**IAES International Journal of Robotics and Automation (IJRA)**
Vol. 14, No. 2, June 2025, pp. 181~190
ISSN: 2722-2586, DOI: 10.11591/ijra.v14i2.pp181-190 

# Multi-microcontroller system for Mecanum robots with gripper-shooter mechanisms

**Mohammed Mareai[1], Juhen Fashikha Wildan[2], Mochamad Ridho Afkarean[2]**
[1]Department of Electrical Engineering, Faculty of Advanced Technology and Multidiscipline, Airlangga University, Surabaya, Indonesia
[2]Department of Robotics and Artificial Intelligence Engineering, Faculty of Advanced Technology and Multidiscipline, Airlangga University, Surabaya, Indonesia

**Article Info**

***Article history:***

Received Jan 1, 2025
Revised Mar 6, 2025
Accepted Mar 18, 2025

***Keywords:***

Agricultural robotics
Digital control system
Mecanum wheels
Multi-microcontroller system
Real-time control

**ABSTRACT**

This study presents the design and implementation of a multi-microcontroller digital control system for a Mecanum-wheeled robot with gripper and shooter mechanisms, tailored for agricultural applications. The proposed system integrates an Espressif32 master controller with Arduino Nano slave microcontrollers, enabling precise control of robot movement and functional components. Wireless control is facilitated by a PlayStation 3 controller, while Mecanum wheels ensure omnidirectional mobility in dynamic environments. Experimental results indicate a 66.67% success rate in seedling planting and an 83.33% success rate in ball collection tasks. Despite its notable performance, enhancements in sensor feedback and automation are recommended to improve efficiency. This research underscores the potential of cost-effective, multi-microcontroller systems for advancing real-time control and task execution in agricultural robotics.



***Corresponding Author:***

Mohammed Mareai
Faculty of Advanced Technology and Multidiscipline, Airlangga University
Jl. Dr. Ir. H. Soekarno Kampus C, Mulyorejo, Kec. Mulyorejo, Surabaya, Jawa Timur
Email: mohammed.abdullah.ahmed-2022@ftmm.unair.ac.id

## 1. INTRODUCTION

Agricultural robotics has been widely studied for its potential to transform farming practices. Zanwar and Kokate [1] developed an autonomous robot using direct current (DC) motors, infrared sensors, and microcontrollers for efficient cultivation. For example, Cho *et al*. [2] developed a smart farm robot that integrates RGB-D sensing, precision manipulation, and real-time object detection to automate plant growth monitoring in dense cropping systems. In another approach, Zhang *et al*. [3] combined mechanical, pneumatic, and vision technologies on a mobile platform to enable fully autonomous fruit harvesting in orchards. Meanwhile, Otani *et al*. [4] demonstrated a multifunctional robot capable of sowing, pruning, and harvesting under solar panels, highlighting the versatility of robotic solutions across diverse polyculture environments. In general, agricultural robots can be implemented in various applications, such as crop spraying robots, livestock monitoring robots, soil sampling robots, fruit sorting robots, and harvesting robots [5].

Arduino and Espressif32 (ESP32) are microcontrollers that can be implemented to design digital control modules that are widely used to control robot platforms. Arduino is recognized for its accessibility and ease of programming, making it suitable for educational and simple applications [6]. Arduino microcontrollers are available in most markets at a relatively low cost, having a strong community that provides schematics, source codes, and forums [7]. The ESP32 microcontroller, on the other hand, has more computing power than the Arduino microcontrollers. This means that complex algorithms can be run, which is important for advanced robotic systems [8], [9]. The ESP32 microcontroller is a considerable choice for efficient modules that enable wireless communication [10].

Systems relying on single microcontroller architectures often struggle with real-time coordination due to limited processing power, making them unsuitable for handling complex, multi-functional operations. Previous research, such as that conducted by Swetha *et al.* [11] and Bharti *et al.* [12], demonstrates the limitations of single-microcontroller setups, such as encountering bottlenecks in real-time processing, leading to delays in task execution and reduced overall efficiency. This limits their effectiveness in multi-step tasks, particularly in dynamic environments like agricultural fields. To overcome these obstacles, researchers tend to use microcontrollers or processors with high computational abilities that increase the overall system cost.

In agricultural robotics, grippers and shooters are critical mechanisms for performing dynamic tasks. Grippers enable object manipulation, ensuring delicate objects such as seedlings can be securely grasped and positioned accurately [13]. Meanwhile, shooters allow for controlled projection of objects, such as transferring harvested materials to designated zones. Coupled with Mecanum wheels, which allow omnidirectional movement, these mechanisms provide significant advantages in navigating and operating within dynamic environments such as agricultural fields. Mecanum wheels are particularly advantageous for agricultural tasks due to their ability to maneuver in tight spaces, adapt to uneven terrains, and execute precise movements in constrained environments [14], [15].

Tasks such as seedling planting, sorting operations, and the collection of harvestable crops require not only precision but also adaptability to changing environmental conditions. Studies by Yahaya *et al*. [16] and Singh *et al*. [17] highlight major obstacles in agricultural robotics, such as path planning, environmental variability, and scalability. However, these studies primarily focus on high-level robotic architectures without addressing specialized mechanisms, such as grippers and shooters, that are vital for these tasks.

This study investigates how a multi-microcontroller digital control system, composed of low-computation Arduino Nano microcontrollers, can be integrated with a single ESP32 controller to enhance multitasking capabilities in robotic applications. This research proposes a novel multi-microcontroller design utilizing ESP32 as a master device and multiple Arduino Nano microcontrollers as distributed controllers, each assigned with a specific task. The system is integrated into an agricultural robot that facilitates movement using Mecanum wheels, grippers, and shooter mechanisms. The proposed system’s effectiveness is evaluated in managing multitasking in the Indonesian contest named Kontes Robot Abu Indonesia (KRAI) 2024.

## 2. METHOD

We implemented a remotely controlled robot design utilizing a PlayStation 3 (PS3) controller as the primary input device. The control signals generated by the PS3 controller are received by an ESP32 microcontroller, which serves as the master device in the control system. The master device is configured to communicate with 9 Arduino Nano microcontrollers, each designated as a slave device. Although interrupts and multiple pulse width modulation (PWM) pins can be used simultaneously, this number of microcontrollers is chosen to distribute the computational load of robot functionalities because of the limited computational capabilities of Arduino Nano when it comes to multitasking in dynamic and complex environments. Moreover, using more capable controllers will increase the overall cost. These slave devices are individually addressed with unique identifiers A, B, C, D, E, F, H, J, and K. Each Arduino slave device is responsible for transmitting a PWM signal to a specific motor. The master and slave device configurations serve as the digital control of the robot's movement.

### 2.1. Master device and slave devices integration

The ESP32 microcontroller master device initiates a Bluetooth connection with the PS3 remote controller. The PS3 controller features a button configuration with four left (L) and right (R) buttons numbered as 1R, 2R, 1L, and 2L. It also features buttons designated by the shapes of a triangle, square, cross, and circle. Furthermore, it features two joysticks on the left and right, designated as L3 and R3 [18]. Input commands are generated by the PS3 and transmitted to the master device, which performs the necessary computations to determine the parameters to be sent to the slave devices. These parameters are transmitted to slave devices via a communication protocol operating at a baud rate of 115200. After this, the PWM electrical signals are generated using the Arduino slave microcontrollers, which use an 8-bit timer, capable of producing binary values from 0 to 255 [19], [20]. However, to ensure operational precision, we set the maximum PWM value to 250, which avoids reaching the maximum PWM limit of 255 and provides a buffer. These PWM signals control the speed of the DC motors used.

#### 2.1.1. Master to Mecanum wheels slave devices control

The ESP32 microcontroller master device is connected to the slave devices A, B, C, and D, which are responsible for controlling four Mecanum wheels. The PWM values sent to the slave devices A, B, C, and D are $m_1$, $m_2$, $m_3$, and $m_4$, respectively. They are calculated based on the real speed parameter ($V_r$). In our design, when the R1 button on the PS3 controller is pressed, the real speed variable ($V_r$) is increased by 7, with the condition that the resulting value does not exceed 250. If the incremented value exceeds 250, the master device defaults to 250. When the R2 button is pressed, the real speed is set to 40. If neither R1 nor R2 is pressed, the real speed is set to 100. Flowcharts of the system shown in Figures 1 and 2 start from the PS3 controller to all robot functional components, namely Mecanum wheels as well as the grippers and shooter mechanisms. Figure 1 shows the design of the Mecanum wheel control system.

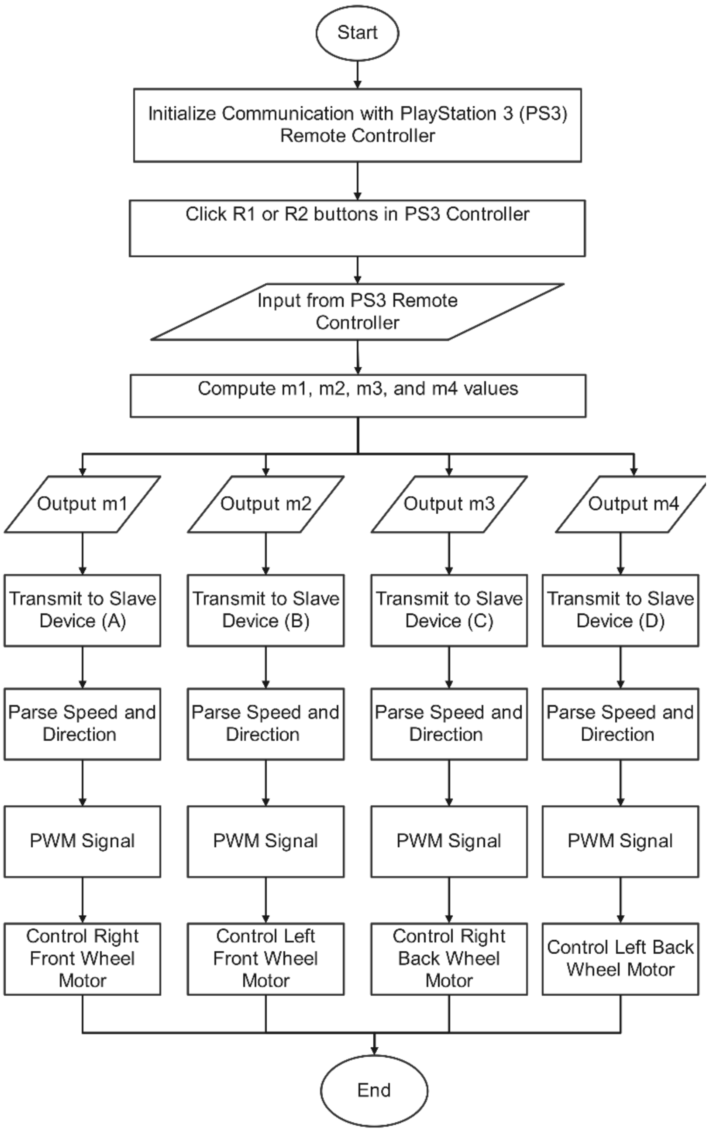



Figure 1. Master device to slave devices operation Mecanum wheel control operation

The two joysticks (R3 and L3) inputs from the remote control include $lX$, $lY$, $RX$, and $RY$. Specifically, $lX$ represents the horizontal movement of the left joystick. $lY$ represents the vertical movement of the left joystick. $RX$ represents the horizontal movement of the right joystick, and $RY$ represents its vertical movement. These joystick values are mapped to a range from $-V_r$ to $V_r$. From these joystick inputs, we calculate the radius ($r$), side-to-side movement ($w$), and angle ($\theta$). These variables' values are set according to (1). From radius, side-to-side movement, and angle, we can obtain PWM parameters $m_1$, $m_2$, $m_3$, and $m_4$ using (2) to (5).

$$r = lY, \quad w = lX, \quad \theta = atan2(RX, RY) \tag{1}$$

$$m_1 = \min\left\{rsin\left(\theta + \frac{\pi}{4}\right) - 0.7w,\ 250\right\} \tag{2}$$

$$m_2 = \min\left\{rsin\left(\theta + \frac{3\pi}{4}\right) + 0.7w,\ 250\right\} \quad (3)$$

$$m_3 = \min\left\{rsin\left(\theta + \frac{\pi}{4}\right) + 0.7w,\ 250\right\} \quad (4)$$

$$m_4 = \min\left\{rsin\left(\theta + \frac{3\pi}{4}\right) - 0.7w,\ 250\right\} \quad (5)$$

### 2.1.2. Master to grippers and shooter mechanisms slave devices control

Grippers and shooter mechanisms in the robot are controlled by slave devices E, F, H, J, and K. Figure 2 shows the design of the grippers and shooters mechanisms control system. The grippers and shooter slave devices require gripOn¸ triangleBtn, crossBtn, spdLift, neckTrigger, and spdShooter variables. These variables are transmitted from the master device to slave devices.

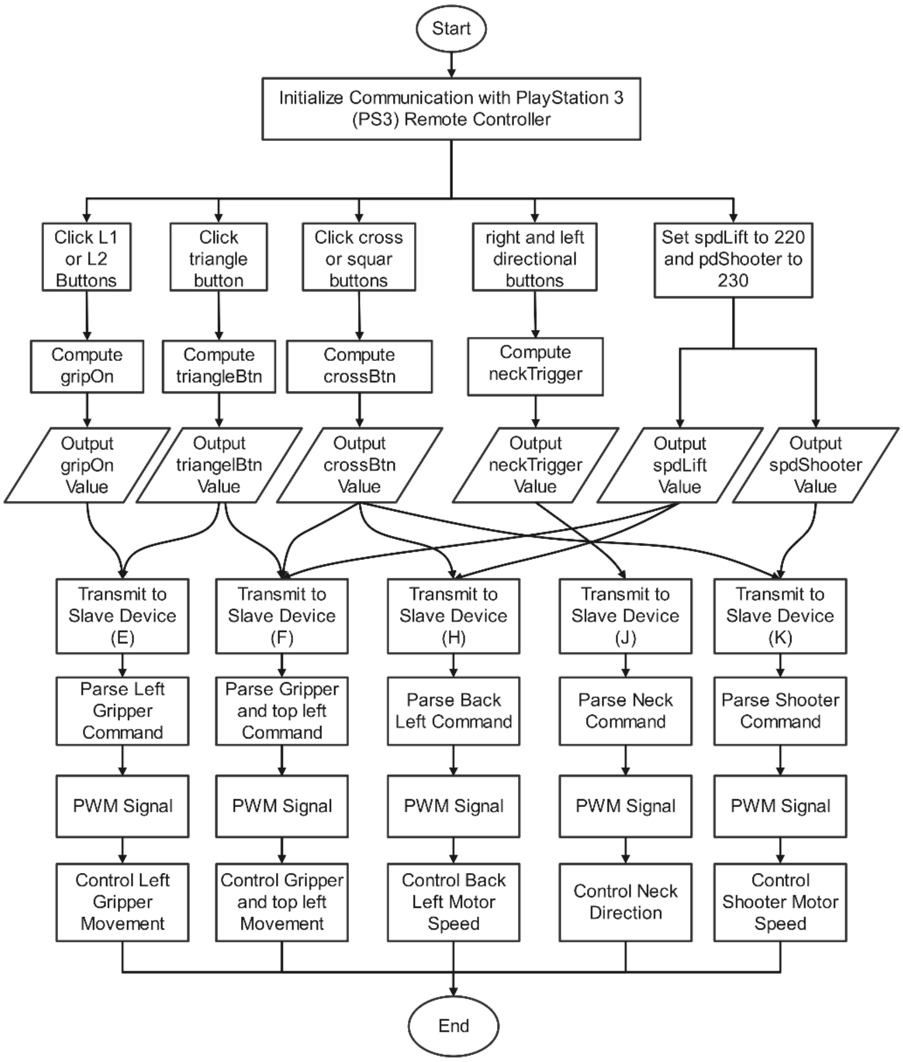



Figure 2. Master device to slave devices operation: gripper and shooter control mechanisms

The grippers and shooter slave devices' parameters are obtained using the conditional logic explained in Table 1. In the system, each slave device is assigned specific parameters based on its function. Slave Device (E) receives gripOn and triangleBtn to control the gripper's state and additional modes. Slave Device (F) is provided with crossBtn, spdLift, and triangleBtn to manage lift operation and speed. Slave Devices (H) is configured with crossBtn and spdLift for similar lift control functions. slave device (J) receives neckTrigger to adjust the neck's position. Finally, the slave device (K) is assigned crossBtn and spdShooter to control the shooting mechanism.

Table 1. Slave devices (E, F, H, J, and K) parameters manipulation

| Parameters | Description | Conditional logic |
|---|---|---|
| gripOn | gripOn determines whether the gripper should be engaged or disengaged based on the input from the L1 and L2 buttons. | gripOn is set to 11 if L2 is pressed, 10 if L1 is pressed, and 5 otherwise. |
| triangleBtn | triangleBtn parameter represents the control signal associated with the triangle button. | triangleBtn is assigned as 10 if the triangle button is pressed and 5 otherwise. |
| crossBtn | crossBtn parameter is derived from the cross button. | crossBtn takes values of 5, 10, or 11 based on the cross-button state and a cycling condition involving crossBtn condition with an override to 12 if the square button is pressed. |
| spdLift | spdLift parameter specifies the speed setting for the lift mechanism. | spdLift is directly passed from the master device to be 220. |
| neckTrigger | neckTrigger parameter controls the neck movement and positioning. | neckTrigger is set to 11 if the right arrow button is pressed, 10 if the left arrow button is pressed, and 5 otherwise. |
| spdShooter | spdShooter: this parameter determines the speed of the shooter mechanism. | pdShooter is directly passed from the master device to be 230. |

### 2.2. Slave devices and robot environment integration

The engineered control system employs PWM signals to regulate the speed and direction of the motors affixed to the robot. This technique enables each motor to function according to the distinct requirements of the mechanism it governs, including wheel movement, gripper actions, and shooter operations. The system design incorporates diverse DC motors, including PG45, PG36, and RS-775, alongside an RDS3115 servo, chosen according to their distinct features, torque, and speed specifications.

#### 2.2.1. Slave devices management for Mecanum wheels

The slave devices controlling the four Mecanum wheels' motion allow the robot to move with flexibility in all directions, including forward, backward, sideways, and rotating. The four main slave devices that control Mecanum wheels are A, B, C, and D. Each of these slave devices is responsible for controlling the right front, left front, right rear, and left rear wheels independently. With the system's ability to control each wheel independently, the robot can perform complex and precise maneuvers, providing advantages in mobility and flexibility in real time.

Each wheel is powered by a PG45 DC motor, selected for its ability to deliver high torque with efficient power consumption. This motor is available in different models. In one of these models, the motor can provide an efficient torque of 197 kgf.cm and a maximum force torque of 276 kgf.cm. It features a gear ratio optimized for precise speed and torque control, making it suitable for applications requiring complex maneuvers, such as Mecanum-wheeled robots [21]. The motor's speed and direction are controlled using a PWM signal.

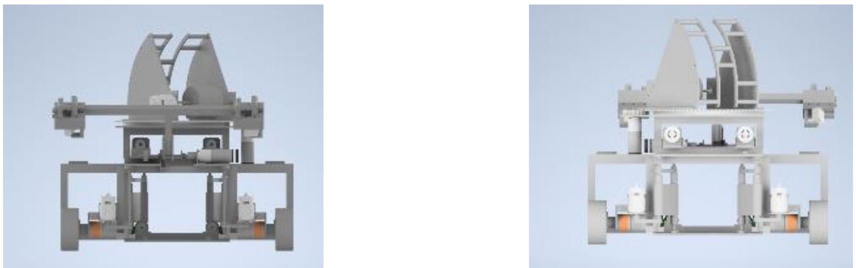
#### 2.2.2. Slave devices management for grippers and shooter mechanisms

Grippers and shooter mechanisms control is achieved through the master device that coordinates five slave devices: E, F, H, J, and K. Each of these slave devices is responsible for controlling specific motors and mechanisms. The slave device management approach ensures that each mechanism on the robot operates optimally and according to its specific needs.

Slave devices E, F, H, J, and K control PG36 and RS-775 DC motors as well as RDS3115 servo. Slave devices E and J control PG36 motors, which offer high torque in a compact size, making them smaller and more space-efficient compared to PG45 motors. This motor is available in different models. An example of these models is that they can operate with a torque of 18 kg-cm at 12 volts. PG36 motors are well-suited for applications requiring precise control, such as grippers and neck mechanisms [22]. Slave device F controls an RS-775 motor and RDS3115 servo. The RS-775 is a high-speed and high-torque DC motor capable of operating in one of its models at a speed of 3500 rpm for 12 V [23]. It is well-suited for applications requiring high power, such as top lift mechanisms. The RDS3115 servo, weighing 100 g, is capable of delivering 15 kg·cm of torque and is used for precise control of the gripper mechanism [24]. Slave devices H and K are responsible for controlling additional RS-775 motors.

#### 2.2.3. Robot system environment

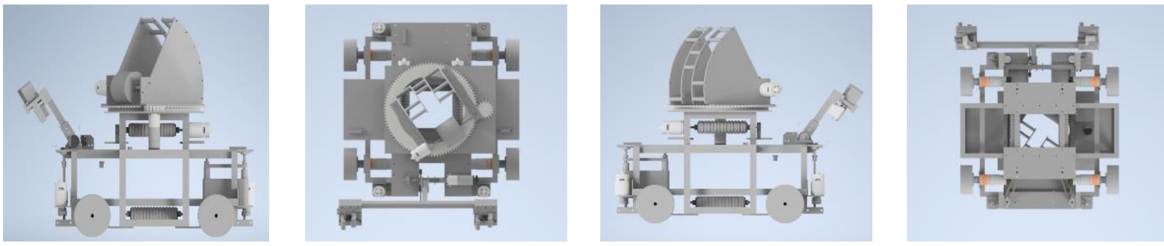
The digital control system is integrated with the robotic mechanical system environment shown in Figure 3. The robot features a metallic frame, with motors mounted on the structure using thick plastic plates secured by screws, incorporating several distinct features. First, it is equipped with four Mecanum wheels, each driven by an individual motor, allowing omnidirectional movement and enhanced maneuverability. Second, a gripper mechanism is integrated as a floating component in the front, enabling the robot to perform tasks requiring object manipulation and grasping as shown in Figure 3(a). Finally, the robot includes a shooter mechanism mounted on top, providing projectile functionality as shown in Figure 3(b). These features collectively represent the designed robot's functionalities.



(a) (b)

Figure 3. Robot 3D design from (a) front-side view and (b) back-side view

Figure 4 provides a detailed view of the robot from different sides, showcasing its intricate design and functionalities. Figures 3(a) and 3(b) reveal the robot's dual-gripper design. The grippers are attached to a central rod that facilitates vertical motion, driven by an additional motor. The gripper mechanism is also shown in Figure 4(c) on the front side of the robot. The Mecanum wheel system is shown in Figure 4(d). Each wheel is individually driven by a dedicated motor. The shooter mechanism is located at the top of the robot. The shooter works after the object is placed inside the robot in the center. The shooter features a rolling, cylindrical component made of plastic, designed to accelerate the shooting process. A directional cover is integrated into the design of the shooter to guide the trajectory of the projectiles forward.



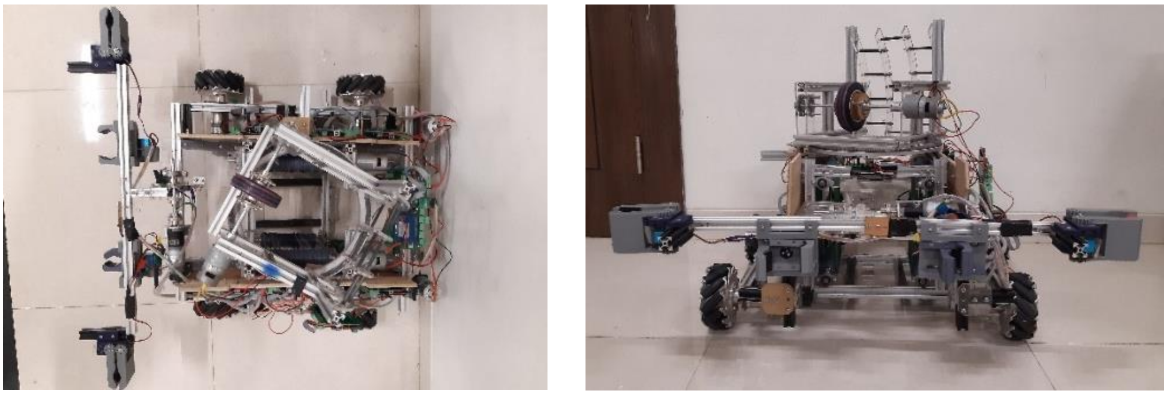
(a) (b) (c) (d)

Figure 4. Robot 3D design from (a) left-side, (b) upper-side, (c) right-side, and (d) bottom-side view

All components of the robot work together, enabling it to perform its functions. The robot moves according to the input commands from the PS3 controller using its Mecanum wheels. After it reaches the position in which an object is in front of it, the grippers start to work. The robot is facilitated with rubble rods that enable the transfer of objects from the front grippers to the center of the robot, ensuring the object remains securely within the robot's structure. After this, the robot can be moved to another location where the shooter can be activated. Once the shooter mechanism is activated, a secondary set of rubber rods propels the object vertically. The mounted shooter, equipped with a wheel, further accelerates the object, while the shooter cover ensures that the trajectory is directed forward.

## 3. RESULTS AND DISCUSSION

The practical implementation of robot design is illustrated in Figure 5. The 3D design was the guide through the implementation process. However, some adjustments were needed. One adjustment is that two additional grippers, powered by two servo motors, were incorporated to enhance the robot's gripping mechanism, as shown in the front of the robot in Figure 5(a). The dual grippers previously introduced in the 3D model were retained for handling left and right gripping tasks, while the new two grippers handle front gripping tasks. The remainder of the robot's design was constructed in alignment with specifications detailed in the 3D model with slight modifications for sizing and dimensions, such as reducing the size of the rolling, cylindrical component in the shooter mechanism as shown in Figure 5(b).



(a) (b)

Figure 5. Robot 3D design from (a) top-side and (b) front-side view

### 3.1. Robot performance at KRAI 2024

The proposed robot was evaluated during the KRAI contest. This provides an opportunity to assess the robot's digital control system and its functionalities under competitive conditions [25]. In the contest, the robot was expected to do two tasks in two different areas. These tasks were:

a. Seedling planting at area 1: the robot was tasked with planting representations of rice seedlings, mimicking the initial step of sowing rice seeds in prepared plots. The robot is tasked with planting seedlings in designated circles within area 1.
b. Handling paddy rice and empty grains at area 2: robots must pick up balls that represent mature rice grains (paddy rice) and separate out empty grains, simulating the sorting and collection of harvestable rice. The robot's task was to collect and deposit "empty grain" and "paddy rice" balls into the storage zone at area 3.

The robot demonstrated commendable performance in the competition. In area 1, the robot successfully planted seedlings four times in six attempts, yielding a success percentage of 66.67%. In area 2, the robot collected balls successfully in five out of six matches, yielding an 83.33% success rate. This was accomplished using the Mecanum wheel system that facilitated omnidirectional movement along with grippers and shooter mechanisms that played a vital role in ensuring dragging the balls and shooting them to the correct place.

During the contest, failures in some of the contest matches were observed to be caused by certain reasons. The failure that occurred in the ball-throwing system from area 2 to storage zone at area 3 was caused by high-frequency vibrations in the rubber belt system because it was rotating at high speed. The deviation observed in the ball-throwing trajectory averaged ±15 degrees from the intended path. The gripper mechanism, designed to hold and plant multiple seedlings, has the limitation of its inability to adjust its position automatically. For the shooter mechanism, the external interference from the opposing team, which repositioned the balls, created challenges for the robot during the collection process.

### 3.2. Comparison with other methods

Digital multi-microcontroller control systems have been introduced in many previous literatures. Mondada *et al*. [26] have developed a multi-microcontroller architecture used in the Khepera robot. In this architecture, a main microcontroller (Motorola MC68331) handles high-level control, while additional microcontrollers manage low-level tasks such as sensor data acquisition and motor control. Henrey *et al*. [27] designed a multi-processor system-on-chip (MPSoC) architecture implemented on a field-programmable gate array (FPGA). The system is integrated with the Abigaille-III robot, consisting of seven soft processors: one coordinating processor for high-level control and six leg processors for low-level control of each leg. The comparison of this research control method with these modules' methods is presented in Table 2.

Based on Table 2, we can find that the proposed method offers a balanced solution for multitasking environments, with moderate efficiency and real-time response capability. While the Khepera robot method also shows moderate efficiency, the proposed method enables a more scalable and low-cost solution that outperforms older modular systems that are constrained by the MC68331 CPU's old architecture. Furthermore, the proposed method offers a balance between cost, scalability, and efficiency, making it suitable for general-purpose applications while remaining cost-effective in comparison to the Abigaille-III robot control method.

Table 2. Performance comparison between proposed method and other methods

| Criteria | Proposed Method | Khepera robot | Abigaille-III robot |
|---|---|---|---|
| Architecture | ESP32 with 9 Arduino Nanos | MC68331 with peripheral microcontrollers | FPGA-based MPSoC (7 MicroBlaze soft processors) |
| Efficiency | Moderate: optimized for multi-tasking | Moderate: optimized for modularity | High: parallel processing, 1 kHz control loops |
| Real-time Response | Moderate: limited by the number of handled tasks | Moderate: limited by 1990s architecture of the controller | High: ultra-low latency with parallel loops |
| Scalability | High and simple | Moderate: limited MC68331 capabilities | Moderate: limited by FPGA resources |
| Power consumption | Low | Low | Moderate |
| Cost | Low | Low | Moderate-high |
| application | General-purpose | General-purpose | Specialized |

## 4. CONCLUSION

This study presents the design and implementation of a digital control system for a Mecanum-wheeled robot equipped with gripper and shooter mechanisms. The main contributions of this study lie in the development of a novel multi-microcontroller-based digital control architecture. The control method is optimized for multitasking, handling Mecanum wheels for omnidirectional maneuverability, grippers for precise object manipulation, and a shooter mechanism for efficient object projection. This study also presents proposals for further improvements. To enhance the introduced grippers and shooter mechanisms, the integration of more advanced sensors with PID feedback loops is proposed. The designed module can also be expanded to incorporate advanced automation features, enabling seamless integration with larger robotic systems for complex tasks such as autonomous object handling and real-time decision-making. Overall, this study makes a significant contribution to the advancement of control modules in robotics by introducing a scalable, multi-functional, low-cost robotic control system capable of executing complex tasks in dynamic environments, such as agricultural applications.

## ACKNOWLEDGEMENTS

The author sincerely thanks the Faculty of Advanced Technology and Multidiscipline at Airlangga University for their support and guidance throughout this work. The robot design was conducted using materials available in the faculty research laboratory.

## FUNDING INFORMATION

This research was partially funded by the Faculty of Advanced Technology and Multidiscipline, Airlangga University.

## AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

| Name of Author | C | M | So | Va | Fo | I | R | D | O | E | Vi | Su | P | Fu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mohammed Mareai | ✓ | ✓ | ✓ | | ✓ | ✓ | | | ✓ | ✓ | | ✓ | ✓ | ✓ |
| Juhen Fashikha Wildan | | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ | | ✓ | ✓ |
| Mochamad Ridho Afkarean | | | ✓ | ✓ | | | ✓ | ✓ | ✓ | | ✓ | | | ✓ |

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

## CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

## DATA AVAILABILITY

The authors confirm that the data supporting the findings of this study are available within the article.

## REFERENCES

[1] S. R. Zanwar and R. D. Kokate, "Advanced agriculture system," *IAES International Journal of Robotics and Automation (IJRA)*, vol. 1, no. 2, pp. 107–112, Jun. 2012, doi: 10.11591/ijra.v1i2.382.
[2] S. Cho *et al.*, "Plant growth information measurement based on object detection and image fusion using a smart farm robot," *Computers and Electronics in Agriculture*, vol. 207, p. 107703, Apr. 2023, doi: 10.1016/j.compag.2023.107703.
[3] K. Zhang, K. Lammers, P. Chu, Z. Li, and R. Lu, "System design and control of an apple harvesting robot," *Mechatronics*, vol. 79, p. 102644, Nov. 2021, doi: 10.1016/j.mechatronics.2021.102644.
[4] T. Otani *et al.*, "Agricultural robot under solar panels for sowing, pruning, and harvesting in a synecoculture environment," *Agriculture*, vol. 13, no. 1, p. 18, Dec. 2022, doi: 10.3390/agriculture13010018.
[5] A. J. Moshayedi, A. Sohail Khan, Y. Yang, J. Hu, and A. Kolahdooz, "Robots in agriculture: Revolutionizing farming practices," *EAI Endorsed Transactions on AI and Robotics*, vol. 3, pp. 1–23, Jun. 2024, doi: 10.4108/airo.5855.
[6] A. Bhargava and A. Kumar, "Arduino controlled robotic arm," in *2017 International conference of Electronics, Communication and Aerospace Technology (ICECA)*, Apr. 2017, pp. 376–380. doi: 10.1109/ICECA.2017.8212837.
[7] A. D'Ausilio, "Arduino: A low-cost multipurpose lab equipment," *Behavior Research Methods*, vol. 44, no. 2, pp. 305–313, Jun. 2012, doi: 10.3758/s13428-011-0163-z.
[8] K. Chenchireddy, R. Dora, G. B. Mulla, V. Jegathesan, and S. A. Sydu, "Development of robotic arm control using Arduino controller," *IAES International Journal of Robotics and Automation (IJRA)*, vol. 13, no. 3, pp. 264–271, Sep. 2024, doi: 10.11591/ijra.v13i3.pp264-271.
[9] M. J. Espinosa-Gavira, A. Agüera-Pérez, J. C. Palomares-Salas, J. M. Sierra-Fernandez, P. Remigio-Carmona, and J. J. González de-la-Rosa, "Characterization and performance evaluation of ESP32 for real-time synchronized sensor networks," *Procedia Computer Science*, vol. 237, pp. 261–268, 2024, doi: 10.1016/j.procs.2024.05.104.
[10] H. Dietz *et al.*, "ESP32-CAM as a programmable camera research platform," *Electronic Imaging*, vol. 34, no. 7, pp. 2321–2326, Jan. 2022, doi: 10.2352/EI.2022.34.7.ISS-232.
[11] K. R. Swetha, D. Monisha, H. B. Thejaswini, K. P. Nikhil, and N. U. Rahul, "IoT and wireless sensor network based autonomous farming robot," in *2024 International Conference on Knowledge Engineering and Communication Systems (ICKECS)*, Apr. 2024, pp. 1–6. doi: 10.1109/ICKECS61492.2024.10616854.
[12] A. Bharti, M. H. Reddy, P. Raja, Mukesh, N. Kumar, and Ratish, "Agrobot- an IoT-based automated multi-functional robot," in *2022 IEEE Conference on Interdisciplinary Approaches in Technology and Management for Social Innovation (IATMSI)*, Dec. 2022, pp. 1–6. doi: 10.1109/IATMSI56455.2022.10119284.
[13] N. Govindan, B. Ramachandran, P. H. V. Sai, and K. M. Krishna, "A novel hybrid gripper capable of grasping and throwing manipulation," *IEEE/ASME Transactions on Mechatronics*, vol. 28, no. 6, pp. 3317–3328, Dec. 2023, doi: 10.1109/TMECH.2023.3264287.
[14] E. Navas, R. Fernández, D. Sepúlveda, M. Armada, and P. Gonzalez-de-Santos, "Soft grippers for automatic crop harvesting: A review," *Sensors*, vol. 21, no. 8, Apr. 2021, doi: 10.3390/s21082689.
[15] C.-C. Hung, H.-Y. Hsu, W.-C. Li, C.-Y. Li, and J.-D. Lee, "Automatic collecting and shooting mobile robot," *International Journal of Mechanical Engineering and Robotics Research*, pp. 401–407, 2020, doi: 10.18178/ijmerr.9.3.401-407.
[16] Z. A. Yahaya, S. Buyamin, H. Chiroma, M. S. Azimi Mahmud, F. Hassan, and A. A. H Badi, "Paths planning for agricultural robots: Recent development, taxonomy, challenges, and opportunities for future research," in *2022 IEEE 20th Student Conference on Research and Development (SCOReD)*, Nov. 2022, pp. 7–12. doi: 10.1109/SCOReD57082.2022.9973836.
[17] S. Singh, R. Vaishnav, S. Gautam, and S. Banerjee, "Agricultural robotics: A comprehensive review of applications, challenges and future prospects," in *2024 2nd International Conference on Artificial Intelligence and Machine Learning Applications Theme: Healthcare and Internet of Things (AIMLA)*, Mar. 2024, pp. 1–8. doi: 10.1109/AIMLA59606.2024.10531517.
[18] L. Fanucci, F. Iacopetti, and R. Roncella, "A console interface for game accessibility to people with motor impairments," in *2011 IEEE International Conference on Consumer Electronics -Berlin (ICCE-Berlin)*, Sep. 2011, pp. 206–210. doi: 10.1109/ICCE-Berlin.2011.6031883.
[19] S. Nakamori, "Arduino-based PID control of humidity in closed space by pulse width modulation of AC voltage," *WSEAS TRANSACTIONS ON CIRCUITS AND SYSTEMS*, vol. 21, pp. 49–56, Apr. 2022, doi: 10.37394/23201.2022.21.6.
[20] N. Cameron, *ESP32 formats and communication*. Berkeley, CA: Apress, 2023. doi: 10.1007/978-1-4842-9376-8.
[21] L. T. Purnomo, S. N. Asyfia, A. A. Aziz, I. M. Rodiana, M. R. Rosa, and A. Suhendi, "Experimental investigation into the system performance of rack and pinion gear using inverse kinematics for lifting mechanism in ABU robocon mobile robot," in *2023 International Conference on Radar, Antenna, Microwave, Electronics, and Telecommunications (ICRAMET)*, Nov. 2023, pp. 368–374. doi: 10.1109/ICRAMET60171.2023.10366634.
[22] S. Kautsar, B. Widiawan, B. Etikasari, S. Anwar, R. D. Yunita, and M. Syai'in, "A simple algorithm for person-following robot control with differential wheeled based on depth camera," in *2019 International Conference on Computer Science, Information Technology, and Electrical Engineering (ICOMITEE)*, Oct. 2019, pp. 114–117. doi: 10.1109/ICOMITEE.2019.8921165.
[23] İ. A. Mertkan, T. Tezel, and V. Kovan, "Improving surface and dimensional quality with an additive manufacturing-based hybrid technique," *The International Journal of Advanced Manufacturing Technology*, vol. 128, no. 5–6, pp. 1957–1963, Sep. 2023, doi: 10.1007/s00170-023-12055-z.
[24] T. Triwiyanto *et al.*, "Embedded machine learning using a multi-thread algorithm on a Raspberry Pi platform to improve prosthetic hand performance," *Micromachines*, vol. 13, no. 2, Jan. 2022, doi: 10.3390/mi13020191.
[25] A. Setiwan, M. I. Faisal, E. H. Binugroho, H. S. Maulana, N. F. Satria, and R. S. Dewanto, "Design and fabrication of swerve drive mechanism for mobile robot platform," in *2023 International Electronics Symposium (IES)*, Aug. 2023, pp. 348–353. doi: 10.1109/IES59143.2023.10242502.
[26] F. Mondada, E. Franzi, and A. Guignard, "The development of khepera," in *Proceedings of the 1st International Khepera Workshop*, 1999, pp. 7–14.
[27] M. Henrey, S. Edmond, L. Shannon, and C. Menon, "Bio-inspired walking: A FPGA multicore system for a legged robot," in *22nd International Conference on Field Programmable Logic and Applications (FPL)*, Aug. 2012, pp. 105–111. doi: 10.1109/FPL.2012.6339248.

**BIOGRAPHIES OF AUTHORS**

**Mohammed Mareai** is a bachelor student at Airlangga University at the Faculty of Advanced Technology and Multidiscipline. His major is electrical engineering. He has a talent for system modeling. His current focus is on the field of system control and signal processing. He can be contacted at mohammed.abdullah.ahmed-2022@ftmm.unair.ac.id.

**Juhen Fashikha Wildan** is a bachelor's degree student in robotics and artificial intelligence engineering at the Faculty of Advanced Technology and Multidiscipline, Universitas Airlangga, Indonesia, since 2022. His research interests include robotics, artificial intelligence, the Internet of Things, and autonomous systems. He can be contacted at juhen.fashikha.wildan-2022@ftmm.unair.ac.id.

**Mochamad Ridho Afkarean** is a bachelor's degree student in robotics and artificial intelligence engineering at the Faculty of Advanced Technology and Multidiscipline, Universitas Airlangga, Indonesia, since 2022. His research interests include robotics, mechanical and the Internet of Things. He can be contacted at mochamad.ridho.afkarean-2022@ftmm.unair.ac.id.