Multi-Axis Robot Arm with Mobile Control and Real-Time Object Recognition

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***Abstract*—This paper implemented an advanced robotic arm managed through a mobile application on an Android device employing Bluetooth technology to link the smartphone with an Arduino board for the seamless and distant operation of the arm. The Android application features sliders for manual adjustment of servo positions and buttons for storing, executing, and resetting preprogrammed motions, allowing users to independently manage each arm joint or perform a series of actions automatically. The proposed mechanical arm has five degrees of freedom for joints, a gripping mechanism, and a platform with Mecanum wheels for movement in all directions, which helps in maneuverability in confined areas. A camera module from ESP is also integrated into the setup to detect and recognize objects in time through OpenCV for image processing and the YOLO algorithm for object identification. Due to the integration of Bluetooth control technology, computer vision, and enhanced mobility features in the system design, the robotic arm is more accurate, flexible, vulnerable, and cheaper than the existing solutions.**

Keywords*—Robotic arm, Mecanum wheels, Omnidirectional movement, OpenCV, YOLO algorithm, Object detection, Image processing.

I. INTRODUCTION

Over the last decade, service robots have been in higher demand due to their versatility in several situations. Automation is one of the essential aspects of the developing industrial world. It paves the way to increase effectiveness and productivity in industrial applications by incorporating additional support structures [1]. The automated robot can execute specific tasks repetitively with one-time human instruction. The robot's path can be customized according to needs and Current tasks.

In the present scenario with technology, computers, and engineering, industrial automation is becoming significantly important in the assembly production and manufacturing process because computerized or robotic machines can handle repetitive tasks rapidly and efficiently [2-3]. Pick and place systems are used to complete manufacturing tasks in Industrial automation. However, the technology of the Pick-place Arm system has not evolved dynamically. The proposed automated robot tech takes a new step towards evolution and making the stationery and signal purpose pick-place arm system mobile and multipurpose.

This project introduces an affordable robotic arm mounted on a Mecanum wheel platform, enabling omnidirectional movement and equipped with vision-based object detection via a camera module. Controlled in real-time through an Android app, it combines cost-effectiveness, adaptability, and user-friendliness. Integrating affordable components with advanced functionalities makes robotics more accessible and relevant in both educational and professional contexts, empowering users to tackle real-world challenges and fostering innovation in automation.

II. RELATED WORK

In recent years, robotic arms and mobile platforms have played an important role in fields like education, research, entertainment, and industrial applications. Inspired by these trends, this project presents a mobile robotic arm system that is going to be replaced by the latest technologies (computer vision, object detection, etc.) with an Android interface through Bluetooth [4]. This makes the main function of this system either accurate manual or automated control, making adaptable tasks from household to industrial. Test specialists have made major strides in research in robotics, particularly in the fields of writing submission of service robots, the design of mobile systems, and recognition of objects [5]. These innovations establish a firm foundation for the creation of the robotic arm system described in this work.

A study [6] highlights the integration of navigation and object detection for service robots in dynamic environments. It focuses on computer vision applications within a banquet hall simulation. Because this study is relevant to our research, it emphasizes precise real-time control for robotic arm operations. However, the complexities of such environments present unique challenges. Although the findings are promising, further exploration is necessary to understand the implications fully. The paper [7] presents a cost-efficient Mecanum wheel platform for educational purposes; this initiative is guiding our quest to create an affordable yet functional robotic arm suitable for both educational and industrial applications. However, the development process is complex. Although we strive for functionality, there are challenges we must address because balancing cost and performance is crucial. This platform serves not only as a tool for learning but also as a foundation for practical use in various fields.

In [8], a multi-objective optimization framework is proposed for robotic arms, emphasizing material selection and vibration analysis. This initiative aids your project by enhancing structural efficiency and decreasing power consumption. The experiment [9] designed a lightweight robotic arm for kiwifruit pollination, optimizing weight, structure, and control to achieve precise agricultural tasks. This work provides insights into lightweight design and efficient motion control; therefore, it enhances the precision and efficiency of robotic arm-based pick-and-place systems. Paper [10] provided a comprehensive review of current techniques for robotic arm manipulation and mobile navigation, offering an extensive overview of cutting-edge methodologies. Although their insights into robotic arm design and control logic closely align with our project's objectives, they also provide valuable guidance for implementing robust and efficient control systems. Because of this, we can enhance our approach significantly. The study [11] comprehensively reviews robotic arm technologies in precision agriculture, focusing on hardware such as manipulators and end-effectors and software for motion planning and control. This research is valuable for improving the design and adaptability of robotic arms in various tasks, aiding my pick-and-place project (because of its comprehensive approach). The investigation [12] presented a novel robotic arm, RoboFiSense, which utilizes WiFi-based CSI and an attention-based BiVTC network for recognizing robotic arm activity without visual aids. This method offers insights for enhancing sensorless, privacy-preserving activity detection in your robotic arm pick-and-place project; however, it raises questions about the limitations of such technologies.

The experiment [13] indicates the development of a closed loop pose/force controller for soft robotic manipulators through deep reinforcement learning, which facilitates adaptive dynamic interactions. This investigation presents valuable insights into the utilization of learning-based control and mechanical intelligence; such advancements can significantly enhance both precision and adaptability in tasks involving robotic arm pick-and-place operations. In the paper [14], the Calibrator Fuzzy Ensemble (CFE) is introduced, which integrates eight machine learning-based calibrators to improve the accuracy of industrial robotic arms, successfully reducing errors by 8.59%. Although this approach can markedly boost precision in pick-and-place tasks, it also underscores the importance of integrating advanced calibration techniques in your robotic arm projects. The research [15] focused on the development of a robotic arm designed for pick-and-place tasks within small-scale industries. The results showed the practicality and economical capability of robotic arms in several possible applications that we considered to model our design to be implemented in real life.

The article [16] proposes a time-optimal trajectory planning method for robotic arms, employing an enhanced Sand Cat Swarm Optimization Algorithm (YSCSO), which results in smoother motion and a remarkable 42.72% reduction in time. Thus, this research sheds light on the significance of efficient trajectory planning for operations involving pick-and-place robotic arms. In [17], an optimized Informed-RRT motion planning method is proposed for a robotic arm; this method aims to ensure smooth and stable movements during delicate fruit harvesting (minimizing vibration impacts). However, this approach can enhance your robotic arm's precision and stability for pick-and-place tasks, although some challenges may arise. Because of the intricate nature of fruit harvesting, achieving the desired results might require further refinement in the planning algorithm.

III. Proposed Method

This project is grounded in four fundamental pillars, as illustrated in the accompanying flowchart in Fig. 1. We have partitioned the project into four distinct processes; this division aims to establish a coherent and systematic approach. However, the cohesion of these procedures may sometimes be challenged because of overlapping responsibilities. The different hardware components and software tools required to implement the proposed arm are shown in Fig. 2 and Fig. 3.

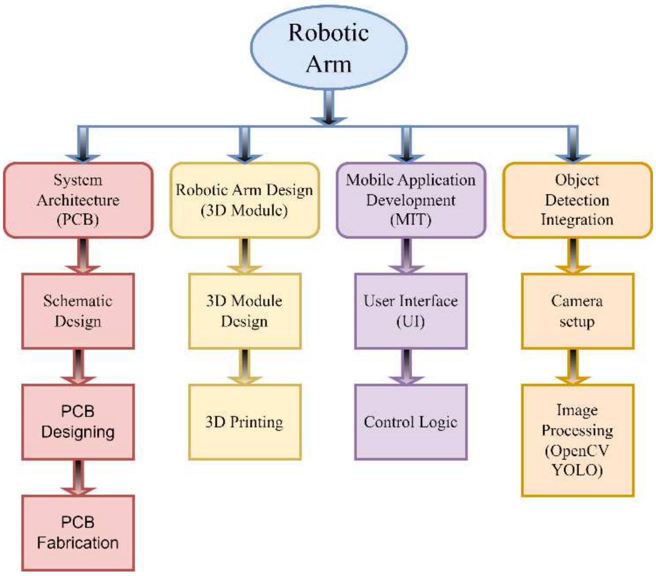

Fig. 1. Block diagram of the proposed method

Fig. 2. Hardware Components

Fig. 3. Software Tools

A. System Architecture

The mobile-controlled robotic arm comprises several key components: an Android application, an Arduino board, a Bluetooth module (HC-05), an ESP camera module, and servo motors (MG996R and SG90). Bluetooth facilitates seamless communication between the application and the Arduino. A custom printed circuit board (PCB) has been developed to integrate these elements (however, this also simplifies wiring while improving reliability). The PCB layout guarantees efficient trace routing, which makes manufacturing straightforward. Although this approach benefits the project by minimizing complexity, it also enhances performance and enables easier maintenance. Ultimately, this ensures the effective operation of the robotic arm, but careful consideration must be given to the interaction of each component.

1) Schematic Design: The schematic design for the mobile-controlled robotic arm is shown in Fig. 2. We utilize easyEDA to create circuit diagrams and PCB layouts; this facilitates a lucid visualization of the linkages between the Arduino, Bluetooth module, servo motors, and ESP camera. However, this visualization assists in the early detection of problems. Furthermore, Prothiya's website provides valuable resources and tutorials that augment the design process for a reliable robotic arm system. Although challenges persist, the resources available can significantly enhance the outcomes because they furnish crucial insights into the design.

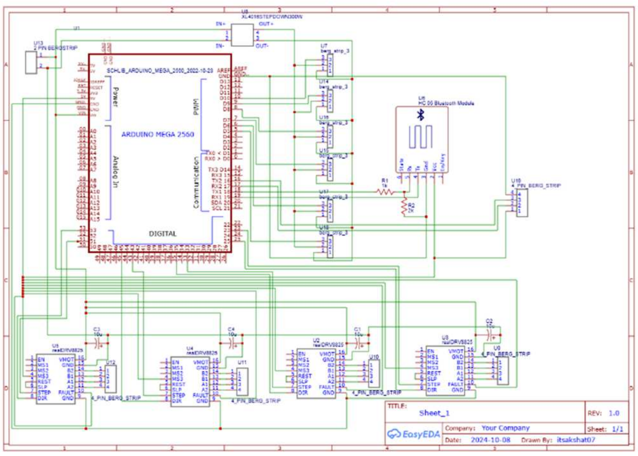

Fig. 4. Schematic Design

2) PCB Designing: The process of designing a PCB entails the careful development of a layout that incorporates a variety of electronic components through conductive pathways etched onto a non-conductive substrate. In the context of our project, the PCB functions as the essential backbone of the control system for the robotic arm, interconnecting the Arduino board, Bluetooth module, ESP camera, and servo motors in a compact yet reliable manner. However, this enhancement in design boosts the system's performance and simultaneously improves durability, enabling easier troubleshooting and maintenance. Although challenges are inherent in PCB design, its importance in realizing a functional, efficient, and scalable robotic arm cannot be overstated because it is crucial for the overall effectiveness of the project.

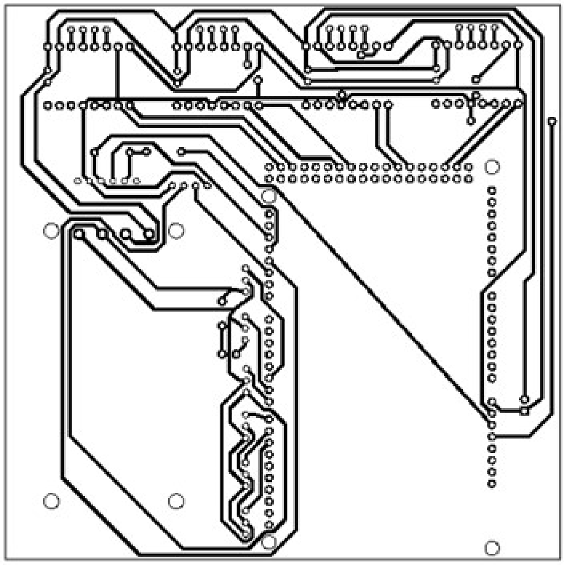

Fig. 5. PCB Design

3) PCB Fabrication: In the domain of PCB fabrication, the layout is inscribed onto a copper-clad laminate. This stage is succeeded by etching, a technique employed to eliminate excess copper, thus creating conductive pathways that link diverse components such as the Arduino and the Bluetooth module. However, this exact process is essential for guaranteeing dependable communication and optimal performance of the mobile-controlled robotic arm, which depends on these connections to operate effectively. Although the procedures might appear to be uncomplicated, scrupulous attention to detail is imperative as any error could compromise the overall system's efficacy.

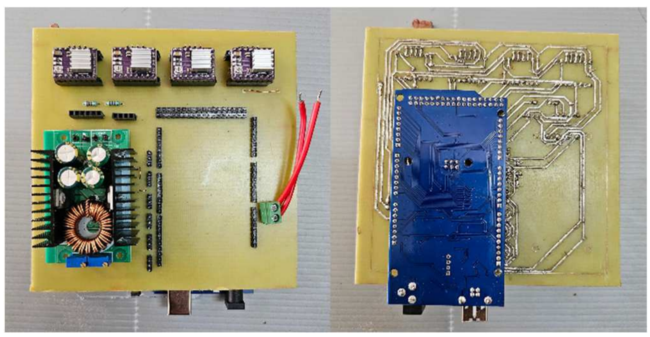

Fig. 6. Fabricated PCB

B. Robotic Arm Design (3D Module)

The emergence of 3D printing markedly expedites the robotic arm initiative. This methodology promotes swift prototyping and design iterations, thereby diminishing lead times and expenses. It allows for the fabrication of lightweight yet intricate geometries, which improves performance; however, it simultaneously optimizes production and reduces time-to-market. Although there exist challenges associated with this technology, the advantages of 3D printing cannot be disregarded because it revolutionizes our conceptualization of design and manufacturing.

The 3D model is first designed on SolidWorks software. Slicing software is used to generate the G-code of the designed model. The G-code is input to the 3D printer to print the essential parts required for the robotic arm design.

Fig. 7. 3D printed parts

C. Mobile Application Development (MIT)

The employment of MIT App Inventor within the framework of a robotic arm initiative significantly augments (1) velocity, precision, and overall functionality. Its visual interface (which is undeniably user-friendly) facilitates expedited prototyping; this enables modifications with relative ease, without necessitating extensive coding. Bluetooth integration provides real-time control: this enhancement markedly improves responsiveness. Intuitive sliders not only assist in achieving precise servo adjustments, but they also empower users to fine-tune their designs, because they are straightforward to manipulate. Features such as save, reset, and restart commands serve to streamline automation, making repetitive tasks more efficient. However, one must consider the learning curve associated with mastering these tools, although the resultant benefits are indisputably substantial.

1) User Interface (UI): The utilization of MIT App Inventor within the context of a robotic arm initiative substantially enhances (1) velocity, precision, and overall functionality. Its visual interface (which is, without a doubt, user-friendly) facilitates expedited prototyping; this allows modifications to occur with relative ease without necessitating extensive coding. Bluetooth integration offers real-time control: this enhancement significantly improves responsiveness. Intuitive sliders not only aid in achieving precise servo adjustments, but they also empower users to fine-tune their designs because they are straightforward to manipulate. Features such as save, reset, and restart commands serve to streamline automation, rendering repetitive tasks more efficient. However, one must contemplate the learning curve associated with mastering these tools, although the resultant benefits are indisputably substantial.

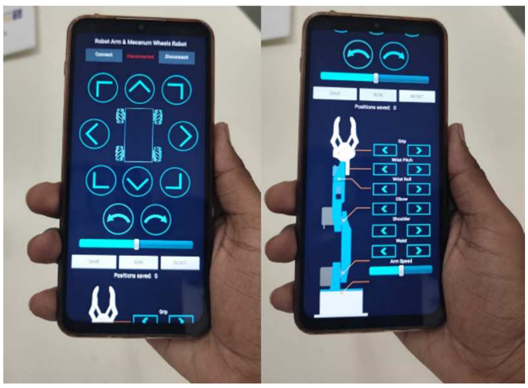

Fig. 8. User Interface for Arm Controller

2) Control Logic: Within MIT App Inventor, one can indeed construct an uncomplicated interface that incorporates buttons and sliders intended for the operation of a robotic arm. It is essential to connect sliders to servo motors via the Send Text function, which facilitates Bluetooth adjustments. The utilization of the “when Slider. Changed” block is crucial for ensuring responsiveness; however, it is also important to incorporate “SAVE,” “RUN,” and “RESET” buttons to manage various movements effectively. Although adding error handling may seem like an extra step, this ensures a seamless user experience, particularly for precise manipulation of the arm.

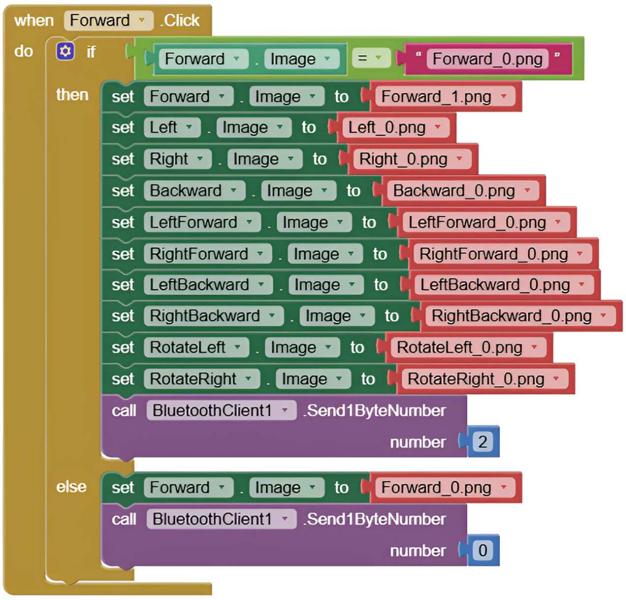

Fig. 9. Logic blocks behind each control for User Interface

D. Object Detection Integration

To enable object detection in the robotic arm, OpenCV using the YOLO algorithm has been implemented. YOLO divides images into grids for rapid and accurate object detection. But, to work in the best way, the algorithm needs to be trained on an adequate dataset. While this process with paper-based maps may be complicated, the identified positions can easily be passed onto the Arduino for accurate manipulation. Also, it is particularly advantageous in different applications as it closes the loop between AI and automated capabilities of the arm devices seamlessly.

1) Camera Setup: The ESP-32 CAM module has been used to capture live video in the proposed robotic arm. The real-time video is utilized for object detection and performs pick-and-place operations by arm.

2) Image Processing: The robotics arm project makes use of OpenCV and YOLO algorithms for object identification and tracking. OpenCV has more than 2,500 optimized algorithms for a variety of tasks, from object detection to image filtering and motion analysis, among others. YOLO facilitates the robotic arm's capacity to swiftly and precisely detect and manipulate objects, thereby augmenting the system's overall automation and effectiveness. This advances the arm's autonomy and accuracy significantly and helps in making effective decisions for real-world applications. The robotic arm can make instant decisions using visual data since

it has efficient processing capabilities. This improves the arm's degree of automation and intelligence through effective fusion with artificial intelligence and machine learning technologies.

IV. Experimental Results

The Multi-Axis Robotic Arm System has been tested extensively. After assessing its free mobility and movements on three axes, the robotic arm's free motion along all axes smoothly performed precise action, enabling complex operations without disruption. The servos used here, the MG996R and SG90, were powerful and able to deal with complex motions and accurate control as we expected. Overall, the stepper motors resulted in a steady performance from beginning to end. to the arm's versatility. In terms of response time, the system performed exceptionally well, with command execution resulting in near-instantaneous movement after the program was deployed. This low-latency performance is a critical component in any robotic system and ensures smooth, real-time control when interacting with the robot. Table 1 and Table 2 show the various configurations of the robotic arm.

TABLE I. Specification of the Camera Module & Rower with Mecanum Wheel

Configuration	**Articulated Robotic arm**
Bluetooth range	10-20 meters
Bluetooth versions	HC-05 Bluetooth 2.0 + EDR (Enhanced Data Rate)
Movement of Mecanum Wheels	Omnidirectional
Motor Name	Neema 14 stepper motor
Camera Name & Range	10-20 meters
Object Detection Range	10-20 meters
Rower Dimension	310 mm x 230 mm x 85 mm.

TABLE II. Design Specification of the Developed Robotic Arm

Configuration	**Articulated Robotic arm**
Degrees of Freedom	360 degrees
Horizontal reachability	600 mm
Vertical reachability	750 mm
Motor used	MG996R Servo, SG90 Servo motor,
Working area	600 mm x 600 mm x 500 mm.
Gripper type	Parallel motion two-jawgripper.
Payload	100 gm

Moreover, the image detection accuracy provided by YOLOv11 and OpenCV was great. With an accuracy of 85–90%, the system was capable of detecting objects even in different lighting conditions and aided the arm in making decisions regarding tasks. Such accuracy is essential for tasks such as pick-and-place and requires high-quality detection with correct identification of the objects. During multiple tests (10 iterations), the arm performed 8-9 tests with accurate identification and placement of the objects, which reflects the robustness of the system. The communication infrastructure consisting of the MIT Instrument App and the HC-05 Bluetooth module worked flawlessly in real time, illustrating the effectiveness of the communication channel. The Save, Run, and Reset features of the app enabled easy, intuitive control of the robotic arm, and users could record movements, initiate the robotic arm's automated tasks, and restart sequences as necessary. Considering the various forms of testing environments, the Bluetooth connection was highly stable across all, leading to a conclusion of strong versatility and reliability of the overall system. With accurate execution of complex tasks in real-time and a robust connectivity offering, the robotic arm is a competitive invention in robotic automation and control.

Having a multiple-degree of freedom, capable of executing complex tasks in low latency with real-time performance and with a strong connectivity offering, the robotic arm is a competitive invention in robotic automation and control the angular input values, usually between 0° and 180°, determine the arm's position in three-dimensional space. Below is a graphical representation illustrating the angular value for each motor in Fig. 10.

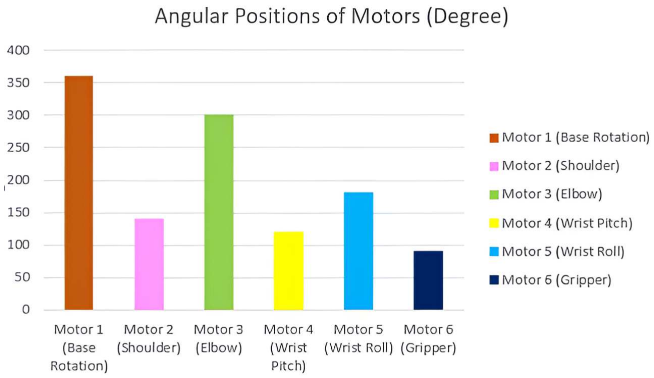

Fig. 10. Angular Position (Degrees)

The articulated robotic arm (a versatile device) exhibits six degrees of freedom, thereby facilitating precise movement and adaptability in diverse automation tasks. It possesses a horizontal reach of 600 mm and a vertical reach of 750 mm (thus enabling efficient operation within a dimensional framework of 600 mm x 600 mm x 500 mm). This arm is powered by a combination of MG996R servo motors, SG90 micro servo motors, and Neema 14 stepper motors. Because of this, it guarantees smooth operation across various axes. Featuring a parallel motion two-jaw gripper, it can manage payloads of up to 100 grams, rendering it suitable for lightweight and intricate tasks. However, despite its sophisticated features, the arm remains budget-friendly (with an estimated build cost of ₹12,000); this renders it an excellent option for small-scale industrial and educational applications. Although the technology may seem complex, it remains accessible for individuals seeking innovative solutions.

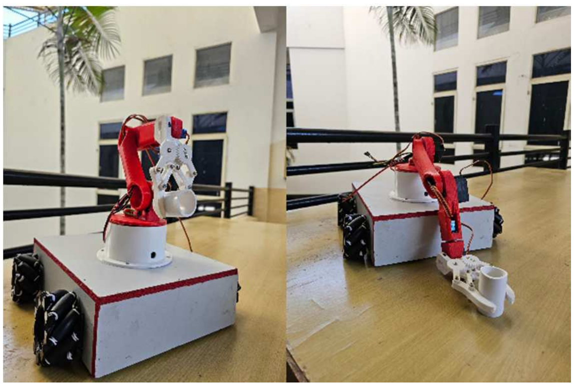

Fig. 11. Implemented Project Hardware

V. Conclusion

These systems offer unique value for mobile services, with Mecanum wheels augmenting mobility and allowing omnidirectional movement and precise navigation through tight or complex spaces, making these systems especially effective in dynamic and space-constrained operations. Using MG996R and SG90 servo motors, as well as a Nema 14 stepper motor, it provides precise control to perform all tasks between sorting, pick-and-place, and handling light materials, with a working area of 600 mm x 600 mm x 500 mm. Its two-jaw parallel motion gripper can handle payloads of up to 100 grams. Also, in e-waste management, the integration of a camera module in the module allows for real-time object detection and facilitates real-time positional adjustment, which further increases automation efficiency in smart warehouses, autonomous delivery systems, etc. It is adept at multitasking in modern manufacturing and logistics environments due to the mobility offered by the Mecanum wheel and the precision of the arm.

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