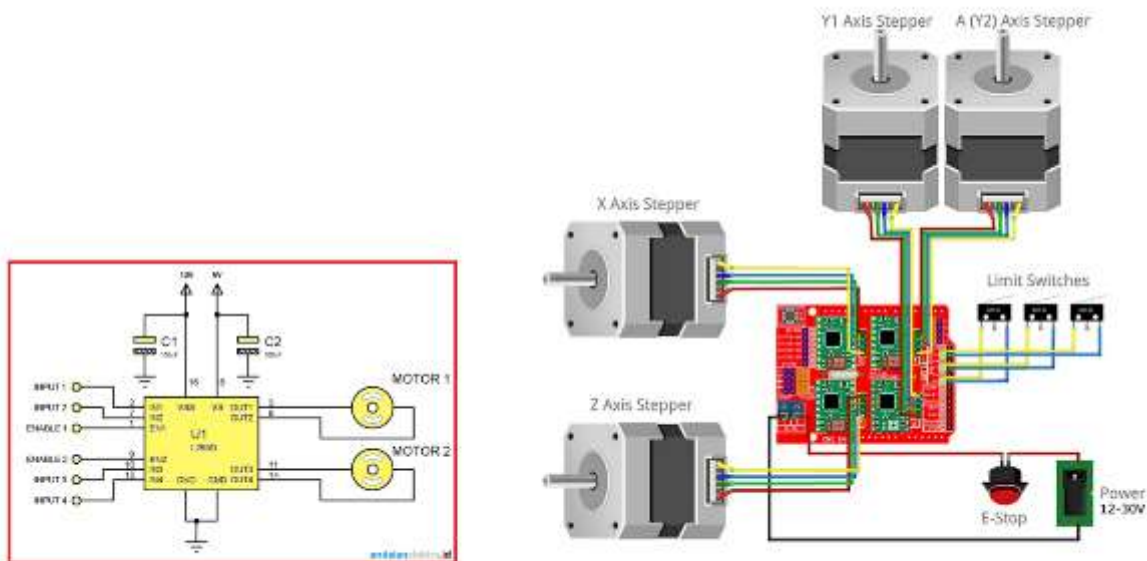


Figure 5. Robot Schematics

3.6 Development of robot baseframe

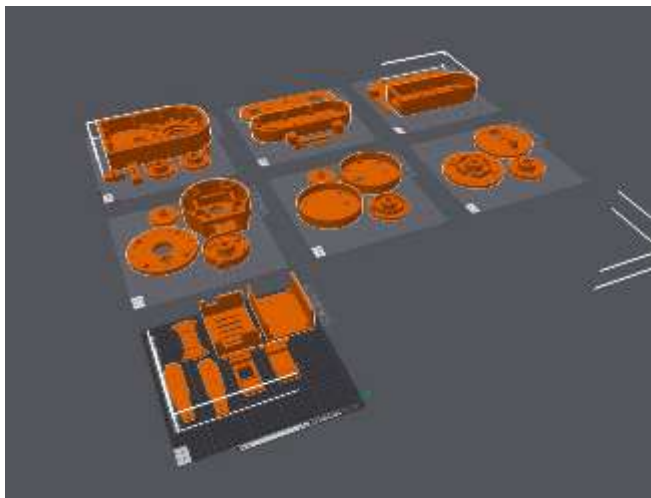
The basic robot frame is made of iron and is used to support the robot so that it can withstand the load when carrying out programming instructions.



Figure 6. Robot Baseframe

3.7 Preparing and Printing 3D designs

The components are molded using ABS plastic material to maintain durability and not be too heavy when carrying out programming instructions.



(a). 3D Design



(b). Printed 3D Component

Figure 7. 3D Component

3.8 Component Installation

After the components are designed and printed using a 3D printing tool, the next step is to install the components to the robot base frame that has been made previously. The installation of these components is done by combining micro components with the robot. Installation is done manually by connecting the bolt threads that have been made and placed on the components.

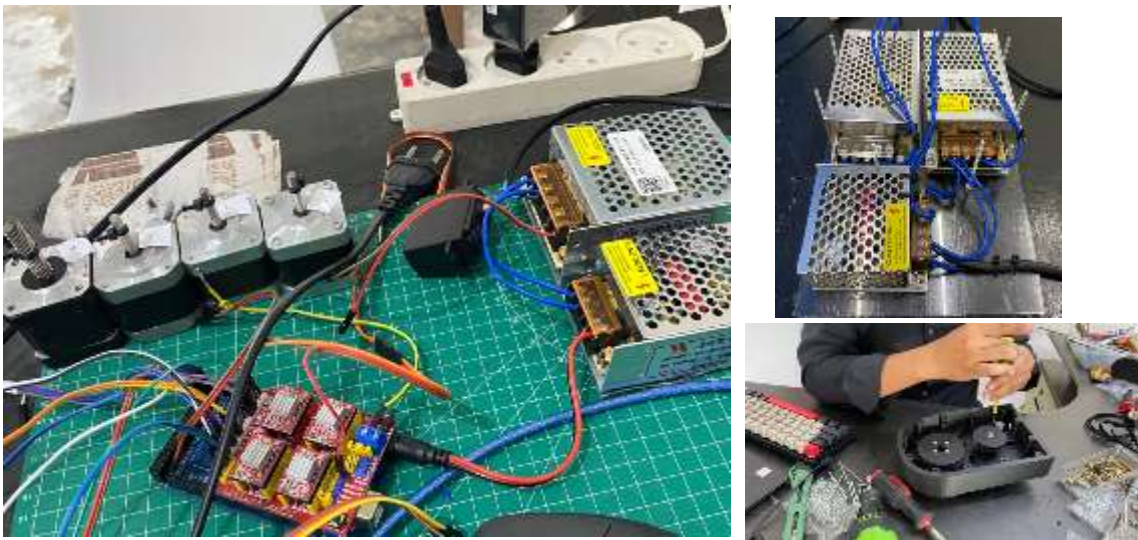


Figure 8. Component Installation

3.9 Installation code microcontroller

This stage aims to connect the microcontroller with the physical robot that has been installed. This process also connects the electric current to the robot arm and connects the program function on the computer as the arm robot brainware

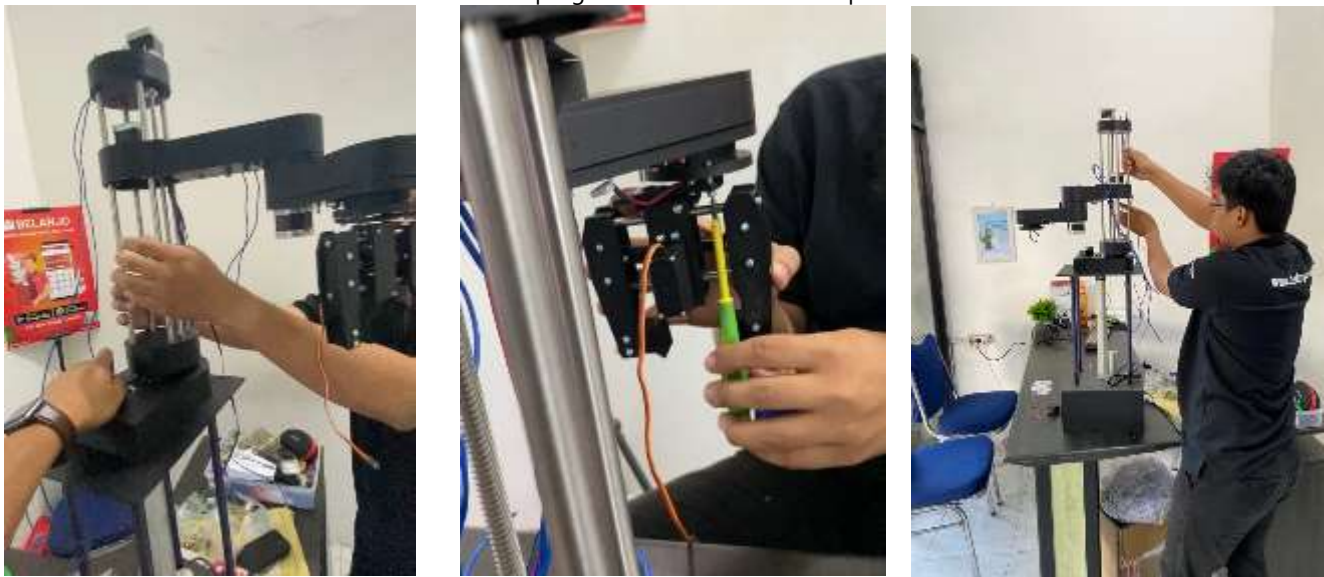


Figure 9. Installation of micro and physical components

3.10 Integration of Artificial Intelligence (AI) algorithms with the robot

After all hardware components and microcontroller code have been installed, the next step is to test the robot arm instruction program. The test results using AI with the robot obtained 9 instruction functions that can be used by the robot arm. These functions include:

- a. Pick & stow function using QR code
- b. Object detection function
- c. Voice recognition function
- d. Pose landmark function
- e. Face recognition function
- f. Object following function (classification)
- g. Hand gesture function
- h. Hand landmark function
- i. 3D Object function

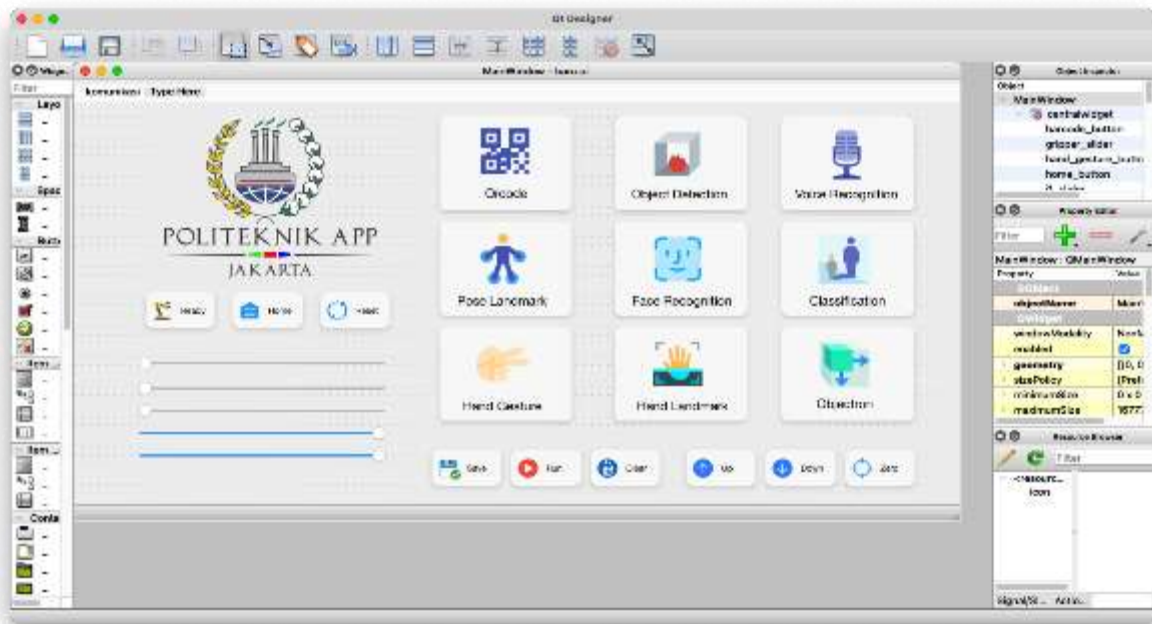


Figure 10. Display of Artificial Intelligence instruction function on robot arm

3.11 Pick & stow goods using QR code

This function instructs the robot to read the QR code containing instructions for picking and stowing goods, and can also detect information about goods that have been inputted into the QR code. The QR code reading process can be seen in Figure 11.



Figure 11. AI camera detection QR code

3.12 Object Detection

This function instructs the robot arm to detect objects recorded by the camera so that it can be used for industry as information for detecting objects that pass through the camera, so that the camera can provide information on objects detected by the camera. The object detection function can be seen in Figure 12.



Figure 12. Camera with AI can detect object

3.12 Voice Recognition

This function is embedded into the robot program, to carry out instructions using voice. This function can also be used to recognize voices by operators who are using robots that have been licensed by the robot program. In industry, this function can be used to carry out commands using voice recognition.

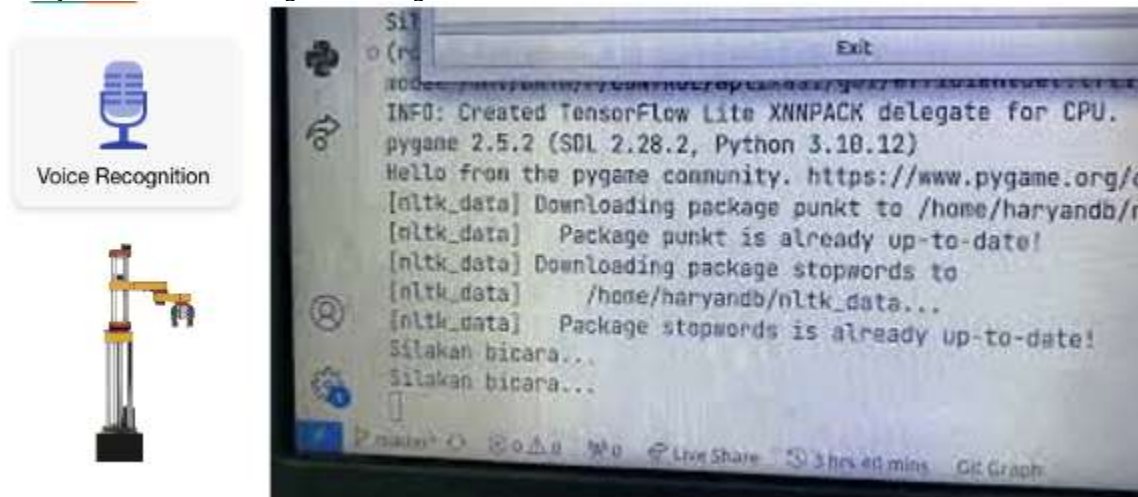


Figure 13. Arm robot can recognize voice

3.14 Pose Landmark

This function detects moving objects and can recognize what objects are moving, so the robot arm will follow the pose landmark that has been detected by the AI camera. In industry, this function can be used to detect the movement of objects through the AI camera, so that the robot can function according to the pose landmark instructions.



Figure 14. Arm robot can detect object movement (*pose landmark*)

3.15 Face recognition

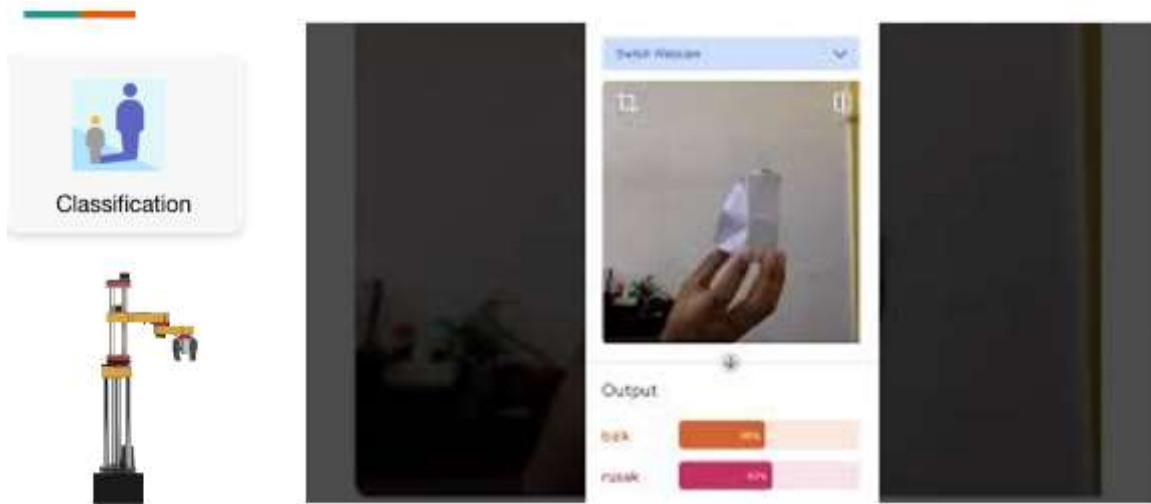
Through the camera, this function detects the face of the user, and recognizes the user who operates the robot. This function can also be used as a facial recognition to operate or deactivate the robot, so that it no longer requires a connecting device to operate the robot. In industry, this function can be used to recognize the faces of staff or operators who can give commands to the robot.



Figure 15. Arm robot can detect the face of the operator

3.16 Image classification

This function detects objects and the shape of the object, through a program that has been recognized by the robot with various shapes such as square, round, oval, cylinder, and others. In industry, the robot arm can recognize products that enter or leave the warehouse, and is also able to detect data and ownership of the product.

Figure 16. Arm robot performs *image classification*

3.17 Hand gesture

This function detects hand movements (hand gestures). Hand movements will be detected by the robot with an AI camera that can provide instruction information through hand gestures. In industry, this function is used to provide instructions using hand gestures.

Figure 17. Arm robot can detect *hand gesture*

3.18 Hand Landmark

This function is almost the same as hand gestures, but hand landmark emphasizes more on symbols formed by the hand so that the robot can recognize instructions based on symbols from landmarks formed by the hand. In industry, robots can be instructed using objects (landmarks) made by hand



Figure 18. Arm robot can detect *hand landmark*

3.19 Objectron

This function can be used to recognize 3D object. 3D products will be easily recognized and detected by robots with AI cameras. In the industry, it is very important to recognize 3D objects.



Figure 19. Arm robot can detect *3D object*

3.19 Trial and Observation by Experts

At this stage, 5 experts from 3PL (third party logistics) logistics service companies and express delivery services were invited to conduct trials and observations on the developed robot arm with the following conclusions:

1. The function of the arm robot is in accordance with the needs of the logistics industry, the function of the Artificial Intelligence (AI) produced is in accordance with the function of modern era technology today.
2. The main function of the robot, namely pick & stow using QR code is a technological advancement and is more effective in identifying goods, because it makes it easier than the previous robot (existing) using color identification.
3. The function of the arm robot developed is very suitable for logistics service companies that have fast delivery capacity, suitable for express logistics and expedition service companies.
4. It is necessary to develop robots to be applied actually to logistics companies, and can be connected to the information system owned by the logistics company (Warehouse Management System).
5. Industrial companies are expected to be able to recognize robotic technology that can increase efficiency and effectiveness in the goods delivery process.

4. Conclusion

Based on the results, the following conclusions can be drawn. The arm robot is developed with several processes starting from designing system requirements, designing microcontroller commands, designing artificial intelligence algorithms, designing electronic schemes, creating a robot base frame, preparing 3D designs, printing 3D designs, installing components, connecting microcontroller codes with robots, and connecting artificial intelligence algorithms with robots. The arm robot is a 5-axis pick & stow system, equipped with 9 (nine) features according to the needs of the logistics industry such as a pick & stow system using QRC codes, object detectors, voice recognition, body movement direction, face recognition, object classification, hand gesture recognition, hand movement direction recognition, and 3-dimensional object recognition. The test results showed that the arm robot is in accordance with the needs of the current logistics industry which focuses on operational speed and efficiency, therefore further testing is needed by combining the Warehouse Management System (WMS). In addition, the arm robot that has been created can be utilized with the actual operational conditions of the company, and can be integrated with the existing company system. As a suggestion, further researchers can utilize 4.0 technology such as Augmented Reality (AR) and Virtual Reality (VR).

- **Disclosure of potential conflicts of interest**

The authors whose names are listed immediately certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

- **Research involving Human Participants and/or Animals**

This article does not contain any studies with human or animal subjects

- **Informed consent**

There are no human subjects in this article and informed consent is not applicable

References

- A. Parasuraman, Valerie A. Zeithaml. Leonard Berry. 2011. *A conceptual Model of Service Quality and Its Implication for Future Research*. Journal of Marketing, Volume 49.
- Agus, P. U., & Novita, M, *Analisis Tata Kelola Teknologi Informasi (IT Governance) Pada Bidang Akademik dengan Cobit Framework Studi Kasus pada Universitas Stikubank Semarang*, 2011.
- Boylestad, Robert. L ;Nashelky, Louis.(2011). *Electronic Devices and Circuit Theory*. New Jersey : Prentice Hall Inc.
- Caon, A., Branz, F., & Francesconi, A. (2022). Development and test of a robotic arm for experiments on close proximity operations. *Acta astronautica*, 195, 287-294.
- Cong, V. D., Hanh, L. D., Phuong, L. H., & Duy, D. A. (2022). Design and development of robot arm system for classification and sorting using machine vision. *FME Transactions*, 50(1), 181-181.
- Craig, S., Cecere, M., Young, G. O. & Lambert, N, *IT Governance Framework: Structures, Processes, and Communication*, 2015
- Daryanto Fauzi, "Monitoring Kebutuhan Bahan Baku dengan Menggunakan Wireless Sensor Network", PENS-ITS, 2011.
- George, Michael L.; Maxey, John; Rowlands, David T.; Price, Mark. (2005). *The Lean Six Sigma Pocket Tool Book : a quick reference to nearly 100 tools for improving process quality, speed, and complexity*. McGraw – Hill, New York.
- Jogiyanto, H.M dan Abdillah, W, *Sistem Informasi Teknologi Informasi*, Yogyakarta, 2011.
- Hernandez, J., Sunny, M. S. H., Sanjuan, J., Rulik, I., Zarif, M. I. I., Ahamed, S. I., ... & Rahman, M. H. (2023). Current designs of robotic arm grippers: a comprehensive systematic review. *Robotics*, 12(1), 5.
- Corke, P., Jachimczyk, W., & Pillat, R. (2023). Robot arm kinematics. In *Robotics, Vision and Control: Fundamental Algorithms in MATLAB®* (pp. 275-328). Cham: Springer International Publishing.
- H. Bin-Abbas, & S. H. Bakry, "Assessment of IT governance in organizations: A simple integrated approach, *Computers in Human Behavior*," Volume 32, ISSN 0747-5632, pp. 261-267, 2014.
- J. A. O'Brien and G. Marakas, "Foundation Concept: Information Systems in Business," in *Management Information System*, New York, The McGraw-Hill Companies Inc, 2010, p. 4.
- M. Ayat, M. Masrom, & S. Sahibuddin, "Issues in implementing it governance in small and medium enterprises," Proceedings of the 2nd International Conference on Intelligent Systems, Modelling and Simulation (ISMS), Phnom Penh, Cambodia, 2011.
- Mathiassen, Lars; Munk-Madsen, Andreas; Nielsen, Peter Axel; Stage, Jan. (2000). *Object Oriented Analysis & Design*. Marko Publishing ApS, Denmark.
- Mira Lestari, D., Hardianto, D., Nizar Hidayanto, A., "Analysis of User Experience Quality on Responsive Web Design from its Informative Perspective", *International Journal of Software Engineering and Its Applications*, Vol.8, No.5, pp.53-62, 2014.
- Puzatova, A., Shakor, P., Laghi, V., & Dmitrieva, M. (2022). Large-scale 3D printing for construction application by means of robotic arm and Gantry 3D Printer: A Review. *Buildings*, 12(11), 2023.
- Ricoida, D., I. & Mulyati, *Studi Penerapan IT Governance Menggunakan Framework COBIT dalam Mendukung Layanan TI (Studi Kasus AMIK XYZ)*, 2012.

- Sarjono, Herman Dwi. 2007. *Elektronika Teori dan Penerapan*. Jember: Cerdas Ulet Kreatif.
- Sanyoto, Nugroho Tri, Moch Romli, dan Toto Trikasjono. 2009. *Rancang Bangun Surveymeter Digital Menggunakan Pancake Detector*. BATAN: Yogyakarta. (Diakses pada tanggal 16 April 2019).
- Sekiya, H., Tokano, K., Zhu, W., Komiyama, Y., & Nguyen, K. (2022). Design procedure of load-independent class-E WPT systems and its application in robot arm. *IEEE Transactions on Industrial Electronics*, 70(10), 10014-10023.
- Sutrisno. 1987. *Elektronika, Teori Dasar dan Penerapannya*. Bandung. ITB.
- Szczepanski, R., Erwinski, K., Tejer, M., Bereit, A., & Tarczewski, T. (2022). Optimal scheduling for palletizing task using robotic arm and artificial bee colony algorithm. *Engineering Applications of Artificial Intelligence*, 113, 104976.
- Tan, W., Cater-Steel, A., & Toleman, M., *Implementing IT Service Management: A Case Study Focussing On Critical Success Factors*, 2009
- Wazzan, A. N., Basil, N., Raad, M., & Mohammed, H. K. (2022). PID Controller with Robotic Arm using Optimization Algorithm. *Int. J. Mech. Eng*, 7(2), 3746-3751.
- Zahidi, Leonard, P, Tirtana M, *Rancang Bangun Aplikasi Sistem Rantai Pasok Industri*. Jurnal Riset Industri 2016.