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STUDY OF VISION BASED OBJECT SORTING ROBOT MANIPULATOR

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Abstract

The development of vision-based object sorting manipulators has significant attention due to their potential applications in various industrial and domestic environments. The study presents a comprehensive framework for a vision-based robotic manipulator designed for sorting objects based on their visual characteristics. The system integrates advanced image processing techniques and machine learning algorithms to identify and classify objects in real- time. Key components include a high-resolution camera, a robotic arm equipped with multi- degree-of-freedom manipulators, and a central processing unit for data analysis and control. Once an object is classified, the robotic arm, guided by precise control algorithms, sorts the objects into designated categories. The vision-based sorting manipulator shows promise for enhancing automation in manufacturing, recycling, and inventory management, providing a robust solution for efficient and intelligent object handling. Through the project, students engaged in a cross-functional team approach via the 3D EXPERIENCE platform, gaining hands-on experience with DELMIA software and robotic simulation, as well as developing an image classifier AI model. These practical experiences underscore the project's educational and technological contributions to the field of automated object sorting.

1. Introduction

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The most aged method of sorting products is by manual picking and placing of objects. Sorting operation is generally conducted manually, but it can be conducted using mechanical, pneumatic, and hydraulic means also. Currently, the operation is performed manually at the industry but a slower rate and less accuracy. There is a fair chance that automating this process might speed up the rate of work when compared to the manual execution. To overcome these disadvantages, the entire manual process in the sorting process is to be automated. In this project, a pick and place machine is designed to lift the objects that need to be sorted precisely. Suction cups are designed as holders for these machines to hold the objects and place it on separate bins for packaging. The Vision-based Object Sorting Robotic Manipulator project represents a cutting-edge integration of computer vision and robotic manipulation technologies to automate the sorting process in various industries. This innovative solution aims to enhance efficiency, accuracy, and speed in sorting objects based on their visual characteristics. At its core, the project relies on a sophisticated combination of hardware and software components. The robotic manipulator serves as the physical arm responsible for picking up and placing objects, while computer vision algorithms analyze visual input to make intelligent sorting decisions. The hardware setup includes a robotic arm equipped with grippers, cameras for vision sensing, and a processing unit to execute the control commands. The grippers are designed to securely hold diverse objects, promoting adaptability in handling a range of items. The cameras capture high-resolution images of the objects to provide detailed visual information for the sorting algorithm. The key enabler of this project is the computer vision algorithm, which acts as the brain of the system. Initially, the algorithm processes the visual input to identify objects, relying on image recognition techniques. Deep learning models play a pivotal role in training the system to recognize specific objects based on their visual features. Once the objects are identified, the algorithm then determines the sorting criteria. This could involve classifying items based on color, size, shape, or other relevant attributes. The flexibility of the algorithm allows for customization to meet the specific requirements of different industries. The decision-making process involves a feedback loop where the algorithm continuously refines its understanding of objects through iterative learning. This ensures adaptability to variations in object appearance and the ability to handle a dynamic sorting environment effectively. The integration of machine learning with the robotic manipulator allows the system to learn from experience, improving its sorting accuracy over time. This adaptive capability is crucial for handling diverse objects and accommodating changes in the sorting criteria without requiring reprogramming. Efficiency is a key highlight of this project. The parallel processing capabilities of the algorithm enable real-time decision-making, ensuring rapid and continuous sorting operations. This efficiency contributes to increased throughput and productivity in industrial settings, making the system an asset for manufacturing and logistics operations. Moreover, the project addresses the need for precision in object manipulation. The robotic manipulator's movements are orchestrated with precision, avoiding damage to delicate items, and ensuring the accurate placement of sorted objects. This level of control is particularly advantageous in industries where the integrity of products is paramount. In terms of applications, the Vision-based Object Sorting Robotic Manipulator finds relevance across various industries such as e-commerce, manufacturing, and recycling. In e-commerce warehouses, the system can streamline order fulfillment by automating the sorting of diverse products. In manufacturing, it enhances assembly line efficiency by automating the segregation of components. In recycling facilities, the system aids in the separation of recyclable materials based on visual characteristics.

1.1 Background

The research is discussed mainly on design and structural analysis of a robotic arm, which reduces the man power and have a good effect on production rate. This change can motivate the industry and academics such that the business of the firm is increased. The development in automation can reduce the revenue cost and raise in capability of delivering the services at low-cost scaling. To look at the safety of the workmen, we designed a pick and place operator i.e. a robotic arm and for the feeding mechanism pneumatic suction cup is designed. The research considered about RCC control for designing the robotic arm. In this the system integrates manipulator position sensor into the robots control routine. It also gives the robot its ability to interact with nature. So, depending upon these conditions the manipulator makes it more efficient by providing self-optimization system. With this self-awareness of the robot there will be 11 work safety in the environment onsite. Due to this RCC the efficiency of the manipulator increases. To design these RCC model we need to compare with revolutionary symmetric structure and circular periodic structure, due to this we can achieve low stiffness and material will remain same. Before designating about the pick and place operators, we have undergone various methods like use of conveyor belt, pulleys, and other simplified mechanisms for this operation. But after a broad search and enquiry, we decided to design an articulated robotic system that makes the entire process more flexible and easier in inducing the mechanism without any employee payload. The reason for selecting only this robot as a solution depends upon many factors. The transportation of objects in this process is done using a gripper with suction cups connected to a conveyor belt. Our main motive is to reduce the risk factor involved physically in this operation. So, we took a forward push of designing a six jointed robotic system with good and malleable end effector to it. Basically, in our study the articulated robots are of rotary joint system, that can range from two to ten jointed and are mechanized by servo motors. They are various robotic systems, which could be articulated and non-articulated. But according to our operation we prepared rotary joint system which is articulated, in this the space consumption is précised as the joints are supported in chain. The major factors of initiating this system are it is having a continuous path, acceptable degree of freedom, proper grip, cyclic rotation, good accuracy and reach, speed control, repeatability, and high resolution.

1.2 Articulated Arm Robots

Articulated arm robots are generally used to perform risky, treacherous, and highly repetitive and obnoxious works. This entire system is controlled by a trained operator using a portable device like a teach pendant to a robot to do its work manually. The main prospective is not the working of the robot, but how it is to be safeguarded in a regular usage in the industries. The maintenance depends only on technical operators, how hazardous the use of the robot system is its environment conditions, position, initialization requirements, technical errors, and other functions. While many engineers working on these robot systems they could be associated with risks in the operation. In this combination, they need to use safeguarding methods like repetition and backup systems and the entire thing should be monitored by a human operator. As the entire system is to be controlled by an electric device, they are two controllers' servo and non-servo. The use of servo controller gives immense feedback about the robot system and that continually monitors the robot axes which are correlated with the position, velocity and the entire data is stored in the robot's memory. Articulated robots are among the most common types of industrial robots use today, known for their versatility and range of motion. They have a series of joints (often referred to as axes) that allow them to move in multiple directions. Here are the main types of articulated robots based on the number of axes they have:

1. Four - Axis Articulated Robots:

These robots have four degrees of freedom and are commonly used for simpler tasks where the additional axes of more complex robots are not necessary. Applications: They are often used in packaging, palletizing, and simple assembly tasks.

2. Six - Axis Articulated Robots:

The most common type of articulated robot, these have six degrees of freedom, allowing for a wide range of movements. The six axes typically correspond to the ability to move up and down, left, and right, forward, and backward, and rotate on three perpendicular planes. Applications: Widely used in industries for tasks such as welding, painting, assembly, pick and place, and machine tending due to their flexibility and precision.

3. Seven -Axis Articulated Robots:

These robots include an additional axis, often referred to as a redundant axis, which provides even greater flexibility and dexterity. This extra axis can allow the robot to navigate around obstacles and perform more complex movements. Applications: Suitable for tasks that require navigating tight spaces or complex maneuvers, such as in automotive assembly, aerospace applications, and advanced manufacturing.

4. Other Multi-Axis Articulated Robots:

Description: While less common, robots with more than seven axes exist, providing specialized capabilities for tasks. These robots can offer even more flexibility and control for intricate applications. Applications: Highly specialized tasks in industries such as aerospace, research and development, and custom automation solutions.

2. Literature Review

The development of vision-based object sorting robot manipulators has roots in several key areas:
2.1 Mechanical Design: The most important aspect and backbone of this thesis is the mechanical

design of the robotic arm. A robotic arm has certain design specifications and certain parameters are to be taken into the consideration. Since, the design is an area related to thought, many varieties of designs come to the mind at the initial stages of the design [1]. Everything might not be fruitful and the trial-and-error method cannot be trusted blindly. So, keeping all these things in mind, we have decided to design the robotic arm whose dimensions are loosely based on the dimension standards of Fanuc robotic arm [2]. The basic points to be noted and followed for the design are:

A] Functionality: The arm should have the ability to lift, move, lower, and release an object while closely mimicking the motion of the human arm with full extension. Any device that can perform the required motions to pick and place an object required would have met the requirements of this criterion [3] The choice of the number of the parts in this robotic arm is taken by comparing it with a human arm. Let the action of human hand picking up a container appear in your mind. We have the waist, shoulder, elbow, arm, wrist, and fingers do the job. This is the motivation for the choice of the number of parts. This robotic arm also has 7 parts and 7 joints which are pretty much like the human hand.

B] Reliability: The device should be able to consistently pick up and place objects in a smooth manner. i.e., the motion of the device should be smooth enough to not drop the objects that are being lifted [4] Therefore, any device that can lift and move an object from one place to another without losing any grip would meet the criteria. After a detailed study, the choice of end effector is made. Since, this device is used for picking and placing variety of objects, the option in front of us was to use suction cups to lift the objects. This is the most used technique for the transportation objects in industries all over the world. So, we had decided to use this technique for this purpose. Also, the industry also had the use of suction cup and a linear robot for the transportation of object in the picking and packaging process so we have enough motivation and data to use this technique [5].

C] Motion Range and Speed: Like human body the robots are constructed with same joints between bones, here we have a constrained limit for the movement of axis. In our design application, every axis has its own capacity of motion. The degree of movement of robot is calibrated from centre base of axis. By this the speed in pick and place operation might vary, and this is occurred because each axis moves at different speeds. The complete motion of the operation is recorded in terms of degrees travelled per second [6].

D] Payload: The limited weight of each robot is its payload. So, the critical specifications and tooling weights are sotted out. The payload refers to the maximum weight that the robot's wrist can support, including not only the workpieces but also any end-of-arm tooling (EOAT) and bracketing integrated with the robot wrist. It is essential to accurately calculate and set the payload to ensure optimal performance and avoid potential issues. When selecting a robot for a particular application, considering the payload capacity is crucial. Choosing a robot with an inadequate payload can lead to application failure, potential damage to the robot, or even safety hazards. On the other hand, selecting a robot with a payload capacity that exceeds the requirements can result in inefficiencies, increased cycle times, and unnecessary floor space utilization. Therefore, it is essential to find the right balance and select a robot with the optimal payload capacity. Setting the correct payload is not just about determining the weight that the robot can carry. It also plays a vital role in ensuring safety, especially in collaborative robot environments where human-robot interaction is anticipated. By setting the payload for each motion, the robot becomes aware of the weight it is carrying and the forces it should be experiencing. If the applied force exceeds the predefined safety setting, the robot can react accordingly, such as slowing down or stopping to prevent accidents or injuries. Therefore, setting the payload accurately is crucial for maintaining a safe working environment. In addition to safety considerations, the payload setting also affects the robot's acceleration. The robot needs to be aware of the payload it is carrying to ensure proper acceleration without overloading the motors or causing undercurrent issues. If the robot is programmed with a higher acceleration setting while carrying a heavy payload, it may trigger overcurrent warnings or emergency stops. Conversely, if the robot thinks it has a certain payload but is carrying a lighter load, it may accelerate too quickly, leading to collisions or misalignments. Therefore, accurately setting the payload is crucial for maintaining smooth and controlled acceleration [7].

E] Reach: In the articulated robot, we need to check the two extremities that is nothing but the V-reach and H-reach. Vertical reach is considered to know how high our robot can go in terms of height extension. Whereas the Horizontal reach is considered to know the distance of fully extended arm from base to wrist. In few other applications, we need to even consider a short Horizontal reach.

F] Axes: The distinctive segments of our robot are associated with mechanical joints, that serves as an axis of movement. We have designed our articulated robot with 6-axis of movement.

3 Methodology

3.1 Operations performed:

They studied introduction to the whole ecosystem of 3D Experience Software by Dassault Systems. Based on the selected problem statement, i.e., Vision Based Object Sorting Robotic Manipulator and learnt about types of robots, manipulators, the scope of AI and automation in the process. Later, the company organized a 2-day seminar where they taught us how to use variousparts of 3DExperience Software and the related tools (CATIA, DELMIA, SIMULIA). Next, we explored how such a manipulator can be applied to be used in real life situations. After putting thought into it, we decided to pursue this project under Packaging and Logistics. To be specific we decided to automate packaging and sales in Malls and shopping complexes using Bin Picking and Packaging. Later designing of the components was started based on literature review and other available data. Designing of all components of the robot, its assembly, simulation, and digital manufacturing was carried out using the 3D Experience Platform by Dassault Systems.

3.2 Software used in the project are:

- **CATIA V5:** Computer Aided Three-dimensional Interactive Application (CATIA) is a computer-aided design software developed by Dassault Systèmes. It is primarily used to design, simulate, and analyze complex engineering systems, such as aircraft, ships, cars, industrial machinery, and consumer goods.

- **DELMIA:** DELMIA, a brand within Dassault Systèmes, is a software platform designed for use in manufacturing and supply chain professionals. It offers various tools encompassing digital manufacturing, operations, and supply chain management, including simulation, planning, scheduling, modeling, execution, and real-time operations management.
- **SIMULIA:** SIMULIA simulation software accelerates the process of evaluating the performance, reliability and safety of materials and products before committing to physical prototypes. Explore the engineering disciplines that we support.

A universal robot design (UR5) with a rated load of 5 kg was used as a reference to create the basic structure of our manipulator. Later, various claw designs were explored for grasping the objects to be sorted/manipulated. A 3 fingered claw was employed in this case.

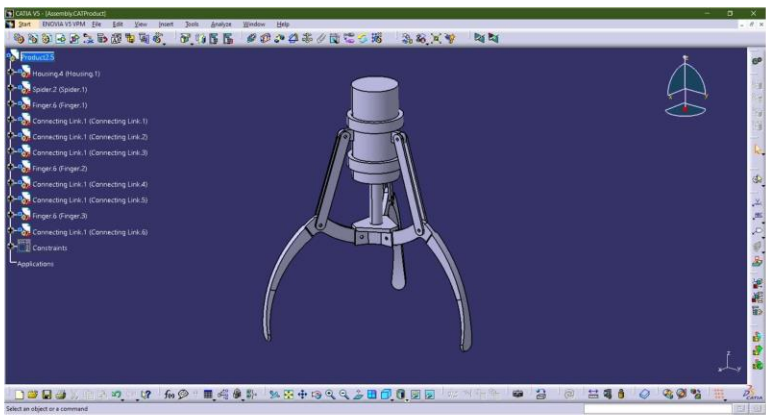

Fig. 1. Gripper open position

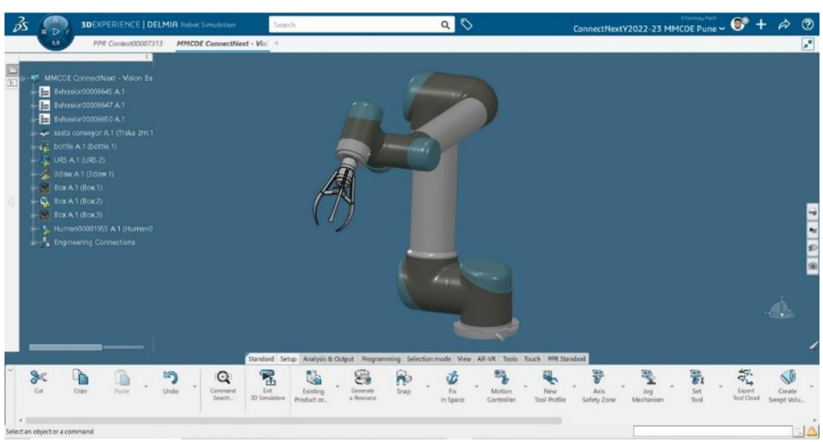

Fig. 2. Final Assembly

3.4 Forward and Inverse Kinematics:

Kinematics is the study of motion without considering the cause of the motion, such as forces and torques. Inverse kinematics is the use of kinematic equations to determine the motion of a robot to reach a desired position. For example, to perform automated bin picking, a robotic arm used in a manufacturing line needs precise motion from an initial position to a desired position between bins and manufacturing machines. The grasping end of a robot arm is designated as the end-effector. The robot configuration is a list of joint positions that are within the position limits of the robot model and do not violate any constraints the robot has.

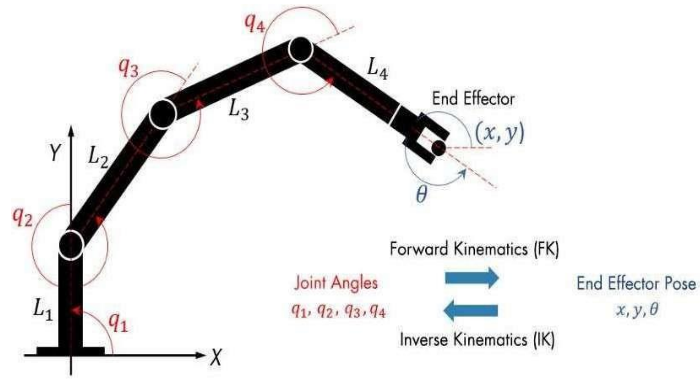

Fig. 3. Kinematics of Robot

In contrast to forward kinematics (FK), robots with multiple revolute joints generally have multiple solutions to inverse kinematics, and various methods have been proposed according to the purpose. In general, they are classified into two methods, one that is analytically obtained (i.e., analytic solution) and the other that uses numerical calculation. To approximate a robot configuration that achieves specified goals and constraints for the robot, numerical solutions can be used. Each joint angle is calculated iteratively using algorithms for optimization, such as gradient-based methods.

Numerical IK solvers are more general but require multiple steps to converge toward the solution to the non-linearity of the system, while analytic IK solvers are best suited for simple IK problems. Numerical IK is more versatile in that robot kinematic constraints can be specified and external constraints, like an aiming constraint for a camera arm to point at a target location, can be set to IK solvers. Determining which IK solver to apply mainly depends on the robot applications, such as real time interactive applications, and on several performance criteria, such as the smoothness of the final pose and scalability to redundant robotics systems.

4. Conclusions

An object sorting robot manipulator can greatly improve the efficiency and accuracy of sorting objects in various industries. Such a robot manipulator typically consists of a robotic arm, a gripper or end-effector, sensors, and a control system. By using advanced sensors and algorithms, the robot can accurately detect and classify objects based on their shape, size, color, and other characteristics. The gripper can then pick up the objects and place them in the appropriate location, such as a bin or conveyor belt. The use of a robot manipulator for object sorting can improve the speed and accuracy of the process, while also reducing the risk of injury or strain for human workers.

Additionally, the robot can operate continuously without the need for breaks or rest, allowing for a more efficient and productive workflow. Overall, the object sorting robot manipulator is a valuable tool for various industries, including manufacturing, logistics, and warehouse management. As technology continues to advance, we can expect to see more advanced and capable robot manipulators that can handle increasingly complex sorting tasks with greater speed and accuracy.

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