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6 DOF Robotic-Arm Using Gesture Control

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A. Abstract— This paper describes the design and development of a gesture-controlled 6-DOF robotic arm to enhance automation in industrial applications. This robotic arm is specially designed for pick-and-place operations with advanced gesture recognition and image classification capabilities to sort objects based on their color, shape, and size. These projects tackle almost all the issues related to robotic arms, including latency in gesture control, precision at object manipulation, and sorting technique scalability. A Jetson Nano acts as the central processing unit; flex sensors provide input for gestures; a camera detects objects in real time; and NEMA stepper motors provide smooth and precise movement for the methodology. The System Architecture Design ensures coordination by Component across the ROS Robot Operating System middleware Framework., Experimental results show significant improvement in gesture control accuracy as well as sorting efficiency making this arm suitable for industrial environments where precision is required alongside user-friendly interface concerns. These results are not only reliable but also reinforce researchers' confidence in making further modifications to improve performance. Robots can control more robust systems by operating gesture-controlled systems with improved capabilities that also address shortcomings sorted by current methods.

Keywords— Gesture-Controlled Robotics, ***6-DOF Robotic Arm***, ***Industrial Automation***, ***Pick-and-PlaceOperations***

1. INTRODUCTION

The pace at which automation and robotics have developed has changed the industrial operations of today, reducing much human labor while increasing precision and efficiency. Central to this change are robotic arms that conduct activities like assembly, sorting, and material handling in various automated systems. Standard robotic arms limit their operation to executors of previously scripted commands; hence they cannot adapt to new or changing environments. Gesture-controlled robotic arms offered a way out by allowing intuitive human-robot interaction with greater maneuverability possible. This paper here talks about a6-DOF gesture-controlled robotic arm designed specifically for pick-and-place applications in industries. Such an arm is highly maneuverable, providing excellent precision in object handling across multiple axes and planes. Combining gesture recognition technology with robotics control creates more natural human-robot interaction and real-time adaptability, which is most needed for industrial applications where accuracy and quick response are essential factors. The review study focuses on several aspects of gesture-controlled robotic arms starting from analyzing the primary components as well as technologies involved, such as gesture recognition algorithms sensor integration control mechanisms. It also assesses alternative methodological strategies aimed at enhancing system performance addresses current issues such as latency plus scalability and recognizes research voids within the domain. Finally, this manuscript elucidates prospective trajectories concerning the development of gesture-controlled robotic systems alongside probable implications for industrial automation.[1][15][16].

II. Methodology

BLOCK DIAGRAM

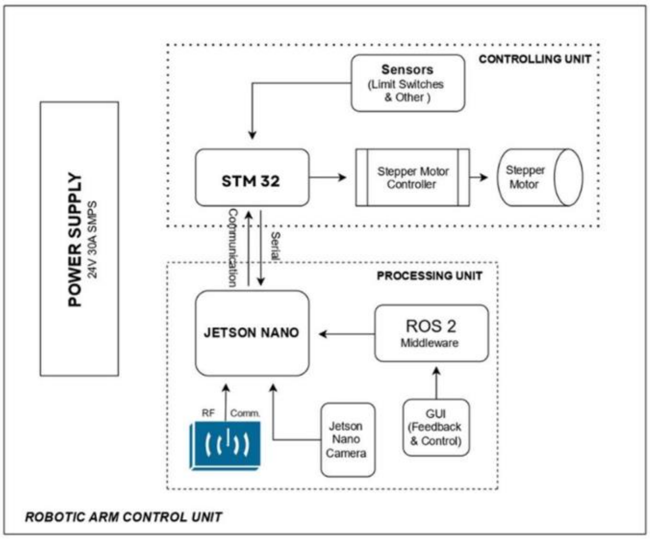

Fig 1.0 Block Diagram

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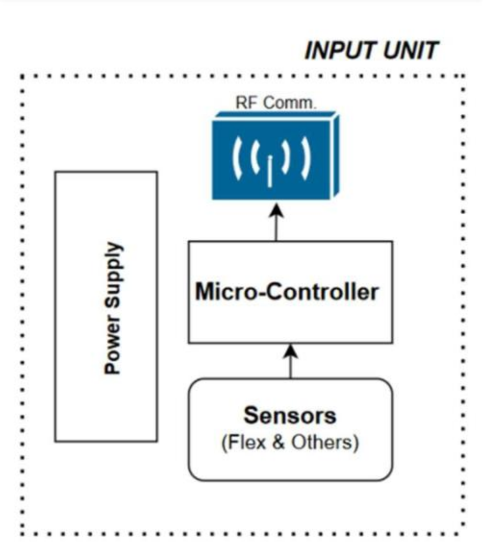

Fig 2.0 Block Diagram

This project entails the designing of a 6DOF robotic arm that is capable of performing complex pick and place action with enhanced accuracy through gesture control as a primary control medium. As shown in the Figure 2.0 the system architecture is consisting of three core units which are input unit, controlling unit and processing unit relatively useful in the robotic arm. Input unit: A glove containing flex sensors and other positioned on the hand that are used to collect gesture data from the user, this can also be in electrical form. A microcontroller interprets these signals and transmits through RF communication to the processing unit, providing real time hand gesture data.

The controlling unit interfaces with the stepper motor controllers through a STM32 microcontroller, driving each joint of the robotic arm according to commands received from a processing unit. In addition, it incorporates feedback mechanisms like limit switches and other position-monitoring sensors to ensure that the movement is safe and accurate.

The Jetson Nano-powered processing unit acts as a middleware that leverages ROS 2 (Robot Operating System) for component communication, task management, and arm movement in response to detected gestures. It also takes care of more complex machine learning tasks such as image classification for object detection and identification using various characteristics, including color, shape, and size. The camera integrated within the Jetson Nano generates a good amount of image data that let the technology perform selected AI tasks. Thanks to the modular software architecture, which has been designed using ROS 2, it has a scalable and flexible approach to managing the control and functions of the robotic arm. Operational parameters are set, task execution is visualized, and real-time monitoring and control of processes is done through the Graphical User Interface (GUI).

All components are supplied from a stable 24V 30A SMPS which creates the required operational performance for all the elements like the stepper motors and processing modules even when under high load usage. The communication process starts with a real- time transmission of gesture inputs which are transmitted from the input unit to the processing unit wirelessly. These inputs are then interpreted by the processing unit, performed object classification when necessary and then motor control unit issued the appropriate command. To achieve this effect, the arm was additionally provided with machine learning capabilities, permitting it to classify objects and choose appropriate handling strategies according to their features. Primarily, this methodology was based on empirical evidence collected in the literature review, and uses gesture-based control along with AI based processing to eliminate the known challenges in robot control and object manipulation.

A Communication

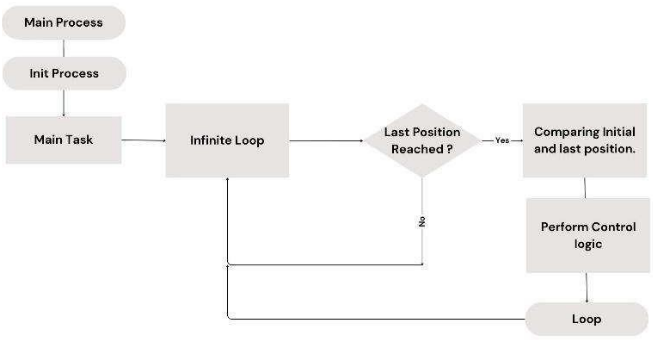

Fig 3.0 Communication Flow Chart

The above Figure 3.0 shows the flow chart that deals with the communication protocol in respect of the current project describes the use of a feedback system for the control of the robotic arm while ensuring that it moves accurately to the target positions. It starts with the main process, then initialization of the system where the parameters, sensors, and motors to be used are made ready in the system. The system then comes to the main task – it goes into an endless cycle or loop where there is constant feedback and control of the motion of the robotic arm. In this loop, there is a juncture which poses the question of whether the arm has attained its Last Position or the target position by assessing the final position against the current position. Should the position be achieved, the control systems logic is applied in order to regulate or enhance the arm to the desired position. If this is not the case, then the loop continues to execute its order and pushes the arm further and closer to the target position. In this way, permanent control, evaluation and modifications in real time are possible and are used in control of the robotic arm.

B. Hardware specification.

Fig 4.0 STM32F446RE

Table 1: Hardware specifications

Processor	STM32F446RE
Processor features	Arm Cortex-M4 core with DSP and FPU, 512 Kbytes of Flash memory, 180 MHz CPU, ART Accelerator
Communication interfaces	2 x CAN bus (CAN2 transceiver is not soldered), 1 x USB
Stepper drivers	TMC5160
Stepper drivers features	SPI comms, 10-35V, 3A max, protection features
Inputs	2 x ISOLATED
Ouputs	2 x ISOLATED, 0.5A current output
Estop input	Dedicated pin on MCU for ESTOP interrupt, 2 ESTOP connections on control board
Power supply	18V minimal, 24V maximal voltage
Stepper drivers	Rated current 2.5A, maximal current 3.6A (Short burst or extreme cooling)
Isolated Inputs voltage	24V nominal voltage, min 12V max 50V
Isolated Outputs voltage	Max 48V
Cooling fan	Maximal allowed current draw for cooling fan is 0.3A

C Motor Driver

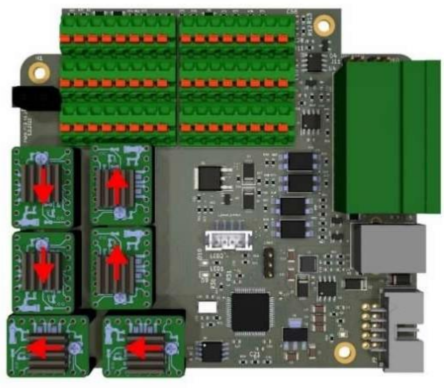

Fig 5.0 Motor Driver

The above Figure 5.0,depicts the motor driver board which can be used for multiple motors hence can be used for robotics and industrial automation. It has the number of green terminal blocks for the connection of motors which provides the opportunity to control multiple motors. There are clamping connectors to make sure that the motors are securely connected for optimal performance to take place. The areas outlined by red arrows could perhaps be where individual motors' driver modules are situated such as H-bridges or MOSFETs and these can control the motors RotatingSpeed and direction via PWM Signals.

There are also such interface connectors and pins included on the board allowing it to be interfaced with a microcontroller or main processing unit such as Raspberry Pi, or an Arduino which shall command the control signals for the movement of the motors. To ensure that motors are properly operational, a dedicated power connector is available which means that most of the motors require higher voltage and current than whata microcontroller can produce.

Diodes to suppress hiking voltage that is related to inductive motors further too are other protective elements that may be found on the board together with other feedback elements such as current sensing as motor load was being monitored. It can be assumed that the middle part of the integrated device that contains a microcontroller manages the control logic, which enables the input signals to direct the motor and its movements. This motor driver board is vital to controlling the six degrees of freedom of the robotic arm with precision motion control needed for positioning or manipulating an object.

D. Kinematics

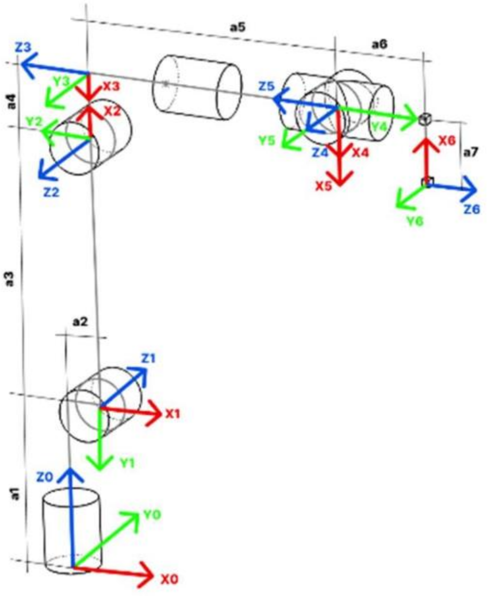

Fig 6.0 Kinematics Diagram

Forward kinematics

Forward kinematics is a fundamental concept in robotics that involves determining the position and orientation of a robot's end effector (such as a gripper or tool) based on the known joint angles and link parameters. In simpler terms, it's the process of calculating the robot's pose (position and orientation) in space given the joint configurations. The forward kinematics problem is about understanding how the robot's various joints and links combine to determine the position and orientation of the end effector. It's like tracing the path of the robot's movements to find out where its hand or tool ends up.

Inverse kinematics

Inverse kinematics is considered part of the inverse kinematics chain, which can determine parameters or angles of movement in a smooth robotic structure, allowing an end-effector to reach a predesigned position and/or orientation. In other words, it is the working of finding a particular configuration of joints that will cause the end effector such as the tool or the hand of the robot to move to a specified position that has a defined orientation as well. As illustrated in the Figure 6.0, the case of a robotic arm, forward kinematics is the calculation of the end effector's (hand/working tool) position and orientation, depending on the joint angles that are set. And looking now at the situational awareness of inverse kinematics, we can summarize that it's working the other way around: the position and orientation of the end effector are given and the task is to define the joint angles which will cause the particular ending position of the end effector. Inverse kinematics can be regarded as trivial or more or less complicated for a 3 DOF simple robot, but relative to a more complex robotic system with multiple joints and almost infinite degrees of freedom, it can be deemed upland strenuous. Solving inverse kinematics is basically the reality of being able to find the roots of nonlinear equations for given x-joint angles that determine the variables set alongside the actual pose that's well desired. Depending on how the robot is configured and depending on the task itself, these more or less defined mathematically systems can produce multiple solutions, a single unique solution, or no solution at all.

E. Robot Specifications

The below Figure 7.0 shows the Schematic model of the robotic arm.

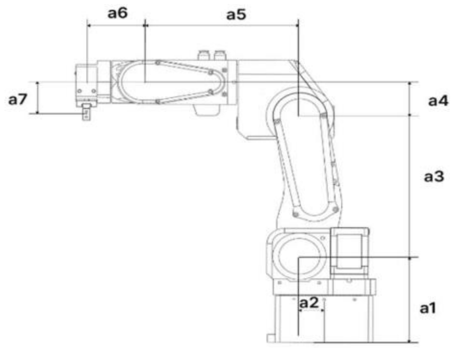

Fig 7.0 Design

Table 1: Robot specifications

Payload	1 Kg
Weight	5.5 Kg
Degrees of freedom	6 rotating joints
Motors	Steppers
Gearboxes	precision planetary and bets
Position sensing	Limit switches for open loop version
Drivers	Open-loop stepper drivers for open loop version

III. FINDING FROM LITERATURE SURVEY

1. In the reviewed research paper, the authors put forward a concept of a robotic arm, controlled by natural human fires of the arm, using accelerometers to record data of arm movement. The accelerometers are interfaced with a microcontroller for the motion of the robotic arm. The focus is to build a prototype capable of

performing tasks it is unsafe or impossible to do them by physical means such as depositing or retrieving certain objects. This approach increases the potential of robotic systems in situations where people cannot or VKK are scarce. [1]

2. MRD examined the problem of controlling a 6– axled robot arm by means of radio frequency – RF link involving the use of wireless technology. It includes a glove with stress sensors and Arduino Uno and RF transceiver module that transmits to a receiver source connected to Arduino Mega. The data received is then utilized to carry out the motion of the robotic arm. The outline describes closely the steps in data creation using the flex sensors, data transmission over RF and controlling the robotic arm on receiving signals. [2]
3. The authors of the research paper under review argue that the previously unavailable technology IoT could be used to remote actually replicate human hand movements through a robotic arm manipulating them. The design features five end- effectors and employs generative modeling to achieve elements with minimal weight and cost. The hand's movements are recognized by a trained neural network that is used in a Python application. This method enhances efficiency of costs, data transmission, data collection, and availability, in relation to the available computing power and the pace of technological advancement compared to previously used methods of operating the robotic hand [3][17].
4. The study focuses on a pick-and-place type of robotic hand manipulator for automation of product management in a storage which is currently in the age of the Fourth industrial revolution. The text deals with the impact that automated technologies such as intelligent machines, IoT, or AI might have on industrial production processes. The paper discusses the design of a 5-DOF robotic manipulator incorporated in the undertaking to simplify the complicated routing of warehouse process automation. For reliable performance of the system's implementation, mathematical modeling was done and the prototype was constructed for testing. A mobile application for remote control through GSM is also presented for the purpose of improving the accuracy and efficacy of warehouse management.[4][19].
5. The research examines a new structure aimed at the evaluation of picking actions of industrial robots, mainly, robotic manipulators, which are being developed in order to maximize the level of automation in extremal conditions. It provides information about the current works which are being done for the integration of human like features and sophisticated functions in the industrial robots enhancing the efficiency and quality of the products. Such advances are nevertheless not changing the appearance of more contemporary industrial robots which are distinctively non-human but rather consist of manipulator designs which are made out of rigid links and joints that are rotatable. The paper focuses on the design of a 6-axis Force/Torque robotic arm, designed for pick and place operations including loading and packaging processes, and discusses the primary design requirements imposed on the machine in order to provide the necessary level for handling of loading tasks. [5]
6. A remote robotic arm controlled via cloud computing and IoT shows a concept in which an Arduino microcontroller is deployed for pick- and-place operations upon receipt of web commands. This system is an Internet-controlled system that employs a web server designed using HTML and provides control over the robotic arm's servos to achieve required movements. The arm, designed with four servos allowing horizontal movement, joint articulation, and grasp ability, is connected to a wireless network for seamless communication. To keep the system safe during operation, ultrasonic sensors are used to confine the robot's working area. The design process employs simulation in Proteus, to validate the control mechanisms before hardware implementation. This method shows a perfect side of integrating cloud-based control with robotics to enhance industrial automation. [6]
7. The study presents a process for the development of a system with gesture control for reliable and accurate motion in fixed fields. This research portrays the challenges with gesture control, although intuitive, as it may be highly susceptible to misinterpretation with minute disturbances. Which accepted into this study is supposed to tackle such problems by designing a modular firm structure to resist interference and enhance accuracy. The reliability of the system is verified through a range of tests, simulation, and practical experiments. The work receives more attention as it integrates all essential technologies, including the basic sensory systems, the image processing, the actuators, and also the communication via ROS2 for the simplicity and the user-friendly measurement. The result enhances precise motion control in robotic systems through practical solutions. [7][18]
8. Combining the advantages of 6-DOF robotic arms with their phenomenal use in complex environments for achieving precision and accuracy beyond that of human capability has attracted priority of interest in recent years. Traditionally, robotic arms have relied on thewired teach pendants or computer systems to

control them, which can limit some situations where a wireless control over short distances is needed. For precise control of robotic arms, remote data transfer in real-time is an essential, allowing operators to manage these systems fromvirtually any position.[8]

9. IoT technologies and web applications have contributed as a solution to address the issues of near real-time data transmission and multi- platform control interfaces. An advance in this direction is the design and implementation of web-based robotic arm control employing the MQTT (Message Queuing Telemetry Transport) communication protocol with the ESP8266 network data transmission module. In this regard, a robotic device can be controlled platform- independently, thus accurate and real-time manipulation provided from a distance. Using these technologies will allow their operators to increase versatility and efficiency in conducting tasks using robotic systems.[9]
10. This article presents a project-based learning experience developed at the University of Lleida, Spain, to involve Spanish students in the design and implementation of better mechanisms for enhancing the levels of student motivation. The project is based on completely autonomous, self- sustained video cameras. The only purpose of these cameras is to detect movement of small objects placed randomly on a surface. A computer vision system is used to process and analyze the images, and the corresponding outputs obtained from it are used to make the robot pick and place the object detected in a bin. The robot is an educational robotic arm available in the laboratory, while the computer vision system uses the OpenCV library. The activities motivated students to experience computer vision and robotic control concepts with minimum resources. The results support the observation that students learn more complex technical concepts through practical activities. [10]
11. The paper gives an overview of a robotic system capturing grasping actions evaluated on initial industrial products. The objective of the research is to bring the grasping operations on a level of closer resemblance to the abilities required in real industrial environments. Nowadays, the research and development of industrial robots is adapting as robots are required to adapt and are even expected to perform similarly to human operators. Nevertheless, it is recognized that industrial robots do not have a passive mechanical structure. On the capital level, the robot manipulator, or robotic arm, is made up of interconnected links - usually called a chain - giving it the appearance of a limb. The robot can have more or less freedom in motion according to the number of axes the robot uses. An end effector is attached to the last axle of the robot's waist. It can be a welder, a grinder, or, in this case, a 6-axis Force/Torque pick-and-place robot for product loading and product installation. The difference between industrial applications and the previously mentioned unstructured environments is that before the robot starts a new task, the designer needs to know what force levels the robot is submitting. In the case shown here, the part is inserted in the collet. First, the robot tries to grip the object by descending to the collet. However, the sheet metal is still resisting, preventing it from being fixed too tightly to the collet. Now, a new feature can be added, but if the robot does not know how much force the robot is applying to the part, it is difficult to adjust the grip space. The robot, shown in previous pictures with its green-grey five-axle arm configuration, features a sixth axle (the black one located to the right). If transferred onto the picture on the left-hand side to a Virtual Reality, the designer is now able to place a blue cylinder on top of the image. This allows the designer to view the part standing on the to the collet spine. [11]
12. This paper outlines the design and development of a robotic arm that can be deployed in disaster relief operations during situations, such as earthquakes, when humans are unable to get there. This paper describes a system that detects and approaches the objects, using an on-board infrared sensor to enable safe transportation of these objects. It's a device designed to grab objects from awkward angles and orient them, precisely to certain sizes. Important elements covered are the design of a robotic arm, the working mechanism of the system and the block diagram that reflects its architecture. Results from experiments using a 1:25 scale simulation model identified less than 1 deviation (horizontal, vertical and diagonal placements), forming the basis for its potential applicability in disaster response environment. [12]

IV. FUTURE SCOPE

Implementing the six-axis gesture-controlled robotic arm opens up an array of possibilities for future developments and improvements. One potential improvement could be to use better and more advanced AI algorithms like those based on deep learning techniques, which can significantly enhance the accuracy of gesture recognition and object classification. This would allow the robotic arm to perform tasks that are more complex and have applications in relatively larger industry as well as in medical practice. Furthermore, sensors such as force feedback sensors and 3D vision can be added to increase the robot's accuracy and assurance when interacting with gentle, complicated, and irregularly shaped objects, which would be greatly useful in surgery and precision manufacturing. Another possibility is to design a wireless interface with cloud processing, so that the user can remotely monitor almost real-time positions of the robotic arm, and allows minimal latency with controlling the robot. This approach would be really helpful in hazardous environments, where human interface is needed to be minimal. The system can also be made adaptive by learning from the human interaction. By integrating machine learning techniques, the robotic arm can calibrate itself and also optimize the task such that different parameters ensure the best possible outcome especially in industrial use. Lastly, the cost of the system can be significantly reduced and the complexity of the system can be minimized. By integrating the concept and using the framework of edge computing, the cost of the system can be brought down significantly. The hardware can be optimized to make the design aesthetically better and more homogeneous. The use of open-source software for supporting vector machine, deep learning algorithms and classification algorithms can further decrease the cost and make it accessible to small and medium-sized industries, and healthcare as well as for educational purposes.

V. CONCLUSION

It is apparent from the literature review that the demand for sophisticated robotics systems that can take on the disadvantages of automation (inefficiencies and dangers of manual labour) in industry and medicine is rising. The 6 Degree-of-Freedom (DOF) gesture- assisted robotic arm that is part of this work is a positive attempt to mitigate these limitations. Gesture recognition, modular software development with ROS
2 and AI-powered image classification help ensure accurate and natural control of complicated pick-and- place. Gesture-based input makes it natural and easier for the operator to interact with the robot arm, reduces the learning curve, and opens the system up for a variety of uses. Moreover, with real-time monitoring and feedback functions, the system stays very accurate and safe throughout the run.

The AI-powered image classification feature makes the robot arm’s ability to manipulate items based on color, shape, and size an intelligent addition to the automation. This not only streamlines work but makes the robotic system scalable to multiple high-paced industrial workflows, different objects and handling scenarios. With the software architecture being built on ROS 2, you can build your system as modular and scalable as you need it to be and have new features or add-ons without a lot of hassle. Both the steady power supply and optimized communication protocol are also responsible for high-load performance of the robotic arm. Eventually, the project offers a one-stop solution to the challenges that have been reported in the literature, as well as a foundation for further human-robot and automated system improvement.

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