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IoT-Based Industrial Automation Using a Pair of Synchronous Robotic Arms

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ABSTRACT—

By implementing a greater level of automation, the "IoT-Based Industrial Automation Using A Pair of Synchronous Robotic Arms" project seeks to alleviate the difficulties experienced by manual labourers in dangerous industrial situations. Industry-wide robotic arms currently in use operate as discrete, limited-functioning entities, which reduces their effectiveness. The goal of this project is to design and create a pair of synchronous robotic arms for usage in industrial settings.

The project is broken down into three major phases: research and a review of the literature; the building of the mechanical structure using Solid Edge and 3D printing with PLA; and the installation of the control system utilising actuators, a microcontroller simulated in Proteus, and coded in the Arduino IDE. The creation of a graphical user interface (GUI) using Python is the last stage. Each stage is individually created and flawlessly combined.

Excellent outcomes, such as high load-bearing capacities and a broad operating range, are demonstrated by the project as it was carried out. A thread model in the code allows for the concurrent operation of tasks through the control system. The results of this project demonstrate how synchronous arm systems can improve stability and efficiency across a range of industries. These systems also have a long-term durability. Future development can concentrate on adding sensory components to the arms to give them intelligence and allow them to carry out tasks independently without human assistance.

The purpose of submitting this project work for publication is to establish a standard for industrial automation. It is intended that the research results and methodology outlined in this paper would stimulate additional study and advancement in the field, ultimately saving millions of lives by enhancing the safety and effectiveness of industrial operations.

***Keywords*— Synchronous robotic arms, 3D Printing, Control System, Mechanical Structure, Graphical User Interface, Python**

I. INTRODUCTION

The industrial sector has undergone a significant shift in recent years due to developments in automation technologies. Robotic systems are one such cutting-edge technology used in industrial automation. Particularly robotic arms, which provide unmatched precision, efficiency, and safety, have evolved into important instruments in a variety of industrial activities. A pair of synchronous robotic arms has become one of the most effective ways to boost productivity and broaden the use of automation in industries among the various types of robotic systems.

A pair of synchronous robotic arms is a specialized robotic system that consists of two arms performing a variety of industrial activities in unison and synchrony. These robotic arms have several degrees of freedom and a large range of motion, and they are made to move like human arms. These arms are particularly well-suited for industries like automotive and aerospace manufacturing because they can do jobs that call for high levels of accuracy and repeatability because to their ability to mimic human-like dexterity and agility.

The ability of a pair of synchronous robotic arms to work together and synchronically sets them apart from other robotic systems. These robotic arms can do tasks that would be difficult or impossible for a single robotic arm because to their coordinated action. For instance, holding and supporting a workpiece with one arm while accurately manipulating it with the other allows for increased efficiency and task completion. An extremely complicated control system that consists of numerous sensors, actuators, and other parts that enable exact control of the arm's movements is what allows these arms to move in unison.

A project was started to design two synchronous robotic arms with the goal of creating a reliable and effective industrial automation system. The project is based on the mechanical design of the arms, with servos attached at the joints to provide the required motion. A control system, which gets data from a microprocessor, is coupled to these servos. The entry of user commands and tasks through a console offers an easy-to-use interface for controlling the arms.

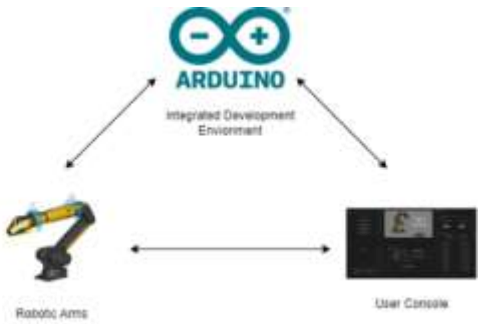

Fig.1 Components of the Project

A pair of synchronous robotic arms' ability to perform properly depends on their control system. The control system can be programmed by engineers using sophisticated software tools, enabling the execution of complex actions and procedures. The capacity to programme enables for task customization based on particular industrial requirements. The power supply system is also essential for ensuring the robotic arms operate steadily and dependably. In order to maximize power efficiency and performance given the high-power requirements of these arms, specialized power supply units, motor controllers, and other components are used.

In industrial automation, the use of two synchronous robotic arms can have a big impact. These sophisticated robotic systems have the potential to improve a variety of industrial applications' productivity, efficiency, and quality. They lessen the need for manual labor and the risks and difficulties faced by human workers in dangerous industrial situations by automating repetitive and physically taxing operations. Additionally, the accuracy and repeatability of these arms help to increase the consistency and quality of the final product, improving manufacturing processes as a whole.

The current research is focused on utilising IoT (Internet of Things) technologies to improve the performance and functionality of a pair of synchronous robotic arms in industrial automation. The robotic arms can be linked to a network and allow for seamless data interchange as well as remote monitoring and control by integrating IoT technologies. Real-time analytics, preventive maintenance, and industrial process optimization are made possible by this connectivity. The potential for more productivity, less downtime, and better decision-making in the industrial sector becomes even more intriguing with IoT-based industrial automation.

An effective way to boost productivity, efficiency, and quality in numerous industrial applications is provided by a pair of synchronized robotic arms, which marks a significant development in industrial automation. These arms work together to complete jobs with high accuracy and repeatability thanks to a sophisticated control system, precise motion capabilities, and coordinated operation. A new era of intelligent and networked industrial automation is possible thanks to the use of IoT technologies, which further increases the potential for improving their usefulness and connectivity.

II. SYNCHRONOUS ROBOTIC ARMS

Mechanization and mass production were brought about by the Industrial Revolution, but industrial automation was what actually transformed industries. Synchronous robotic arms have changed industrial operations with the emergence of IoT. By substituting manual labor and improving efficiency, efficacy, and accuracy, these arms operate in perfect harmony. Automation has advanced significantly, influencing the digital environment and enabling production on a worldwide scale. Automation is essential for increasing production and obtaining mature results in industries, whether it is through machinery performing repetitive activities or intelligent systems analyzing and reacting to their surroundings.

A. Arduino

Due to its user-friendly development environment and extensive hardware options, the open-source electronics platform Arduino has gained enormous popularity among professionals, students, and hobbyists. It offers a flexible and available option for a range of projects and applications. Arduino's sizable and helpful community is a huge asset. Both novice and expert users can benefit from the online forums, documentation, and tutorials. The community actively promotes collaboration and information sharing by contributing libraries, code samples, and project ideas. Additionally, Arduino supports prototyping and experimentation. Due to its reasonably priced boards and components, users can quickly prototype electronic devices by iterating and testing their ideas without breaking the budget. Further enhancing the platform's adaptability and enabling the speedy integration of new functions are Arduino shields, which are add-on boards that extend Arduino's capabilities. The platform makes it simple for newcomers to begin coding by providing a simpler programming language based on Wiring.

The adaptability of Arduino is one of its main benefits. It can be applied to a wide range of tasks, from straightforward robotic systems to intricate studies involving blinking LEDs. Numerous sensors and actuators, including as temperature sensors, motion detectors, servos, motors, and displays, are supported by the platform. Users are given the ability to construct projects in a variety of fields, such as home automation, robotics, environmental monitoring, and the Internet of Things (IoT), thanks to this flexibility.

B. Robotic Arms and Degrees of Freedom

Robotic arms, also referred to as robot manipulators, have transformed industries by replicating the movement and functionality of a human arm. These versatile machines consist of interconnected segments driven by motors or actuators, enabling them to perform a diverse range of tasks across various industries.

The applications of robotic arms span across manufacturing, assembly, material handling, healthcare, and even space exploration. They offer numerous advantages over human labor, including enhanced precision, speed, and endurance. With the ability to operate in hazardous environments, handle heavy loads, and execute repetitive tasks consistently, robotic arms contribute to increased productivity and efficiency.

Designing robotic arms incorporates essential features such as joint mobility, end-effectors, and sensors. The number and type of joints determine the range of motion of the arm, enabling it to reach different positions and orientations. End-effectors, which can be grippers, tools, or specialized attachments, facilitate interaction with objects and the execution of specific tasks. Sensors play a vital role in providing feedback and enabling the arm to detect and respond to its environment, ensuring safe and accurate operation.

Control systems play a crucial role in the functionality of robotic arms. They enable precise control of each joint's position, velocity, and force, allowing the arm to perform intricate movements. Control algorithms, often based on mathematical models and sensor feedback, govern the arm's motion and coordination.

Advancements in technology have led to the development of more sophisticated robotic arms incorporating artificial intelligence, machine learning, and vision systems. These advancements enable robotic arms to adapt to changing environments, learn from experience, and even interact with humans in collaborative settings.

Synchronous robotic arms, as opposed to conventional robotic arms, work in coordination to perform tasks. By synchronizing their movements, these robotic arms achieve increased productivity, enhanced precision, and improved efficiency. They enable parallel processing, reducing cycle times and maximizing throughput. Synchronous robotic arms have the potential to revolutionize industries by overcoming the limitations of single-arm automation and unlocking new levels of performance and competitiveness.

In addition to increased productivity, synchronous robotic arms offer superior precision and accuracy through coordinated movements. By distributing tasks among multiple arms, they can handle intricate operations with ease. These synchronized systems optimize resource utilization, minimize idle time, and streamline processes, resulting in improved overall efficiency. The collaborative potential of synchronous robotic arms, combined with advancements in technologies like machine learning, further expands their capabilities and opens up new possibilities for adaptive and intelligent automation.

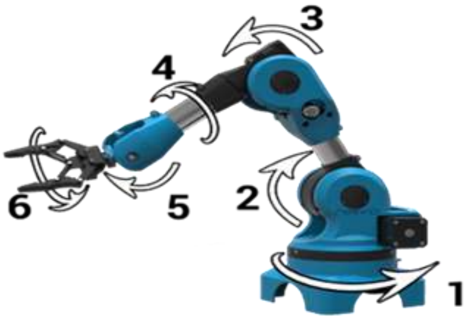

Fig.2 Six Degrees of Freedom in a Robotic Arm

Understanding the degrees of freedom in synchronous robotic arms is crucial for proper system design, motion planning, and control. It allows engineers and programmers to optimize the arm's movements, improve efficiency, and ensure safe and accurate operations in diverse industrial applications, ranging from manufacturing and assembly to automation and collaborative robotics.

III. DESIGN AND DEVELOPMENT

Designing synchronous robotic arms for industrial automation involves several considerations to ensure efficient and precise operation. A few key factors that are considered are Payload Capacity, Reach and Workspace, Degrees of Freedom of the arm, Kinematics, Actuators and Drivers, Control Systems, End-effector tooling, Integration and Safety.

A. Dimensions and CAD Design

3D printing using CAD models offers numerous advantages. Firstly, it allows for the creation of complex geometries that may be difficult or impossible to achieve with traditional manufacturing methods. The versatility of CAD software empowers designers to explore intricate shapes, organic forms, and intricate details. Secondly, CAD models enable customization and personalization. Designs can be easily modified or adapted to meet specific requirements or preferences. This flexibility opens up new possibilities for rapid prototyping, product iteration, and on-demand manufacturing. Moreover, CAD models facilitate the design validation process. Virtual simulations and analysis can be performed on the model before it is printed, allowing designers to identify potential issues, test different configurations, and optimize the design for functionality, performance, and structural integrity.

3D printing using CAD models finds applications across various industries, including aerospace, automotive, healthcare, architecture, consumer products, and more. From creating prototypes and functional parts to artistic sculptures and architectural models, the combination of 3D printing and CAD modelling offers limitless possibilities for innovation and creativity.

3D printing, or additive manufacturing, utilizes various materials to create objects layer by layer. The choice of material depends on the specific requirements of the printed object, such as its intended application, desired properties, and functional characteristics. Here are some common materials used in 3D printing. Thermoplastics like polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) are widely used in 3D printing due to their accessibility, affordability, and versatility. PLA is biodegradable, easy to print with, and has low warping. ABS is known for its strength, durability, and ability to withstand higher temperatures. Other popular plastic materials include polyethylene terephthalate (PETG), polypropylene (PP), and nylon.

Table 1 : Properties of PLA

Parameter	**Value**
Heat Deflection Temperature	52°C
Density	1.24g/cm^3
Tensile Strength	50MPa
Flexural Strength	80MPa
Impact Strength	96.1J/m
Shrink Rate	0.37-0.41%

This project has been manufactured using Polylactic Acid (PLA) due to its low cost, easy accessibility, easy-to-print properties and low warping abilities.

Fig.3 CAD Model of the designed robotic arm

The CAD Model as shown in Figure 3 was designed using Solid Edge. A 6-DoF structure was chosen with six actuators in the form of industrial grade servo motors. Each actuator was designed to facilitate one degree of freedom.

The dimensions of the arm to fit a small-scale industries for simple actions that include but are not limited to pick and place is shown in Fig. 4.

Fig.4 Dimensions of the designed robotic arm

B. *Control System*

The pair of arms have to be fitted with servo motors that act as end actuators and the actuators need to be programmed using microcontrollers. Multiple such components have been used for the successful completion of the project.

1) *Arduino Nano:* Arduino Nano is a small, adaptable microcontroller based on ATmega328P. It provides a flexible and affordable platform for prototyping.

2) *Servo Driver:* Servo Driver PCA9685 is a 16 channel PWM controlled IC that can control multiple servo motors. It works on the I2C communication protocol.

3) *Servo Motors:* The Servo Motors used in the project is MG90S and MG996r with 90g/cm and 9Kg/cm stall torque.

The wiring of these components was done only after a software simulation was done in the Proteus Software. The wiring diagram is depicted in Fig. 5.

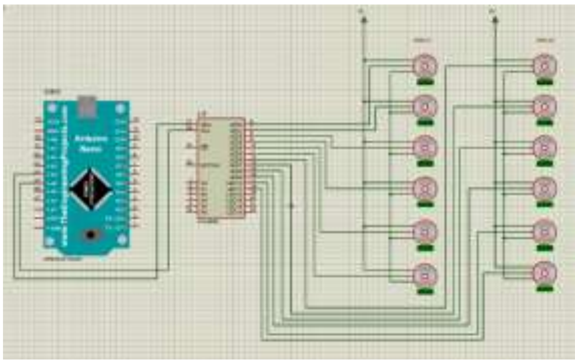

Fig.5 Wiring Diagram

The protocol used is the I2C (Inter-Integrated Circuit), which provides several advantages in Arduino-based projects.

One notable benefit of using the I2C protocol is simplified wiring. It requires only two wires, a data line (SDA) and a clock line (SCL), reducing complexity and the number of required pins on the Arduino board. This simplicity makes I2C a cost-effective and accessible option, particularly for hobbyists and prototyping.

The I2C protocol incorporates an addressing scheme that allows multiple devices to coexist on the same bus. Each device is assigned a unique address, enabling individual communication with specific devices. This addressing capability simplifies the integration and control of multiple peripheral devices in Arduino projects.

Efficient data transfer is another advantage of I2C. It employs a master-slave architecture and a synchronized clock signal for reliable communication. The master device controls the data exchange, ensuring efficient and error-free communication with connected devices. I2C also supports various data transfer modes, providing flexibility in configuring data rates.

Additionally, the I2C protocol is widely supported by peripheral devices such as sensors, displays, and motor controllers. Many manufacturers provide I2C-compatible devices with libraries and documentation, simplifying the integration process and expediting the development of Arduino projects. The flowchart for the firmware of the control system is depicted in Fig. 6.

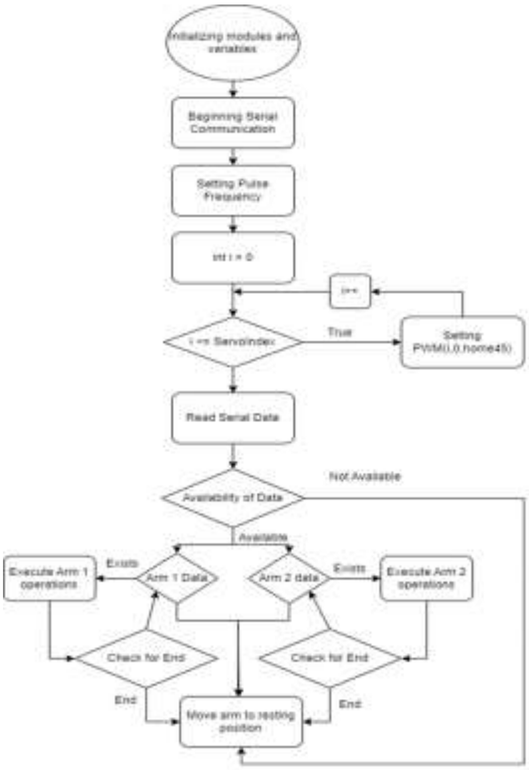

Fig.6 Flowchart for the Control System

C. *Dashboard*

The dashboard for the project is developed using Python. The entire development of the dashboard can be subdivided into two major sections. These sections perform the activities of creating and managing a task and the transfer of the data between the control system and the GUI. These tasks are then called in the main code which will seamlessly integrate the complete GUI. The flowchart for the development of the dashboard is depicted in Fig 7.

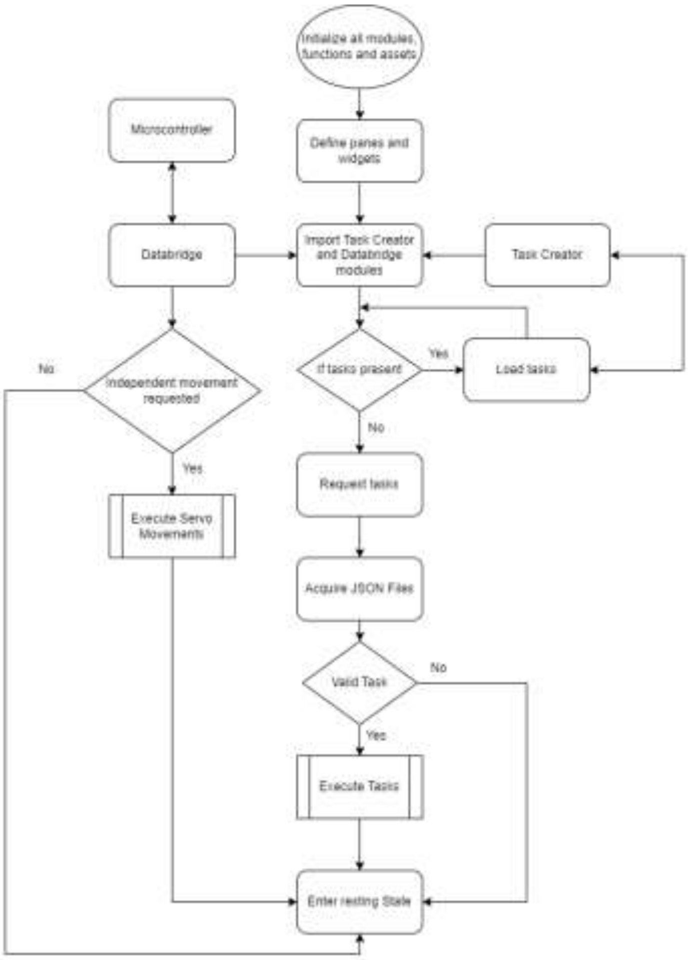

Fig.7 Flowchart for the Dashboard

IV. RESULTS

The results of this project also include the efficient functioning of the robotic arms, but also its safety, range testing and load bearing capacity. The mechanical structure was designed using Solid Edge and was 3D printed with PLA. Hence the structural ability of the arms is very high. Three degrees of translational freedom and three degrees of rotational freedom are allowed due to the mounting of six industrial grade servo motors in each arm as is depicted in Fig. 8.

Fig.8 Mechanical Structure of the Robotic Arm

The three degrees of rotational freedom and the three degrees of translational freedom are not bound to one particular actuator in this project since each actuator moves in an arc. Thus, the degrees of freedom are actually obtained by a combination of one or more of these actuators.

Fig. 9 depicts the end effector tooling that was designed for this project. An opposable thumb model was selected for the end effector, but it was dropped due to low strength and low load bearing capabilities. Finally, a claw-shaped end effector was chosen as the end effector due to its equal stress distribution towards both clasps.

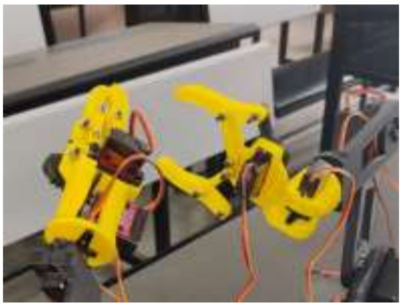

Fig.9 Mechanical Structure of the End effector

A. Graphical User Interface

The Graphical User Interface was designed using Python for both the front-end user console as well as the back-end communication as depicted in Fig. 10.

Fig.10 Graphical User Interface

A few key features provided in the user console are –

- Independent Arm Movement as can be seen in the top right section of the GUI
- Task manipulation as can be seen in the left pane of the GUI
- Independent actuator movement as can be seen in the bottom right pane of the GUI
- Task scheduler
- Pane to retrieve the current and previous coordinates and position.

B. Safety Testing

The entire project was subject to safety testing and measurements so that the project can be as close to an industrially deployable model. The safety testing was done on major fronts which are discussed in detail.

The range of the arms are an important parameter that are defined so that a minimum safe distance can be prescribed for any users to follow so as not to impediment the arm actions and get hurt in the process. Figure 4.9 depicts the dimensions of one arm. Both arms are placed a few distance apart. Each arm has a range of about 250mm. Thus both the arms are placed about 170mm apart for perfect operation. This calculation was done by using the most optimum actuator conditions and range testing. This implies that a safety bubble of 420mm is prescribed for the efficient operation of the arm without hindrances.

The load bearing capabilities of the arm is dictated by the stall torque theoretically and tests for the same are done practically as well. The load bearing of the upper three servos are about 90g/cm and the arm length in itself is 135mm for the same. The load bearing of the lower three servos are about 9kg/cm and the length of the arm in itself is around 115mm. Thus the theoretical load bearing capabilities are computed. The same data is represented in the form of Table 4.1 for easier comparison between the expected results and obtained results for the load bearing capabilities for a single arm operation. Involving two arms in range testing and load studies would vary depending on each operation performed by the arm.

Table 2 : Comparative Study on Load Bearing Capacity

Parameter	**Predicted Value**	**Practical Value**
Upper Arm Load Capacity	121.5g	90g
Lower Arm Load Capacity	10.35Kg	9.2Kg
Maximum Load Capacity	10.47Kg	9.3Kg
Total Load Capacity	9.77Kg	5.8Kg

The disparity between the theoretical value and the practical value obtained is because of the mechanical linkages and the weight of the structure in itself. This implies that a lot of the load bearing capacity is dissipated in supporting the structure in itself. This can be improved by either providing a stronger make for the arm like ABS or Carbon Fiber by compromising on the cost and ease of production or by running algorithms to identify the best possible method to run synchronous tasks.

V. CONCLUSION

Synchronous robotic arms are a key development in automation, providing previously unheard-of levels of productivity, accuracy, and effectiveness. These systems enable simultaneous job execution, cutting cycle times and increasing production rates by harnessing the power of coordination and collaboration. Multiple arms moving in unison improve accuracy, guaranteeing repeatable and trustworthy results in intricate industrial operations. The seamless coordination of the arms is made possible by the integration of sensors, communication protocols, and sophisticated control algorithms, which maximizes resource utilization and reduces idle time. By increasing production, enhancing product quality, and fostering workplace safety, synchronous robotic arms have the potential to revolutionize numerous industries. Prospects for the broad use of these systems are quite promising as technology advances and their capabilities increase.

Moreover, the versatility of synchronous robotic arms allows for their application in diverse industries, ranging from manufacturing and assembly lines to logistics and healthcare. Their ability to handle complex tasks and adapt to changing requirements makes them invaluable assets in dynamic environments. As these systems continue to evolve, advancements in artificial intelligence and machine learning will further enhance their capabilities, enabling adaptive and intelligent behaviour. The ongoing research and development in the field of synchronous robotic arms promise continuous innovation and the potential for even more sophisticated applications in the future. Hopefully, our project will bring forth new avenues of innovation and set forth an example in the field of industrial automation.

The potential for future innovations and breakthroughs in the field of synchronous robotic arms is enormous. Exploration and innovation potential exist in a number of important areas. To increase the effectiveness and adaptability of synchronous robotic arms, sophisticated control algorithms and coordination techniques can be created. Artificial intelligence and machine learning techniques can be combined to further improve work allocation and decision-making. The future of synchronous robotic arms also lies in seamless interaction with people, with research concentrating on user-friendly and secure human-robot interfaces. Through increased perception and learning algorithms, autonomous capabilities can be strengthened, enabling adaptation to dynamic surroundings.

Robotic arms can recognize and manipulate objects more accurately with the help of multimodal sensing and perception. Complex tasks can be handled by the creation of collaborative networks that integrate various limbs. Concerns about employment and safety, as well as ethical and societal ramifications, must also be taken into account. Synchronous robotic arms have the potential to revolutionize automation and advance industry by investigating these areas.

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