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A Review of Emerging Technologies in Robotic Arm for Sorting Applications

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Abstract

In recent times, the growing complexity and scale of manufacturing operations have necessitated the need for a robust material handling system. One of the most important revolutions in this area is the application of a robotic arm to sorting operations. This review provides an overview of the advances in robotic sorting systems, outlining the interactions among component parts. More than 50 peer-reviewed journal articles from 2015 to 2025 were considered for the analysis. Statistical findings show that 4-dof robotic arms dominate the literature with 32%, while Arduino microcontrollers and color as a sorting criterion remain the most widely adopted with 69% and 51% respectively, due to their affordability and ease of use. The survey classifies the present robotic technologies according to a three-level taxonomy: perception, decision, and execution, while stressing the interdependency of this framework. Furthermore, the review recommends the application of reconfigurability, artificial intelligence (AI), and multimodal sensing technologies to existing robotic sorting systems as a means of increasing intelligence and the flexibility of future robotic sorting systems.

1. Introduction

1.1 Material Handling

Material handling (MH) is one of the essential aspects that determines the success of manufacturing industries. It is a process that encompasses the movement, storage, and management of materials and products throughout the manufacturing process, culminating in the delivery of goods made from raw materials [1]. According to research by [2], MH is estimated too account ford between 15% and 70% of the total manufacturing cost. The product time to market can be greatly impacted by proximal efficient MH systems in addition to safety standards, workflow, and operational costs. Besides, MH equipment is composed of hoists, forklifts, and trolleys [3]. Recently, the MH challenge has been effectively solved by technologies such as robotics, automated guided vehicles (AGVs), and conveyor systems. These operations have been made efficient and exact by these technologies through the introduction of novel capabilities such as automated sorting, real-time monitoring, and data-driven decision-making [4]

1.2 Evolution of Sorting Technologies and Mechanisms

Sorting as a material-handling operation has changed drastically over the last few years. In the past, industrially powered mechanical and ID-based sorters were the main tools employed, especially in parcel handling and massive logistics hubs. Conveyor-based mechanisms such as pushers, diverters, and tilt-tray sorters, in combination with barcode and radio-frequency identification (RFID) technologies, are still used to deliver high-throughput performance in cases where the items have standard identifiers. These systems are still the main tool of e-commerce fulfillment centers because of their efficiency and minimal human intervention in the routing of parcels to particular destinations [5,6]. On the other hand, the need for labels that are externally affixed on the items has been one of the factors that has led to the limitation of the use of these systems in streams where the products do not have a consistent way of being labeled, for instance, municipal solid waste or agricultural produce. The way these sorters perform their work reflects the type of sorting technology that they use. The different technologies of sorting can be divided into several groups depending on their operational principles, automation level, and application domains [7]. Knowing the different techniques is essential for deciding the correct technology for industrial applications. These are some of the different sorting mechanisms that exist.

1.2.1 Mechanical Sorting Systems

Mechanical sorting systems rank highly among the first automated sorting solutions that were industrially implemented. They have a reputation for being fast and dependable, which is why they have become the basis of multilayered distribution and logistics operations. Automatic mechanical sorting systems still carry the bulk of the work in modern distribution centers where there are still large product flows to be handled, but now, the processes have to be quick and accurate.

One of the most typical examples is the conveyor-based sorter, which involves the use of mechanical components, sensors, and software parts to automatically separate the articles according to attributes like size, shape, weight, and color. Conveyor-based sorters are labor-saving and money-saving at the same time. They are work-efficient in environments with large volumes of goods. The devices that can be further differentiated into push-bar sorters, tilt-tray sorters, cross-belt sorters, and sliding-shoe sorters [8, 9] are the ones operated by conveyor-based units.

These mechanical systems run at breakneck speeds and generally achieve sorting rates as high as 4,000 items per hour [8]. They are also considered to have a very low cost per unit of sorting and onsite downtimes because of good maintenance practices. However, mechanical sorters also entail some risks. Usually, they occupy a big space and hence cannot fit in some facilities with limited space [9]. It is also limited in their reconfiguration for different product types and sorting criteria. Moreover, in some cases, the system that handles the breakage rate is the one that deals with fragile and irregularly shaped goods. Their disadvantages have slowly compromised their market position in those environments where product variability, space optimization, and adaptability play a significant role.

1.2.2 Identification-Based Sorting Systems

In modern industrial settings, identification-based sorting systems represent a major advancement in automated material handling. These systems identify and sort items based on unique product identifiers, reducing reliance on manual labor while improving accuracy and throughput. Unlike manual sorting, which depends on visual inspection, identification-based systems rely on sensors, cameras, RFID, or AI-based algorithms to detect object characteristics and direct items into appropriate categories. Barcodes and radio-frequency identification (RFID) are two widely used identification technologies. Barcode systems remain popular due to their cost-effectiveness, simplicity, and reliability. They require direct line-of-sight scanning but are well-suited for retail, warehousing, and inventory management. While RFID systems, on the other hand, have gained significant adoption across diverse industries due to their versatility and efficiency. They can detect multiple items simultaneously within a range of up to 10 meters, offering processing speeds of 3,000–8,000 items per hour [10].

Despite their advantages, identification-based sorting systems also face limitations. They require pre-labeled or tagged items, which makes them unsuitable for sorting unlabeled materials such as waste streams or raw agricultural products [11]. In addition, the cost of RFID tags/labels and the vulnerability of identifiers to physical damage or loss remain persistent challenges.

1.2.3 Optical and Sensor-Based Sorting Systems

Over the last three decades, optical and sensor-based sorting systems have been used to identify and classify objects based on their chemical and physical properties. They leverage electromagnetic radiation and diverse sensing mechanisms for sorting operations [12]. Due to their performance, they have been used for industrial automated sortation systems, such as cross-belt sorters forming a hybrid sorting system, capable of delivering enhanced accuracy and efficiency for material handling operations. Other examples of optical and sensor-based sorting systems are: RGB camera systems, near-infrared (NIR) sorters, hyperspectral imaging (HSI), and laser-induced breakdown spectroscopy (LIBS). Optical sorting systems demonstrate high accuracy, material versatility, non-contact operation, and real-time processing.

1.2.4 Artificial Intelligence and Machine Learning-Based Sorting

AI and machine learning plays vital role in the transformation of the manufacturing industry. With this technology, modern sorting systems increasingly employ AI algorithms for improved sorting operation. These technologies have been applied in different industry including waste management. Research by [13] developed a Deep Learning algorithm for Plastic Waste Classification System. Their work demonstrates CNN applications for plastic waste sorting using computer vision systems. Reinforcement Learning, Convolutional Neural Networks (CNNs), and You Only Look Once (YOLO) Algorithms are some the examples of Artificial Intelligence and Machine Learning-Based Sorting [14]. Challenges associated with Artificial Intelligence and Machine Learning-Based Sorting are Training data requirements-large data requirement, Computational latency, Integration complexity and Model generalization [15].

1.2.5 Robotic Sorting Systems

Robotic sorting represents the convergence of mechanical manipulation, sensor technology, and intelligent control. Unlike fixed mechanical sorters, robotic systems offer adaptability, precision, intelligence, and flexibility. The use of a robotic arm for automated material handling is one of the most significant advancements witnessed recently in the manufacturing industries, particularly in sorting tasks. Autonomous sorting robotic arms are designed to manipulate objects based on predefined characteristics, features, or criteria such as size, shape, color, or other distinguishing factors, while a semi-autonomous robotic arm depends on users' or operators'' intelligence via graphical users' interface (GUI) to perform sorting operations [16]. Some of the notable robotic sorters include: Delta robots, SCARA robots, articulated arm robots, and Collaborative robots (Cobots).

1.2.6 Hybrid Sorting Systems

A hybrid sorting system is usually a combination of two or more technologies to form a system with better performance and overall efficiency. A typical example is a Mechanical-Robotic Hybrids sorting system, which is a high-speed mechanical pre-sorting followed by robotic quality control and exception handling; Optical-Robotic Integration-Vision systems identify items for robotic manipulation, combining detection accuracy with handling flexibility; Multi-Stage Systems: Sequential sorting stages using different technologies optimized for specific material streams. Emerging facilities increasingly adopt hybrid approaches due to their benefits [17].

1.3 Review Focus

A sorting robotic arm plays a crucial role in manufacturing industries by automating the process of sorting and arranging items based on predefined criteria. The development of sorting robotic arms has been driven by the need for efficient and precise sorting processes in various industries, including manufacturing, logistics, agriculture, and recycling [18,19,20]. These robotic systems offer several advantages over manual sorting, including increased speed, consistency, and accuracy, while also reducing labor costs and minimizing errors [21,22]. They find application in industries ranging from sorting products on assembly lines or defined workspaces to separating recyclable materials in waste management facilities [23]. The evolution of sorting robotic arms continues to be influenced by advancements in AI, machine learning, and sensor technology, further enhancing their capabilities, versatility, and application in automated sorting operations.

As the dynamics of the manufacturing process become more complex and consumer demands increase, the need for dependable and intelligent robotic arm sorting solutions has grown significantly. However, despite the achievements in robotics, the manufacturing industries are still faced with some challenges in the application of this manipulator in material handling. Challenges such as initial cost, limited to a defined workspace, and object characteristics still pose threats to the overall success of the sorting robotic arm. Providing solutions to these challenges is crucial for achieving a successful material handling operation. Hence, this review seeks to investigate current trends, challenges, and suggest future directions in the application of robotic manipulators in material handling operations, while also looking at the control method, application of microcontrollers, and object characteristics.

2. Robotic Arm

Robotic arms, a subset of robots, are programmable mechanical devices that mimic the functions of a human arm, using actuators, sensors, and grippers to manipulate and transfer objects quickly and accurately [24]. They comprise multiple joints controlled by actuators for movement, links for reach, and an end effector to interact with its work environment [25]. Their design and structure ranges from simple to complex, and fixed to flexible devices, having multi-degree-of-freedom capable of executing complex and precise movements often with higher speed, consistency, and strength than human workers [26,27]. According to [28], the concept of robot dates back to the 1950s, with the creation of the first industrial robot called 'Unimate' (Fig. 1) by George Devol and Joseph Engelberger to automate repetitive tasks on production lines. This invention marked the beginning of industrial automation in manufacturing environments [29]. Their application in sorting processes is particularly beneficial in industries such as automotive, electronics, packaging, food processing, and logistics, where precision and speed are crucial.

Fig. 1 *Unimate- the first industrial robot*

2.1 Robotic Arm Structure

Robotic arm technology is often used by companies in the industrial space. They are one of the most common pieces of machinery in factories, plants, and other industrial settings because of their benefits. There are different types of robotic arm based on their structure and characteristics (see Fig. 2) that make one type more suitable for certain applications than others, they include:

i. Cartesian robot: These are robots with three prismatic joints, whose axes are coincident with the cartesian coordinate system (X, Y and Z) for linear movements in three directions. They are highly precise and repeatable, and well-suited for structured environments. Cartesian robots are suitable for CNC machining, 3D printing, Arc welding, handling precision tools and pick and place application.

ii. SCARA: Selective Compliance Assembly/Articulated Robot Arm SCARA robot has two rotary joints which are parallel and are used to provide compliance in a plane; they have high-speed with excellent repeatability and can be used in limited space due to their compact nature. However, with Limited vertical compliance. They are applied for pick and place job, soldering, assembly operations and handling machine tools.

iii. Cylindrical robot: Are robot having axes that forms a cylindrical co-ordinate system with a single arm that moves on a vertical member and can also rotates the robotic arm horizontally. They are compact, so it can fit in limited spaces and complete little and simple jobs. Some of its applications include assembly operations, handling a machine tools, and spot welding.

iv. Articulated Arm: The articulated robotic arm is a general-purpose arm designed to perform task like the human arm. It has at least five joints mounted to a base that has a twisting joint. Articulated arm is one of the most common robotic arm designed to perform simple and complex task. It is used in diecasting, assembly operations, fettling machines, gas welding, arc welding and spray painting.

v. Polar robots: Spherical robot are robots having axes that forms a polar co-ordinate system, they are used for applications such as spot welding, handling machine tools, diecasting, fettling machines, gas welding and arc welding.

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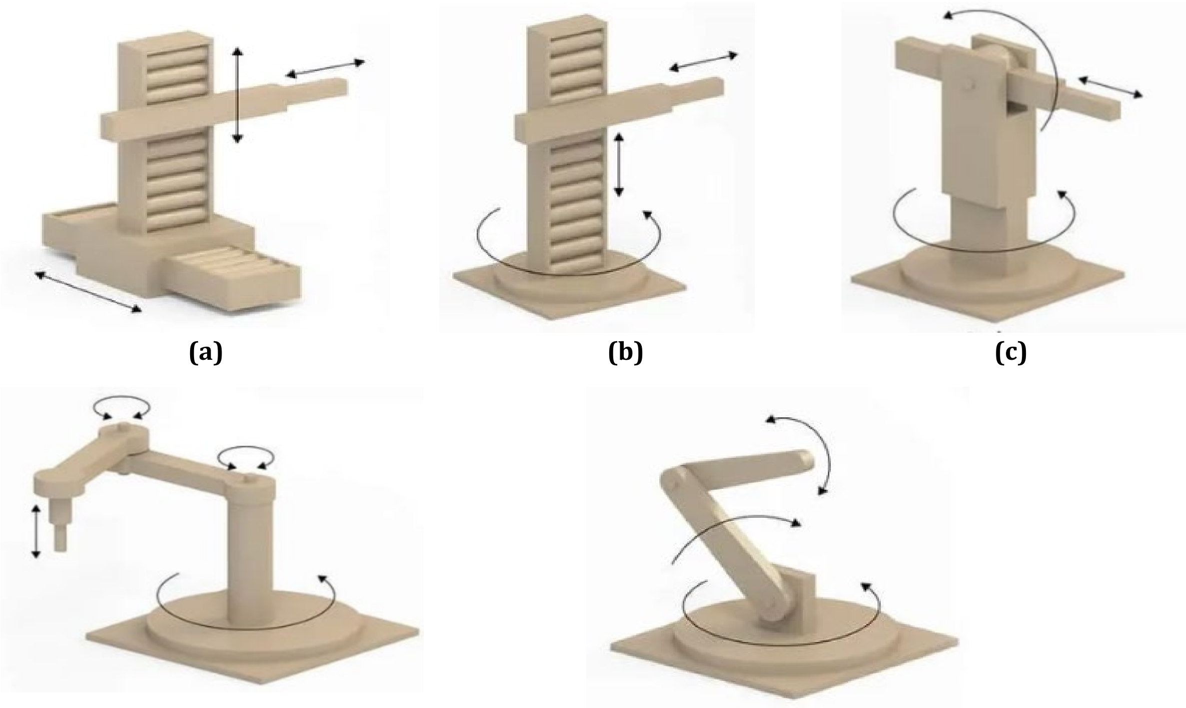

(a) (b) (c)

(d) (e)

Fig. 2 *Types of robotic arm structure (a) Cartesian robot; (b) SCARA; (c) Cylindrical robot; (d) Polar robots; (e) Articulated arm*

2.2 Components of Sorting Robotic Arm

A sorting robotic arm is a type of automated mechanical system designed to identify, classify, and place objects based on predefined characteristics such as size, shape, color, or material. Their applications expand through manufacturing, packaging, recycling, and agricultural industries. The integration of several key interconnected components ensures the efficiency and accuracy of a sorting robotic arm. Below are some of the major components:

2.2.1 End Effectors

End effectors are devices attached to the far end of the robot's arm that allow it to interact with the work environment and perform specific jobs. This device is a critical component of a robotic arm, as it determines the type of task (welding, cutting, sorting, etc.) to be executed by the robotic arm. Grippers are commonly used end effectors for sorting robotic arms, which enable them to pick and place objects based on predefined criteria [30,31]. According to [32], some of the common robotic grippers (Figure 4) are: (a) finger gripper, (b) parallel jaw gripper, (c) vacuum gripper, (d) pneumatic gripper, (e) hydraulic gripper, and (f) magnetic gripper.

(a) (b) (c)

(d) **(e)** **(f)**

Fig. 3 *Different types of grippers: (a) Finger gripper; (b) Parallel jaw gripper; (c) Vacuum gripper; (d) Pneumatic gripper; (e) Hydraulic gripper; (f) Magnetic gripper*

2.2.2 Mechanical Structure (Arm and Joints)

The mechanical structure of a robotic arm mainly comprises the links and joints. These form the physical "skeleton" of the robot. They are designed to look like and mimic the human arm, consisting of multiple degrees of freedom (DOF) to allow complex and flexible movements. Depending on the application, each joint provides a specific type of motion - typically rotational or linear. The joints of a robotic arm determine how precisely the robot can position and orient its end-effector.

2.2.3 Actuators

Actuators are driving systems placed strategically at the joints of a robotic arm, responsible for positioning the end-effect the or to desired location. Several actuators have been used to drive robot arms; however, notable types include stepper motors, servo motors, and DC motors, often paired with geared transmissions to enhance torque. In high-load or industrial applications, brushless motors or pneumatic/hydraulic actuators may be used. The selection of these actuators depends on the required torque, speed, and precision. Actuators are typa ically driven by motor driver that interfaces with the controller. The choice of motor drivers depends largely on the current and voltage rating of the actuator. Depending on the components used, the system may require multiple voltage levels (e.g., 5V for logic, 12V or 24V for motors). For an industrial setup, power conditioning and protection circuits are also included to ensure operational safety.

Recent actuator designs are increasingly focusing on reducing power consumption, using lightweight materials and regenerative mechanisms [33]. Modern sorting robotic arms are becoming faster, intelligent, and more precise in task execution due to recent advancements in actuator technologies. A key development in this technology is the use of smart integrated actuators, which combine the controller, encoder, and motor in a single unit [34]. The outcome provides high-precision control, making them suitable for sorting systems. Also, another recent trend is the use of harmonic drive actuators, providing high torque and zero backlash. This makes them particularly effective for space-constrained environments [33]. Handling fragile objects can be a daunting task for robotic arms, research by [35] suggested the use of variable stiffness actuators (VSAs) and soft actuators [36]. These provide compliance and adaptability, allowing the robot to gently interact with different types of objects during sorting. Other technologies include direct actuators, and AI-powered rive motors, tendon-driven actuators [34, 37, 38]. AI-powered actuators integrate edge computing to enable real-time adaptation, fault detection, and autonomous adjustment of control parameters. This adds intelligence and flexibility to sorting arms, especially in a changing environment. Apart from the fact that AI-powered actuators increase the performance of sorting robotic arms, they also enhance energy efficiency, making them suitable for the future.

2.2.4 Sensors

A sensor is an electronic device that detects events or measures a physical property and sends the information to other electronics (such as PLC, DCS, Arduino, etc.) for necessary action or response. A sensor's sensitivity indicates how much the sensor's output changes when the input quantity being measured changes. Sensors have a wide range of uses, cutting across almost every field in sciences, engineering, medicine, and the like. They can be applied in manufacturing and machinery, airplanes and aerospace, cars, medicine, robotics, and many other aspects of our day-to-day life. There are different types of sensors: proximity sensors, force sensors, tactile sensors, heat sensors, acoustic sensors, gas sensors, and vision sensors [39].

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2.2.5 Microcontrollers

A microcontroller is a compact integrated circuit designed to govern specific operations in an embedded system. It contains a processor core, memory, and programmable input/output peripherals - all on a single chip - which include: Arduino, Raspberry Pi, ESP32/ESP8266, STM32, Programmable Logic Controllers (PLC). Microcontrollers are often referred to as miniature computers because they integrate all essential components of a computing system. They are very important component of modern embedded systems. Their flexibility makes them ideal for a wide range of applications, from smart home devices to industrial automation and robotics. With the rise of the Internet of Things (IoT), the role of microcontrollers is becoming even more crucial in building intelligent, interconnected systems.

2.2.6 Sorting Robotic Arm

The process of sorting products, tools, or materials into different groups is an important activity in the industry. This task is repetitive in nature, as it involves the picking and placing of objects from one point to another. Robotics technologies offer several benefits that enable them to assist or replace humans, performing tasks that are difficult, unpleasant, repetitive, or take place in hazardous environments. Sorting robotic arms can be used to perform this task, regardless of their working environment, with great accuracy and precision, thereby enhancing the overall efficiency of the process. In manufacturing industries, they can be used to sort objects into different classes. [18] developed a robotic arm for sorting finished products based on their color. Their research is capable of enhancing automation and streamlining sorting processes. Sorting robotic arms play a very important role in waste management, where they are used for sorting objects into different categories. [40] in research developed a 6 DOF automatic can sorting system for the waste management process. The system can sort cans with a precision sorting rate of 93% at an average sorting time of 10.82 seconds. In agriculture, sorting robotic arms are used for harvesting and sorting agricultural products with great flexibility. This system is capable of automating the fruit harvesting and sorting of products such as tomatoes, cabbage, and apples [41,42]. The application of sorting robotic arms is not just limited to manufacturing, waste management, and agriculture but also in medicine. The application of sorting robotic arms in the field of medicine can improve the safety of workers by limiting the exposure of such staff to used syringes, needles, broken bottles, knives, razors, and any other harmful objects that could injure or, in worst case, transmit diseases if not properly disposed [43].

3. Methodology

This review employed a systematic approach to evaluating the changes of sorting robotic arms from 2015 to 2025. Studies relevant to the topic were collected based on the use of keywords related to robotic sorting and control systems. From each paper, robotic data such as sorting criteria, sensing/perception technologies, control algorithms, and degrees of freedom were extracted for the purpose of comparison. These data were subsequently analyzed to identify the leading technologies, emerging trends, and research gaps. The findings from the research formed the foundation for the Three-Layer Integration Taxonomy that classifies sorting robotic arms into Perception, Decision, and Execution layers.

3.1 Sorting Criteria and Sensor Technologies

Sorting robotic arms rely on sorting criteria and sensor technologies to accurately pick and place objects. Different criteria have been employed in robotic sorting systems, such as color, shape, size, weight, texture, material, as well as unique identifiers like barcodes, QR codes, or RFID tags [61,86]. Sorting, picking, placing, and inspecting tasks require the robotic arm to be able to detect object attributes/criteria like color, shape, size, material type, weight, and proximity, all of which are made possible by these sensors. In a typical robotic sorting system, items are transported to or placed around the robotic work environment/space, where a robotic arm, guided by sensor data or machine vision, identifies, picks, and places the objects based on predefined object criteria. Sorting criteria can be hierarchical or composite. For example, objects may be first classified based on shape, then further sub-classified by height or material type. This multi-layered sorting logic ensures flexibility and allows the system to be deployed across multiple use cases - such as e-waste segregation, food packaging, warehouse logistics, and pharmaceuticals.

Advanced industrial models, however, employ techniques like deep learning-based object recognition and real-time feedback mechanisms often integrated with ROS (Robot Operating System), resulting in a system that not only sorts but also adapts to changing task parameters, making it suitable for Industry 4.0 smart manufacturing setups. This process eliminates the inefficiencies of manual sorting and ensures consistent quality and output. Advanced robotic systems can even make real-time decisions using AI, allowing them to adapt to variations in the objects they handle. Table 1 is a summary of journals showing object characteristics and the type of sensor adopted by authors.

Table 1 *Summary of object characteristics and type of sensor adopted from previous works*

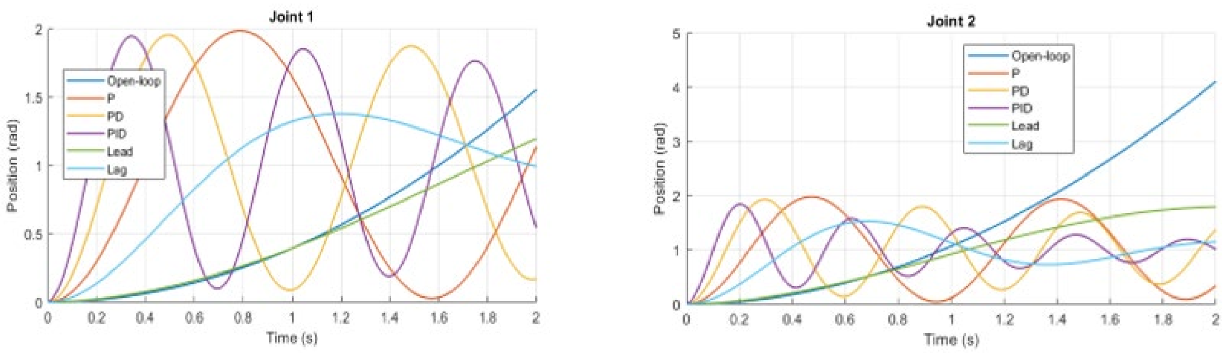
DOF	Object Characteristics	Type of sensor	Ref
2	Color and material type	TCS230 sensor & Metal detector	[87]
4	Color	TCS230 sensor	[88]
4	Color	Infrared (IR) LED sensors	[89]
3	Size	Sonar sensor	[90]
3	Shape	Object coordinate	[24]
3	Color	TCS3200 Sensor	[91]
3	Color	Camera	[92]
4	Color	TCS3200 Sensor	[93]
3	Color	Camera	[94]
6	Color and shape	Camera	[95]
5	Color and shape	Camera	[96]
4	Color	Camera	[97]
5	Material type	Metal detector	[98]
4	Color	Camera	[99]
4	Color	Kinect sensor	[100]
6	Color and height	Camera	[60]
4	Color	YOLOv3	[59]
4	Color	TCS3200 sensor	[101]
3	Shape	USB Camera	[102]
3	Shape and size	Camera & proximity sensor	[103]
6	Color and height	Camera	[60]
3	Color and shape	IR sensor and USB webcam	[61]
6	Color	Camera	[62]
4	Material type	Camera	[104]
6	Color	TCS3200 sensor	[105]
4	Material type	Camera	[63]
3	Color	TCS3200 sensor	[106]
5	Color	Camera	[68]
5	Color	TCS3200 sensor	[70]
4	Color and size	TCS3200 and Ultrasonic sensors	[107]
3	Color	TCS3200 sensor	[108]
6	Material type	Proximity sensors	[109]
6	Material type	Vision sensors	[71]
3	Color and material type	Ultrasonic & color sensor	[110]
4	Material type	Vision sensors	[72]
6	Color	RGB sensor	[73]
3	Color	Camera & RGB sensor	[111]
4	Material type	Stereoscopic camera	[74]
5	Material type	Optical sensor	[112]
6	Material type	Camera	[75]

3.2 Control Strategies and Methods

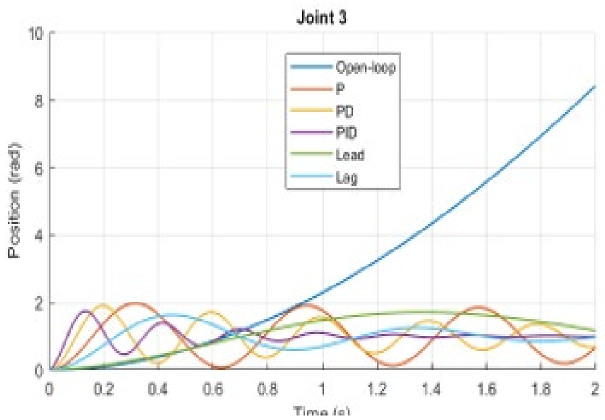
Apart from sorting criteria and sensor technologies discussed in the previous section, robot control strategies can greatly affect the accuracy of sorting robotic arm. Several control strategies/methods have been utilized to drive robotic arm in other to achieve desired task. These methods are broadly divided into two namely: classical and modern control strategies. Classical controllers are modelled from the transfer function of the system, they include the Open-loop (no control), Proportional (P), Proportional-Derivative (PD), Proportional-Integral-Derivative (PID), Lead compensator, and Lag compensator; while the modern control include: fuzzy logic, Convolutional Neural Networks, Artificial Neural Network (ANN) and others. According to [44], the PID control model performs better when deployed to robotic arm for Sorting operations -- however requiring manual tuning to suit different dynamic operation. To validate this claim, a case study of a 4 DOF sorting robotic having a payload of 0.5 kg was simulated using MATLAB 2022b. The performance of various classical control strategies was analyzed for each joint of a 4-DOF robotic arm with varying link lengths and corresponding inertial properties. Controllers examined include Open-loop (no control), Proportional (P), Proportional-Derivative (PD), Proportional-Integral-Derivative (PID), Lead compensator, and Lag compensator. Evaluation was based on standard time-domain metrics: settling time, rise time, overshoot, and steady-state error (SSE), using a unit step input.

From the graphs in Figure 4, result show that joint 1, having the longest link (0.25 m) and the highest inertia, posed the greatest challenge for control. The Open-loop system failed to track the desired position, exhibiting a full steady-state error of 1.0000 radians. Introducing a P controller improved the rise time to 0.196 s and settling time to 1.222 s, but resulted in a high overshoot of 28.34% and a residual SSE of 0.2931 rad. The PD controller significantly improved tracking, reducing overshoot to just 2.98% and SSE to 0.0176 rad, having a faster settling time of 0.388 s. The PID controller outperformed all others with a rise time of 0.042 s, settling time of 0.173 s, overshoot of 0.47%, and a near-zero SSE of 0.0004 rad. The Lead compensator followed closely behind with an SSE of 0.0046 rad, while the Lag controller, despite stabilizing the system, retained high overshoot (28.24%) and similar SSE as the P controller (0.2935 rad); For Joint 2, with a link length of 0.15 m, the system exhibited faster dynamics. The Open-loop case stayed inefficient and thus led to an SSE of 1.0000 rad once more. The P controller showed the following characteristics: rise time - 0.122 s; settling time - 0.870 s; overshoot - 14.98% and SSE - 0.1980 rad. When using the PD controller, the overshoot was minimized to 1.76%, SSE was increased to 0.0075 rad and settling time was shortened to 0.219 s. The PID controller was able to achieve the best result as it had a 0.030 s rise time, 0.106 s settling time, 0.27% overshoot, and 0.0002 rad SSE. The Lead controller was also quite effective, demonstrating 0.038 s rise time and 0.0020 rad SSE, but a little more overshoot. The Lag controller, much like the P, was not very accurate as it had a 0.1981 rad SSE; Joint 3 which had a 0.10 m link, was even quicker in reaction with all control methods. Again, the PID controller was the best performer as it obtained 0.024 s rise time, 0.084 s settling time, 0.20% overshoot, and only 0.0001 rad SSE. The PD controller was next with an SSE of 0.0042 rad, 0.038 s rise time, and some overshoot. The Lead compensator also was a good performer with 0.0051 rad SSE, whereas P and Lag controllers had bigger SSE values (~0.147 rad), thus it can be concluded that even in the case of low-inertia joints and without the use of integral or derivative action, precision suffers; Lastly, for Joint 4 (0.05 m link), the lightest and fastest joint, all controllers had a quick response. Nevertheless, the PID controller was able to produce the best total result comprising a rise time of 0.017 s, settling time of 0.062 s, overshoot of 0.15%, and SSE of 0.0001 rad. Both the PD and Lead controllers were also quite efficient as they had low SSE values (0.0028 and 0.0035 rad, respectively) and were characterized by short rise and settling times. In contrast, the P and Lag controllers, although fast, introduced higher steady-state errors (~0.075 rad), limiting their use in high-precision tasks.

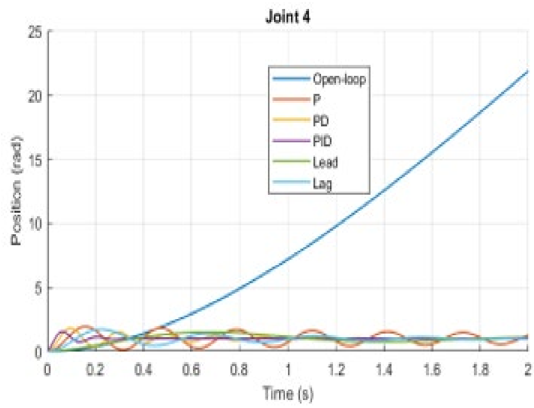
Across all joints, the PID controller consistently delivered the most accurate and stable results, regardless of inertia. It offered the lowest rise and settling times, minimal overshoot, and near-zero steady-state error across the board. However, a PID controller needs manual tuning, making it not suitable for handling tasks with a varying payload.



(a) **(b)**



(c)



(d)

Fig. 4 *A graph of position against time for all joints (a) Joint 1; (b) Joint 2; (c) Joint 3; and (d) Joint 4*

The advent of modern and hybrid control strategies provides robustness and intelligence to robotic arm sorting operations. Recent research has shown that combining more than one controller (hybrid control) can improve the performance of a PID control [45]. According to [46], research presented a comparison between two optimization techniques, Artificial Bee Colony (ABC) and Artificial Bee Colony with Multi-elite Guidance (ABCMG), for optimizing a PID controller on a 3-DoF robot. The results demonstrate that the MGABC algorithm performs better than the traditional ABC algorithm. Similarly, in [47]. Similarly, in [47], PID and fuzzy logic control techniques were implemented s on the SCORBOT-ER V plus robot arm model. The performance of the controller shows an improved trajectory curve and joint error, suggesting an improvement of the system. An optimized PID control system exhibits robustness under various disturbance conditions and dynamic payload. These techniques are viable for PID controller optimization in robotic applications. It has been established from studies that combining control (classical or modern) can give a hybrid control strategy capable of introducing smartness, accuracy, and less human intervention in object sorting [48]. Table 2 is a summary of different research highlighting different control strategies adopted for sorting operations using a robotic arm. The summary shows that 5. 71% of the authors used classical control, while 94.29% used modern or hybrid control strategies. This suggests a paradigm shift from classical to modern or hybrid control strategies.

Table 2 *Summary of sorting criteria and control strategy adopted from previous work*

Control strategy	DOF	Sorting criteria	Ref
Fuzzy Neural Network	5	Color	[49]
Artificial Neural Network (ANN)	5	Color	[50]
Pixy CMU Cam5	4	Color	[51]
Artificial Neural Network (ANN)	4	Color	[52]
AI and computer vision methods	4	Color	[53]
Fuzzy logic	6	Color	[54]
Artificial Neural Network (ANN)	3	Color	[31]
YOLO v8 algorithm	6	Color and shape	[26]
Artificial Neural Network (ANN)	7	Color	[55]
PID control algorithm	5	Color	[56]
Fuzzy logic algorithm	4	Color and weight	[57]
PID algorithm	5	Color	[58]
Cubic spline algorithm	3	Shape	[24]
Convolutional Neural Networks (CNNs)	5	Color (Camera)	[42]
Modbus RTU protocol	3	Shape	[43]
Grasp generator algorithm	4	Color	[59]

Control strategy	DOF	Sorting criteria	Ref
Haar Cascade algorithm with OpenCV	6	Color and height	[60]
Image processing with OpenCV	3	Color and shape	[61]
Image processing Algorithm	6	Color	[62]
Machine learning, image processing, and deep learning	4	Material type	[63]
Open-loop control with MATLAB	5	Material type	[40]
OpenCV-based image processing	6	Color	[64]
Image processing using MATLAB	6	Color	[65]
Intuitionistic Fuzzy Evaluations	5	Color (color sensor)	[66]
Image processing in MATLAB	6	Size, shape, and color	[67]
Python OpenCV image processing	5	Color	[68]
YOLOv8 and object detection	3	Color and material	[69]
Convolutional Neural Networks (CNN)	5	Color	[70]
AI and modular control	6	Material type	[71]
Deep learning with Xception model	4	Material type	[72]
Python algorithm	6	Color	[73]
YOLO-based object detection	4	Material type	[74]
Twin Delayed DDPG (TD3) Algorithm	6	Material type	[75]
Jacobian-based trajectory control	4	Color (camera)	[76]
Adaptive control	-	Multimodal (color, force, position)	[77]
Deep-Learning	6	ID tags	[78]
Artificial intelligence	4	Color, material type	[79]
YOLOv5	5	Color, shape	[80]
OpenCV	-	Color	[81]
GHT-ICP2D machine algorithm	6	Size and shape	[82]
YOLOv7	6	Color	[83]
LABVIEW	6	Position and orientation	[84]
Decision tree classification	6	Color	[85]

3.3 Microcontroller Utilization

Microcontrollers are the brain of a robotic arm; however, they cannot operate independently. The coordination of robotic arm activities relies on data from the sensors and control strategies to effectively position the actuators based on the analyzed data. 69.44% of the total microcontrollers used are Arduino, while 30.56% are for Raspberry Pi, ARM7, PIC, PLC, and others. The Arduino microcontroller is the most widely used microcontroller due to its cost and ease of use [111]. Table 3 shows the different microcontrollers in use for coordinating sorting operations.

Table 3 *Types of microcontrollers adopted for robotic sorting*

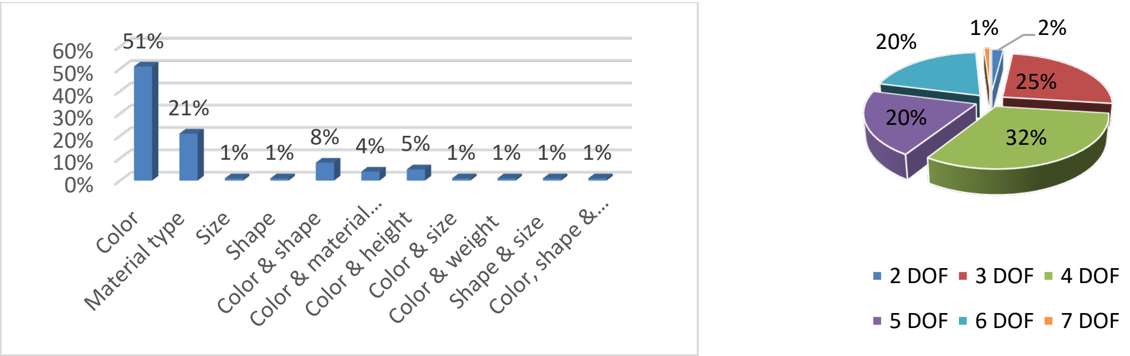
DOF	Type of Controller	Ref
3	PIC microcontroller	[67]
3	Arduino Microcontroller	[112]
3	PIC Microcontroller	[115]

DOF	Type of Controller	Ref
4	Raspberry Pi	[116]
6	Arduino Microcontroller	[117]
6	Arduino Microcontroller	[18]
6	Arduino Microcontroller	[54]
4	Arduino Microcontroller	[118]
4	Arm7 Microcontroller	[119]
4	Arduino Microcontroller	[120]
5	Arduino Microcontroller	[121]
4	Arduino Microcontroller	[122]
3	Arduino Microcontroller	[123]
3	ARM 7 microcontroller	[124]
6	Arduino Microcontroller	[125]
6	Arduino Microcontroller	[126]
3	Raspberry Pi	[127]
3	Arduino Microcontroller	[89]
5	FPGA-based controller	[128]
4	Arduino Microcontroller	[129]
4	CCD based controller	[51]
3	Arduino Microcontroller	[130]
3	Arduino Microcontroller	[94]
4	Arduino Microcontroller	[97]
5	PLC-based controller	[131]
6	Arduino Microcontroller	[30]
3	Arduino Microcontroller	[31]
4	Arduino Microcontroller	[132]
5	Arduino Microcontroller	[133]
3	Arduino Microcontroller	[134]
5	Arduino Microcontroller	[135]
4	Raspberry Pi	[136]
4	Arduino Microcontroller	[137]
6	Raspberry Pi	[138]

4. Review Analysis and Findings

4.1 Sorting Criteria and DOF

The current literature survey (Tables 1 and 2) shows that 51% of robotic arms can sort based on color alone, 1% of robotic arms can sort based on shape alone; 8% of robotic arms can sort based on color and shape alone; 1% of robotic arms can sort based on size alone; 5% of robotic arms can sort based on color and height alone; 4% of robotic arms can sort based on color and material type alone; 21% of robotic arms can sort based on material type alone; 1% of robotic arms can sort based on color and weight alone; 1% of robotic arms can sort based on color and size alone; 1% of robotic arms can sort based on shape and size alone; and 1% of robotic arms can sort based on color, shape, and size alone (see Figure 5a). Making color the most used sorting criterion. Figure 5b is a pie chart showing degrees of freedom (DOF) of the different robotic arms. 2, 3, 4, 5, 6, and 7 DOF cover about 2%, 25%, 32%, 20%, 20%, and 1% respectively of the total journal review (Tables 1, 2, and 3). This implies that a 4 its DOF robotic arm is the most common due to cost and ability to maneuver in the work environment.



(a) **(b)**

Fig. 5 *(a) Sorting criteria adopted; (b) Different DOFs used by authors in percentage*

4.2 Microcontroller Usage

There are different types of microcontrollers used in coordinating the activities of a robotic arm. Table 3 shows different microcontrollers used for coordinating sorting operations, including: PLC, Arduino, Raspberry Pi, PID, ARM 7, CCD, and FPGA controller. The choice of selecting a microcontroller is dependent on cost, ease of programming, availability, and so on [139]. From the review conducted, Arduino microcontrollers are the popular choice for implementing control systems in robotic arm development, occupying about 69% of the reviewed journals (Figure 6). This agrees with the findings of [140], which, according to the author, was due to their ease of programming, cost, adaptability to various tasks, and flexibility.

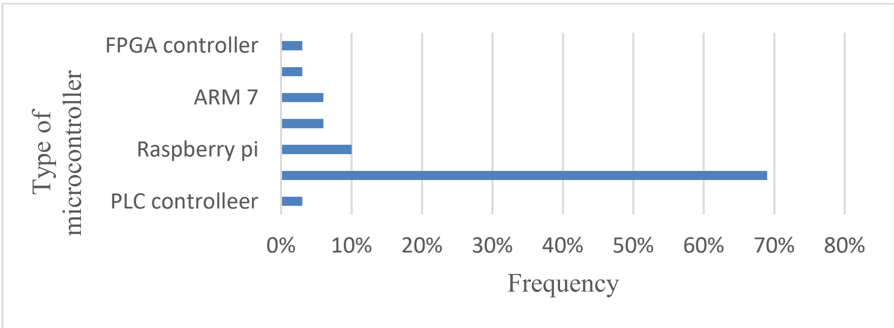


Fig. 6 *Types of controllers used by different authors in percentage*

4.3 Three-Layer Integration Taxonomy

Figure 7 represents an interdependent three-layer taxonomy that collectively determines the performance, precision and accuracy of sorting robotic arm systems. The three-layer framework includes: Perception, Decision, and Execution that together represent the integration of sensing, computation, and actuation to achieve the goal of efficient sorting. The perception layer is heavily reliant on the use of color-based sorting that constitutes 51% of the sorting where mainly TCS3200 and TCS230 sensors are used; however, the most advanced systems employ multimodal sensors. The decision layer makes use of control algorithms to understand the data obtained from sensors. 94.29% of the control systems are either modern or hybrid types that mainly use neural networks, fuzzy logic, and YOLO. Mechanical components and actuators are what make up the execution layer of the system. Stepper and servo motors are generally the sources of motion. Sections 3.1, 3.2, and 3.3 represent three interdependent components that collectively determine the performance, accuracy, and adaptability of sorting robotic arm systems. These elements work synergistically: control strategies orchestrate movement, sensor technologies provide perception, and microcontrollers integrate both into intelligent action.

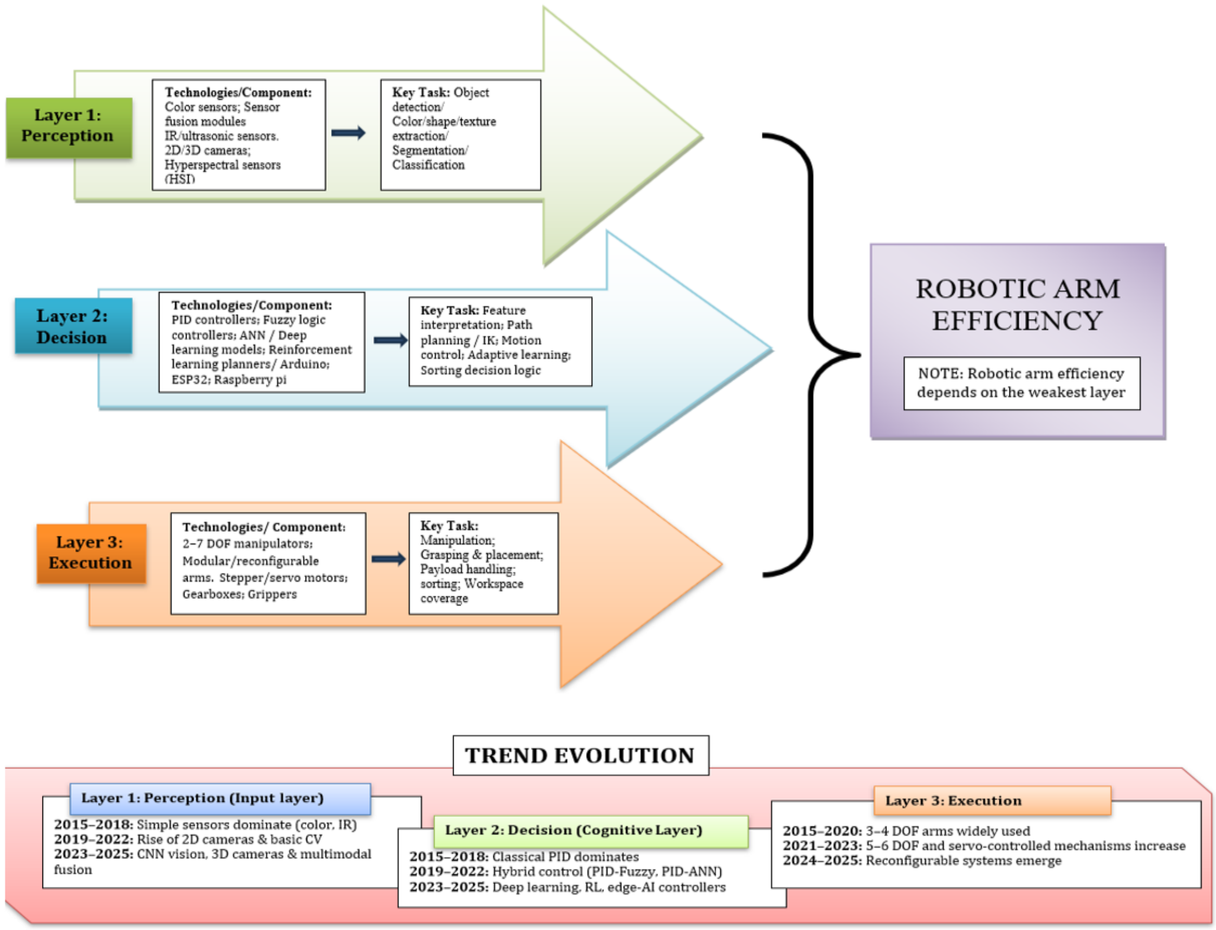


Fig. 7 *Sorting robotic arm taxonomy and trend*

5. Research Trends and Gaps

5.1 Emerging Trends

Between 2015 and 2025, the sorting robotic arms have mainly transformed through three trends. As a result, 94.29% of the systems incorporate AI and machine learning techniques such as CNNs, YOLO, and fuzzy logic for control, thus they no longer have PID controllers and gain higher precision and autonomy of the decision-making process. The majority of the devices (32%) are 4-DOF robotic arms, which provide a good balance between complexity and functionality, while 69% of the robots are controlled by Arduino microcontrollers due to their low price and easy access. Even though 51% of the systems are still using color-based sorting, the use of multimodal sensing with vision, ultrasonic, and material sensors is increasing, thus allowing more detailed characterization of objects. The above trends demonstrate the increased complexity of AI-based sorting robotics, the use of optimized mechanics, and advanced sensing technologies, which, together, are opening the doors to future Industry 4.0 applications with enhanced adaptability and efficiency.

5.2 Critical Research Gaps

Manufacturing sorting robotic arms have evolved, however still suffer from significant limitations in adaptability, with less than 22% of them employing multimodal sensing or adaptive controls, while most of them (51%) rely on fixed programming for single criteria such as color, which is not sufficient in dynamic environments that require multi-attribute processing. This review therefore suggests the application of multimodal sensing technology, advanced control strategy and the principle of reconfigurability to sorting robotic systems to improve intelligence, sorting accuracy and flexibility while making them fit for industrial 4.0 and beyond.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *S. P. Ayodeji, M. K. Adeyeri;* ***data collection:*** *O. I. Joseph;* ***analysis and interpretation of results:*** *O I Joseph, S. P. Ayodeji, M. K. Adeyeri;* ***draft manuscript preparation:*** *O. I. Joseph. All authors reviewed the results and approved the final version of the manuscript.*

Reference

[1] Kareem, J.A.H., Mohammed, B.I., Abdulwahab, S.A. (2022). Optimal Materials Handling Equipment and Defective Product Reduction Skills in Enhance Overall Production Efficiency. *SAGE Open*, 12(4). DOI: https://doi.org/10.1177/21582440221128769

[2] Hellmann W., Marino D., Megahed M., Suggs M., Borowski J., Negahban A. (2019). Human, AGV An Integrated Framework for Material Handling System Selection with Real-World Application in an Injection Molding Facility. *The International Journal of Advanced Manufacturing Technology*, 101(1-4), 815-824. DOI: https://doi.org/10.1007/s00170-018-2958-x SpringerPenn State

[3] Soufi Z., David P., Yahouni Z. (2021). A Methodology for the Selection of Material Handling Equipment in Manufacturing Systems. *IFAC-PapersOnLine*, 54(1), 122-127. DOI: https://doi.org/10.1016/j.ifacol.2021.08.193 ScienceDirectSemantic Scholar

[4] Hamzah, A.A., Abbas, A.F. (2022). Developed an Automated Design Sorting System According to Outer Edges of Object. *The Scientific World Journal*, 2022, Article ID 9439093. DOI: https://doi.org/10.1155/2022/9439093 PubMed CentralWiley Online Library

[5] Global Market Insights Inc. (2024). Material Handling Equipment Market Size - By Product, By Application, By Type, Analysis, Share, Growth Forecast, 2025-2034. Report ID: GMI1384. Available at: https://www.gminsights.com/industry-analysis/material-handling-equipment-market

[6] Kosmacheva, A., Belyanin, I., & Kriegel, I. (2024). New classification of industrial robotic gripping systems for sustainable production. *Scientific Reports*, 14, 274.

[7] Boysen, N., Briskorn, D., Fedtke, S., & Schmickerath, M. (2019). Automated sortation conveyors: A survey from an operational research perspective. *European Journal of Operational Research*, 276(3), 796-815. DOI: https://doi.org/10.1016/j.ejor.2018.08.014 Automated sortation conveyors: A survey from an operational research perspective - ScienceDirect

[8] Wang, C., Tang, C., Su, F. (2023). Energy-saving analysis of the tray sorting machine in airport luggage handling systems. *Logistics Technology & Application*, 28(2), 142-145.

[9] Tuo, J., Tang, C., Xie, Q., & Ye, Y. (2024). Research on the efficiency of visual guidance recognition for tilt tray sorter. In P. L. P. Rau (Ed.), *Cross-Cultural Design: HCII 2024* 14699, 327-340. Springer. DOI: https://doi.org/10.1007/978-3-031-60898-8_22

[10] Smith, Z. (2023). Application of RFID technology in automated baggage handling sorting systems in civil aviation airports. *Traffic & Transportation*, 38(6), 248-250.

[11] Luo, Z., et al. (2023). Applications of convolutional neural networks for intelligent waste identification and recycling: A review. *Resources, Conservation and Recycling*, 190, 106850. DOI: https://doi.org/10.1016/j.resconrec.2022.106850

[12] Tunç, L.T., et al. (2016). Design of an automatic apple sorting system using machine vision. *Computers and Electronics in Agriculture*, 127, 395-405. DOI: https://doi.org/10.1016/j.compag.2016.06.030

[13] Bobulski, J., & Kubanek, M. (2021). Deep Learning for Plastic Waste Classification System. *Applied Computational Intelligence and Soft Computing*, 2021, Article ID 6626948. DOI: https://doi.org/10.1155/2021/6626948

[14] Lu, W., & Chen, J. (2022). Computer vision for solid waste sorting: A critical review of academic research. *Waste Management*, 142, 29-43. DOI: https://doi.org/10.1016/j.wasman.2022.02.009

[15] Mankowitz, D.J., et al. (2023). Faster sorting algorithms discovered using deep reinforcement learning. *Nature*, 618, 257-263. DOI: https://doi.org/10.1038/s41586-023-06004-9

[16] Wen B and Liu T (2023). Automatic assembly with dual robotic arms based on mutual visual tracking and positioning. *Science Progress*, 106(2), 1-24. DOI: https://doi.org/10.1177/00368504231176969

[17] Kumar, S., Yadav, S. S., Kalaskar, A., Shripal, M., & Dattaprasad, N. (2024). Design and Development of a Color Sorting Robotic Arm. *International Journal of Enhanced Research in Management & Computer Applications*, 13(4), 875-876.

[18] Kiyokawa, T., Katayama, H., Tatsuta, Y., Takamatsu, J., & Ogasawara, T. (2021). Robotic waste sorter with agile manipulation and quickly trainable detector. *IEEE Access*, 9, 124616-124631. DOI: https://doi.org/10.1109/ACCESS.2021.3110795 Robotic Waste Sorter With Agile Manipulation and Quickly Trainable Detector | IEEE Journals & Magazine | IEEE Xplore

[19] Zhang, J., Gao, G., Karkee, M., Zhang, X., He, L., Zhang, Q. (2018). Branch detection for apple trees trained in fruiting wall architecture using depth features and regions-convolutional neural network (R-CNN). *Computers and Electronics in Agriculture*, 155, 386-393. DOI: https://doi.org/10.1016/j.compag.2018.10.029

[20] Zabalza, J., Fei, Z., Wong, C., Yan, Y., Mineo, C., Yang, E., Rodden, T., Mehnen, J., Pham, Q., Ren, J. (2019). Smart sensing and adaptive reasoning for enabling industrial robots with interactive human-robot capabilities in dynamic environments: a case study. *Sensors*, 19(6), 1354. DOI: https://doi.org/10.3390/s19061354

[21] Yuan, C., Shuai, C., Zhang, W. (2023). A dynamic multiple-query RRT planning algorithm for manipulator obstacle avoidance. *Applied Sciences*, 13(6), 3394. DOI: https://doi.org/10.3390/app13063394

[22] Diyal, S.Z., Proma, R.A., Islam, M.N., Anannya, T.T., Al Mamun, A., Arefeen, R., Al Mamun, S., Rahman, I.I., Rabbi, M.F. (2018). Developing an intelligent waste sorting system with robotic arm: a step towards green environment. In: *International Conference on Innovation in Engineering and Technology (ICIET)*. DOI: https://doi.org/10.1109/CIET.2018.8660890

[23] Saini, A., Gehlot, N., Vijayvargiya, A., Kumar, R., & Desai, U. (2023). Design Development and Analysis of 3-DOF Robotic Arm. In: 2023 9th IEEE India International Conference on Power Electronics (IICPE), pp. 1-7. DOI: 10.1109/IICPE60303.2023.10474758 Design Development and Analysis of 3-DOF Robotic Arm | Request PDF

[24] Paul, R. P. (1981). Robot Manipulators: Mathematics, Programming, and Control. MIT Press, Cambridge, MA. ISBN: 978-0262160827.

[25] Francis, J., Harikrishnan, K. A., Narayan, K. R., Prasad, R., & Sharika, T. R. (2024). Robotic Arm for Object Sorting Based on Colour and Shape. *International Journal of Science, Engineering and Technology*, 12(4), 1-5.

[26] Iqbal, J., Islam, R. U., Abbas, S. Z., Khan, A. A., & Ajwad, S. A. (2016). Automating Industrial Tasks through Mechatronic Systems - A Review of Robotics in Industrial Perspective. *Tehnicki Vjesnik*, 23(3), 917-924. DOI: https://doi.org/10.17559/TV-20140724220401 Automating industrial tasks through mechatronic systems – a review of robotics in industrial perspective

[27] Hockstein, N. G., Gourin, C. G., Faust, R. A., & Terris, D. J. (2007). A history of robots: from science fiction to surgical robotics. *Journal of Robotic Surgery*, 1(2), 113-118. DOI: https://doi.org/10.1007/s11701-007-0021-2

[28] Gasparetto, A., & Scalera, L. (2019). From the Unimate to the Delta Robot: The Early Decades of Industrial Robotics. In: Zhang, B., Ceccarelli, M. (eds) Explorations in the History and Heritage of Machines and Mechanisms. History of Mechanism and Machine Science, 37, 284-295. Springer, Cham. DOI: https://doi.org/10.1007/978-3-030-03538-9_23 ResearchGateSpringer

[29] Lim, W. J., Teoh, P. S., Ghani, N. M. A., & Abas, M. F. (2021). Automatic Control of Color Sorting and Pick/Place of a 6-DOF Robot Arm. *Journal Européen des Systèmes Automatisés*, 54(3), 435-443. DOI: https://doi.org/10.18280/jesa.540306 Automatic Control of Color Sorting and Pick/Place of a 6- DOF Robot Arm | Request PDF

[30] Muhammad A. B., Mukhtar I. B., Abubakar A. U., Abubakar S. M., Dahiru B., and Umar S. (2022). Global Journal of Research in Engineering & Computer Sciences, 02(03), 18-26.

[31] Khadkotkar P. and Mishra A. K. (2024), Short Review on Gripper System: Introduction, Types and Applications, *International Journal of Enhanced Research in Science, Technology & Engineering* 13(2), 44-53.

[32] Palli, G., Melchiorri, C., & De Luca, A. (2008). On the feedback linearization of robots with variable joint stiffness*. In 2008 IEEE International Conference on Robotics and Automation* (pp. 1753-1759). IEEE. DOI: 10.1109/ROBOT.2008.4543454

[33] Sensinger, J. W., & Weir, R. F. (2006). Improvements to series elastic actuators. In 2006 2nd IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications (pp. 1-7). IEEE. DOI: 10.1109/MESA.2006.296927

[34] Vanderborght, B., Albu-Schaeffer, A., Bicchi, A., Burdet, E., Caldwell, D. G., Carloni, R., ... & Tsagarakis, N. G. (2013). Variable impedance actuators: A review. *Robotics and Autonomous Systems,* 61(12), 1601-1614. DOI: 10.1016/j.robot.2013.06.009

[35] Rus, D., & Tolley, M. T. (2015). Design, fabrication and control of soft robots. Nature, 521(7553), 467-475. DOI: 10.1038/nature14543

[36] Asada, H., & Kanade, T. (1983). Design of direct-drive mechanical arms. Journal of Vibration, Acoustics, Stress, and Reliability in Design, 105(3), 312-316. DOI: 10.1115/1.3269106

[37] Levine, S., Pastor, P., Krizhevsky, A., Ibarz, J., & Quillen, D. (2018). Learning hand-eye coordination for robotic grasping with deep learning and large-scale data collection. *The International Journal of Robotics Research,* 37(4-5), 421-436. DOI: 10.1177/0278364917710318

[38] Mohd Javaid, Abid Haleem, Shanay Rab, Ravi Pratap Singh, Rajiv Suman, Sensors for daily life: A review, *Sensors International*, 2, 2021, 100121, ISSN 2666-3511, https://doi.org/10.1016/j.sintl.2021.100121.

[39] Resti, Y., Mohruni, A. S., Burlian, F., Yani, I., & Amran, A. (2018). Design of Mechanical Arm for an Automatic Sorting System of Recyclable Cans. *Journal of Physics: Conference Series*, 1007(1), 012066. DOI: https://doi.org/10.1088/1742-6596/1007/1/012066

[40] Dewi T, Pola R, and Yurni O. (2022), Fruit sorting robot based on color and size for an agricultural product packaging system, *Bulletin of Electrical Engineering and Informatics* 11(4), 1-10. DOI: https://doi.org/10.11591/beei.v11i4.3859

[41] Hasan M, Nishat V, and Saddam H. K. (2024) Real-Time Sorting of Broiler Chicken Meat with Robotic Arm: XAI-Enhanced Deep Learning and LIME Framework for Freshness Detection, *Journal of Agriculture and Food Research* 18(5):1-20. DOI: https://doi.org/10.1016/j.jafr.2024.101358

[42] Vo C. D., Duy A. D., and Phuong H. L. (2022), Development of Multi-Robotic Arm System for Sorting System Using Computer Vision, *Journal of Robotics and Control*, 3(5): 690-698. DOI: https://doi.org/10.18196/jrc.v3i5.15950

[43] Ajwad S. A., Iqbal J., Islam R. U., Alsheikhy A., Almeshal A., Mehmood A., (2018). Optimal and Robust Control of Multi DOF Robotic Manipulator: Design and Hardware Realization. *Cybernetics and Systems*, 49(1): 77-93. DOI: https://doi.org/10.1080/01969722.2017.1412905 Collaborative Position Control of Pantograph Robot Using Particle Swarm Optimization - International Journal of Control, Automation and Systems

[44] Pedro J. O., And Tshabalala T., (2015) Hybrid NNMPC/PID Control of a Two-Link Flexible Manipulator with Actuator Dynamics, 10th IEEE Asian Control Conference, Kota Kinabalu, Malaysia, May 31-June 3. DOI: https://doi.org/10.1109/ASCC.2015.7244737

[45] Azeez, M.I.; Abdelhaleem, A.M.M.; Elnaggar, S.; Moustafa, K.A.F.; Atia, K.R. (2023). Optimization of PID trajectory tracking controller for a 3-DOF robotic manipulator using enhanced Artificial Bee Colony algorithm. *Scientific Reports*, 13, 11164. DOI: https://doi.org/10.1038/s41598-023-38027-7

[46] Kern, J.; Urrea, C.; Verdejo, H.; Agramonte, R.; Becker, C. (2024). Trajectory Tracking and Disturbance Rejection Performance Analysis of Classical and Advanced Controllers for a SCORBOT Robot. *Robotics*, 13(3), 48. DOI: https://doi.org/10.3390/robotics13030048

[47] Urrea, C., Kern, J., & Torres, V. (2024). Design, Simulation, and Comparison of Advanced Control Strategies for a 3-Degree-of-Freedom Robot. *Applied Sciences*, 14(23), 11010. DOI: https://doi.org/10.3390/app142311010

[48] Chen W., Tongqing X., Junjie L., Mo W., and Dean Z. (2019), Picking Robot Visual Servo Control Based on Modified Fuzzy Neural Network Sliding Mode Algorithm, Electronics-*MPDI*, 8(2), 1-18.

[49] Sanjaya W. S. M., Dyah A., Madinatul M., Yusuf M. S. N., Darmawan S, R., Ahmad S., Ikhsan P, S, and Endah K, P., (2018) Colored Object Sorting using 5 DoF Robot Arm based Artificial Neural Network (ANN) Method. IOP Conf. Series: *Journal of Physics: Conf. Series* 1090 doi :10.1088/1742-6596/1090/1/012070

[50] Muladi, S., Sendari, I. A. E. Z. (2019). Colour-based Project Sorting in a Wide Range and Dense Target Points Using Arm Robot. Advances in Social Science, Education and Humanities Research, 242(1), 217–220

[51] Palasdeokar, K. N., Chavan, A. A., Panchal, M. N., & Patil, R. D. (2022). Design, Analysis and Fabrication of Pick & Place Colour Sorting Robotic Arm. *International Research Journal of Engineering and Technology*, 9(4), 236–237

[52] Baballe, M. A., Bello, M. I., Umar, A. A., Muhammad, A. S., Bello, D., & Muhammad, A. (2022). Design and Implementation of the Hand Pick and Place Cobots' Arms for Color Detection. 3rd International Conference on Applied Engineering and Natural Sciences, 111–112

[53] Abad, A. C., Ligutan, D. D., & Dadios, E. P. (2018). Fuzzy Logic-Controlled 6-DOF Robotic Arm Color-Based Sorter with Machine Vision Feedback. *International Journal of Advanced Computer Science and Applications,* 9(5), 21–23

[54] Lee S. and An D., (2022) AI-Based Posture Control Algorithm for a 7-DOF Robot Manipulator, *MDPI-Machines*,10(8), 651-673.

[55] Kale V. R., and Kulkarni V. A. (2013), Object Sorting System Using Robotic Arm, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering 2(7), 3400-3407.

[56] Nugraha S, Nurfalinda , and Nadapdap T (2023), Implementation of Fuzzy Logic Algorithm on Robot Arm Sorting Goods Based on Weight and Color Using the Mamdani Method, *Tanjungpinang, Indonesia* 4(2), 1-13

[57] Kulkarni, M. S., & Singh, R. P. (2018). Design and implementation of PID controller for 5-DOF robotic manipulator for color-based sorting applications. *International Journal of Robotics and Automation*, 33(4), 412-423. DOI: 10.2316/Journal.206.2018.4.206-5283

[58] Zhang R. N., Lu W., Jian X. L, Luo H. (2023), Intelligent Sorting Method for Assembly Line Based on Visual Positioning and Model Predictive Control of Robotic Arm. *Int J Agric & Biol Eng,* 2023; 16(4), 207-214.

[59] Shaikat, A. S., Akter, S., & Salma, U., (2020). Computer Vision Based Industrial Robotic Arm for Sorting Objects by Color and Height. *Journal of Engineering Advancements*, 1(04),116–122. https://doi.org/10.38032/jea.2020.04.002

[60] Basutkar B, Kotwal P, Sonawane K, and Patil S. M. (2021), Object Sorting by Robotic Arm Using Image Processing, *International Journal of Creative Research Thoughts* (IJCRT), 9(4), 5364-5373.

[61] Murthy, J. (2024). Development of a Robotic Arm with Vision-Based Pick and Place Functionality. *International Journal of Scientific Research in Engineering and Management*. 8(7), 1-9. DOI: 10.55041/IJSREM36339.

[62] Aarsh S. S. (2024) Medical waste detection and segregation using robotic arm International Scientific Journal of Engineering and Management 03(05),1-9

[63] Patil, S., Lakshminarayan, S., & Kumar, D. (2017). Efficient Sorting System for Industrial Use. Manuscript for Sorting Projects, 50–51

[64] Garad, P. V. (2017). Object Sorting Robot Based on the Shape. *International Journal of Advance Research, Ideas and Innovations in Technology*, 3(5), 129–134.

[65] Petrov, P., Bureva, V and Atanassov, K. (2023). Intuitionistic Fuzzy Evaluations of Garbage Sorting Using a Robotic Arm. Intelligent and Fuzzy Systems pp.259-264 doi 10.1007/978-3-031-39774-5_32.

[66] Sanga, A., Shinde, S., & Shaha, S. (2017). Fruit Sorting Robotic Arm Based on Image Processing. *International Journal of Recent Technology and Engineering*, 6(4), 7–9.

[67] Magadum, R. A., & Bombale, U. L. (2019). Intelligent Color Based Object Sorting Using Robotics. *International Journal of Robotics Research and Development*, 9(1), 43–48.

[68] Paudel, P., Shrestha, S., Adhikari, S., et al. (2024). Automated Waste Sorting with Delta Arm and YOLOv8 Detection. *Journal of Artificial Intelligence and Capsule Networks*, 3(4), 201–210.

[69] Lakshitha, W., et al. (2024). Autonomous Fruit Harvesting and Sorting Manipulator Using CNN. *Proceedings of the International Conference on Robotics*, 14(2), 45–50.

[70] Adediran, J., et al. (2023). UIArm I: Development of a Low-Cost and Modular 4-DOF Robotic Arm for Sorting Plastic Bottles from Waste Stream. Journal Européen des Systèmes Automatisés, 56(1), 113–119.

[71] Huang, Y. (2024). Research on garbage sorting robotic arm based on image vision. *Journal of Physics: Conference Series,* 2741(1), 012020.

[72] Kahar, K., Mathurkar, S., et al. (2024). Industrial Robotic Arm System. *Journal of science and engineering,*2(1), 62-67

[73] Goorun, Y., Marais, S., & Nicolls, F. (2024). Robotic Waste Sorting Using Deep Learning. MATEC Web of Conferences, 406(10003), 1–6.

[74] Liu, J., Yap, H. J., & Khairuddin, A. S. M. (2023). Path Planning for Robotic Manipulator in Dynamic Environments. *Journal of Intelligent & Robotic Systems*, 111(3), 1–15.

[75] Lambrache, N., Chen, G., Fisher, J., Olaru, L., & N'Drelan, B. (2024). Sensor Control of Portable Robotic Arms. Proceedings of the 9th North American Conference on Industrial Engineering and Operations Management, 67–75.

[76] Feng, Y. (2025). Adaptive control system for collaborative sorting robotic arms based on multimodal sensor fusion and edge computing. *Scientific Reports, 15*, Article 33383. https://doi.org/10.1038/s41598-025-18344-9

[77] Ozer, A. S., & Cinar, I. (2025). Real-Time and Fully Automated Robotic Stacking System with Deep Learning-Based Visual Perception. *Sensors, 25*(22), 6960. https://doi.org/10.3390/s25226960

[78] Chiranjeevi, K., et al. (2025). Robotic Arm-Cutting Edge Sorting Machine. *JOIG*. https://doi.org/10.18178/joig.13.4.394-405

[79] Paudel, K., et al. (2025). Automated Object Sorting Robotic Arm. *KEC Journal of Science and Engineering, 9*(1). https://doi.org/10.3126/kjse.v9i1.78382

[80] Alrushidy, I., et al. (2025). Design and Fabrication of Color Sorting Machine. *Journal of Science and Technology (UST)*. https://doi.org/10.20428/jst.v30i6.2954

[81] Wang, L., Fan, F., & Gu, Y. (2025). Using GHT-ICP2D machine vision to improve automated robotic sorting in industrial applications*, International Journal of Advanced Manufacturing Technology*. https://doi.org/10.1007/s00170-025-16868-y

[82] Nguyen, V.-T., et al. (2025). Vision-Based Pick and Place Control System. *IEEE Access*. https://doi.org/10.1109/ACCESS.2025.3536496

[83] Balasubramanian, B., & Cetin, K. (2025). *Vision-Based 6D Pose Analytics Solution for High-Precision Industrial Robot Pick-and-Place Applications, Sensors*. https://doi.org/10.3390/s25154824

[84] Ezigbo, P. J., et al. (2025). A Decision Tree-Based 6-Degree-of-Freedom Robotic Crop Sorting System. *Cureus Journal of Engineering*. https://doi.org/10.7759/s44388-025-05656-9

[85] Chavan, P. P., Kale, S. M., Gaikwad, P. P., and Ghadge, S. M. (2015). Intelligent Object Sorting Insolent System. 2015 *International Conference on Pervasive Computing* (ICPC). doi:10.1109/pervasive.2015.70

[86] Shrestha A., Nishan K., Rupesh Y., Monica S., and Sudip P. (2020) Automatic Object Detection and Separation for Industrial Process Automation, *IEEE International Students' Conference on Electrical, Electronics and Computer Science* 1-5

[87] Aung, T., San, Z. Z. M., and Oo, Z. M. (2019). Design and Development of an Automatic Color Sorting Machine on Belt Conveyor. *International Journal of Science and Engineering Applications,* 8(7), 176–177

[88] Reddy, D. V. K. (2014). Sorting of Objects Based on Colour by Pick and Place Robotic Arm and With Conveyor Belt Arrangement. International Journal of Mechanical Engineering and Robotics Research, 3(1), 67–70

[89] Zahur I., Nath P D, Nahiyan H., Uddin K. (2020) Design and Construction of an Articulated Pick and Place Manipulator, *International Conference on Mechanical, Industrial and Energy Engineering, Khulna, Bangladesh* 2591-2596

[90] Giri, V. K., Verma, N. K., Patel, R. K., & Singh, V. P. (2020), Color Sensor-Based Object Sorting Robotic Arm. *Algorithms for Intelligent Systems*. 169-180 doi:10.1007/978-981-15-2369-4

[91] Aburas, O., Hussein, M., Elnageh, A., Ebshish, M., and Algadi, M. (2024), Designing and implementing a 3DOF Robotic Arm for Color Sorting and Object Identification Using Computer Vision Technology, International Journal on Engineering and Information Technology (IJEIT). 12(1), 71-78

[92] Khairudin, A. R. M., Muhammad H. A. K, Asma A. S. Dyanatasya I. Muhammad Y. Y. and Norhaslina M Z (2021), Development of Colour Sorting Robotic Arm Using TCS3200 Sensor, IEEE 9th Conference on Systems, Process and Control (ICSPC 2021), Melaka, Malaysia

[93] Farman M. Al-Shaibah M., Aoraiath Z. and Jarrar F (2018), Design of a Three Degrees of Freedom Robotic Arm, *International Journal of Computer Applications*, 179 (37), 0975-8887.

[94] Swamardika, I. B. A., Budiastra, I. N., Setiawan, I. N., & Sudarma, M. (2017). Design of robotic arm system for color and shape-based sorting using image processing. *International Journal of Engineering and Technology*, 9(5), 3661-3668. DOI: 10.21817/ijet/2017/v9i5/170905302

[95] Kruthika, K., Kailasanathan, B., Sekar, S., & Arjun, P. (2016). Design and development of a robotic arm for object sorting based on color and shape recognition. *IEEE International Conference on Robotics and Automation for Humanitarian Applications*, 1-6. DOI: 10.1109/RAHA.2016.7931866

[96] Asadi, K., Jain H., Qin Z, Sun M, Noghabaei, M, Cole, J., Han, K. and Lobaton, E. (2019), Vision-based Obstacle Removal System for Autonomous Ground Vehicles Using a Robotic Arm. ASCE *International Conference on Computing in Civil Engineering, Atlanta, Georgia*, 328-335. DOI: 10.1061/9780784482438.

[97] Ali Z, Muhammad F S, Rashid A. A., Arif U, Muhammad Y K, Rehan U, and Muammer K., (2024) Design and development of a low-cost 5-DOF robotic arm for lightweight material handling and sorting applications: A case study for small manufacturing industries of Pakistan, Results in Engineering, *ELSEVIER*, 1-10. DOI: 10.1016/j.rineng.2024.101892

[98] El-Shair Z. A., and Rawashdeh S. A. (2019), Design of an object sorting system using a vision-guided robotic arm, Proceedings of the 2019 ASEE North Central Section Conference. 1-12

[99] Apriaskar, E., Fahmizal, & Fauzi, M. R. (2020). Robotic Technology towards Industry 4.0: Automatic Object Sorting Robot Arm using Kinect Sensor. *Journal of Physics: Conference Series,* 1444(1), 012030.

[100] Tirian G. O. (2017) Robotic Arm for Automated Colored Object Sorting, Acta Technica Corviniensis -- Bulletin of Engineering, 4(3), 146-150.

[101] Cong, V. D., and Hiep, T. T. (2023). Support vector machine-based object classification for robot arm system. *International Journal of Electrical and Computer Engineering*, 13(5), 5047–5053. DOI: 10.11591/ijece.v13i5.pp5047-5053

[102] Cong, V. D., Hanh, L. D., Phuong, L. H., and Duy, D. A. (2022). Design and development of robot arm system for classification and sorting using machine vision. FME Transactions, 50(1), 181–192. DOI: 10.5937/fme2201181C

[103] Dao, T. M. P., Vu, H. T., Nguyen, D. H., Hoang, M. H., & Nguyen, V. H. (2024). Design and Development of a 4-DOF Robotic Sorting System Utilizing an Efficient Image Processing Technique. Research Inventy: *International Journal of Engineering and Science*, 14(5), 97–103.

[104] Shah, R., and Pandey, A. B. (2018). Concept for Automated Sorting Robotic Arm. Procedia Manufacturing, 20(1), 400–405. - DOI: 10.1016/j.promfg.2018.02.058

[105] Suryawanshi, S., Sonone, S., Patil, P., & Parbhane, P. (2017). Color Sorting Robotic Arm. *International Research Journal of Engineering and Technology*, 4(10), 1011–1013.

[106] Sefa, M. H. (2024). Construction of a Robotic Arm. Graduation Project Report, University of Basque Country, 15(1), 56–60.

[107] [Khairudin, M., Yusof, H. M., Hamzah, A., & Bakar, S. A. (2024). Implementation of TCS3200 RGB sensor for automated color-based sorting in industrial robotic applications. *Sensors and Actuators A: Physical*, 365, 114892. DOI: 10.1016/j.sna.2023.114892

[108] Bharathesh, S., Ragavan, R., Kumar, P. S., & Venkatesan, S. (2024). Development of intelligent material sorting system using inductive proximity sensors and 6-DOF articulated robot. *Robotics and Computer-Integrated Manufacturing*, 85, 102634. DOI: 10.1016/j.rcim.2023.102634

[109] Anika, T. Z., Hossain, F., Uddin, M. N., et al. (2019). Color Sorting Robotic Arm. IEEE Conference Proceedings, 12(4), 78–81.

[110] Parmar, D., Rajak, S., Patil, S., & Satpute, R. (2024). Robotic Arm for Segregation Using Image Processing. *International Research Journal on Advanced Engineering Hub*, 2(4), 755–760.

[111] Khoo, Z. Y., & Razali, Z. B. (2015). Design, Analysis, and Fabrication of Robotic Arm for Sorting Multi-Materials. ResearchGate.

[112] Sukanya, K., Veni, C. V. N. S., Tejaswini, A., & Prasad, A. D. (2025). Object Detection and Sorting Using Robotic Arm. *International Journal of Innovative Research in Technology* (Ijirt), 11(12), 4155–4158.

[113] Surwade, N. J., Kshirsagar, C., Biradar, K., Zaware, P., & Kulkarni, S. (2022). Design and Development of Arduino-Based Automatic Color Sorting Machine. *International Research Journal of Engineering and Technology,* 9(5), 1435–1436

[114] Amin, U., Ahmad, G., Liaqat, N., Ahmed, M., and Zahoor, S. (2014). Detection & Distinction of Colors using Color Sorting Robotic Arm in a Pick & Place Mechanism. *International Journal of Science and Research,* 3(6), 1163–1165

[115] More, S., Bari, S., Patil, P., & Raut, S. (2019). Robotic Jaw for Object Sorting using Raspberry Pi. IOSR Journal of Computer Engineering, 21(2), 1–5.

[116] Sawant, A., Rane, D., Shaikh, G., & Sethi, M. (2016). Development of Goods Sorting System Based on Color. *International Journal of Technical Research and Applications, Special Issue* 39, 46–51

[117] Poojary, R., Dudhe, R., Rajan, A., & Radhakrishnan, S. (2017). Efficient Automated Fruit and Vegetable Sorter Based on Colour Detection. SSRG International Journal of Electronics and Communication Engineering, 4(4), 30–31

[118] Rane, D. B., Gunjal, S. S., Nikam, D. V., & Shaikh, J. U. (2015). Automation of Object Sorting Using an Industrial Roboarm and MATLAB Based Image Processing. *International Journal of Emerging Technology and Advanced Engineering,* 5(2), 187–188

[119] Singh, G. N. A., Naveen, M., Reddy, M. S., & Manikanta, T. (2021). Implementation of the System for Colour Detection and Identification Using Robotic Arm: A Review. *Journal of Emerging Technologies and Innovative Research,* 8(4), 844–845.

[120] Lal, M., Ali, Z., Pandey, M., Prajapati, N., Gupta, G., & Krishna, K. (2021). Proposed Work on Object Sorting Using Color Sensing. *International Research Journal of Engineering and Technology,* 8(6), 3452–3453

[121] Venkatesham, A., and Nath, G. G. (2020). Mechanized Robotic Arm for Object Sorting Based on Colour Sensing. *International Research Journal of Engineering and Technology*, 8(10), 100–101

[122] Kharade, M., Bhavsar, S., Rathod, S., Molane, K., & Mishra, S. (2020). Microcontroller Based Product Sorting by Using Colour Sensor. *International Journal of Progressive Research in Science and Engineering,* 1(6), 69–70.

[123] Kachare, L. B. (2016). Object Sorting Robot Using Image Processing. *International Journal of Electronics, Electrical and Computational System,* 5(7), 6–7

[124] Joy, A. (2014). Object Sorting Robotic Arm Based on Colour Sensing. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, 3(3), 7741–7743.

[125] Gundu, N., Utekar, S., Pardeshi, A., & Elgandelwar, S. M. (2021). Object Sorting Robotic Arm Based on Colour Sensing. *International Journal of Advanced Research in Science, Communication and Technology,* 6(1), 720–723.

[126] Gulia, V., & Mood, V. (2015). Efficient Movement of Robotic Arm to Enhance Object Handling and Sorting Operation. *International Journal of Science and Research*, 4(7), 893–895

[127] Sadoon, A. T., & Abdul Qader, D. A. K. (2016). Colour Recognizing Robot Arm Equipped with a CMOS Camera and an FPGA*. International Journal of Computer Applications*, 153(2), 24–27. DOI: 10.5120/ijca2016910887

[128] Khan, S. A., Anika, T. Z., Sultana, N., Hossain, F., and Uddin, M. N. (2019). Color Sorting Robotic Arm. 2019 International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST). 507-510. doi:10.1109/icrest.2019.864416

[129] Shetty, P., Tambe, S., Zurkale, S., & Dange, K. (2017). Color Sorting Robotic Arm Using Arduino. UMIT, SNDT University.

[130] Bhalerao A, Chopade K, Doifode P and Gaikwad J, (2019), Pick and Place Robotic ARM using PLC, *International Journal of Engineering Research & Technology* (IJERT) Vol. 8 (08), 667-670.

[131] Goudar S. H and Sushma S. J (2020), Design of Material handling pick and place Robot System using Zigbee Technology for Communication. *International Journal of Engineering Research & Technology* (IJERT), Vol 8 (11), 261-263.

[132] Sengsalonga A. and Widodo N. S. (2019), Object Moving Robot Arm based on Color, Signal and Image Processing Letters, Vol.1(3), 13-19.

[133] Myint, K. M., Htun, Z. M. M., & Tun, H. M. (2016). Position Control Method for Pick and Place Robot Arm for Object Sorting System. *International Journal of Scientific & Technology Research*, 5(6), 57–61

[134] Maneetham D and Leng S,(2018), PC-Based 5DOF industrial robotic arm with object color sorting by image processing, S N R U Journal of Science and Technology, 10 (3), 148-155

[135] Sampreeth A., Harsha A K., Rao A., Desai KV., Rohith K., and Praveena KS (2018) Object Sorting Robot Using Image Processing, *International Journal of Engineering Research & Technology* (IJERT) 6(13), 1-4.

[136] Fernandes, L. and Shivakumar B.R. (2020) Identification and Sorting of Objects based on Shape and Colour using robotic arm, Proceedings of the Fourth International Conference on Inventive Systems and Control (ICISC) IEEE Xplore Part Number: CFP20J06-ART; ISBN: 978-1-7281-2813-9. DOI: 10.1109/ICISC47916.2020.9171174

[137] Pereira, N. (2014). Development of a 6-DOF robotic manipulator controlled by Raspberry Pi for educational purposes. *International Journal of Control and Automation*, 7(11), 371-384. DOI: 10.14257/ijca.2014.7.11.35

[138] Jeevan F. D., Andrew D. R, and Adams C. K (2014) Selecting Microcontrollers and Development Tools for Undergraduate Engineering Capstone Projects, *Computers in Education journal* 5(1), 54-66

[139] Miller, P. (2020). Integration of Arduino in Industrial Automation. *International Journal of Engineering Research*, 45(3), 210-225.