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Design of a Robotic Pick & Place Mechanism for Replacing the Manual Handling of Milk Powder Tin Cans

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Abstract: Automation has become an important part of modern industries as it helps improve efficiency and maintain consistency in repetitive tasks. Pick-and-place operations are widely used in packaging and material handling, where objects need to be moved from one place to another accurately and repeatedly. When these tasks are performed manually, they often lead to variations in cycle time, worker fatigue, and a higher chance of errors.

In this project, an automated pick-and-place system is designed to handle cylindrical containers in an efficient way. The system uses a hybrid Cartesian robotic mechanism, combining linear motion for positioning and rotary motion for orientation. A vacuum-based gripper is used to lift and hold the containers securely. Proper calculations are carried out to determine the required vacuum pressure based on the weight of the containers and the suction area, ensuring safe and reliable operation.

The developed system improves placement accuracy, reduces the need for manual effort, and provides consistent performance. In addition, cost analysis shows that although the initial investment is required, automation offers long-term economic benefits by reducing labor costs. Overall, the system presents a practical and reliable solution for automating repetitive packaging operations.

I. INTRODUCTION

In today's manufacturing environment, automation plays a key role in improving productivity, accuracy, and overall consistency. Many industrial processes involve repetitive tasks like pick-and-place operations, especially in packaging and material handling. When these tasks are done manually, they often lead to variations in cycle time, inconsistent placement, and physical fatigue for workers over time.

Pick-and-place operations involve moving objects from one location to another in a controlled and precise manner. In many industries, cylindrical containers are transferred from a conveyor system and arranged into specific positions inside packaging boxes. This process requires accurate movement in different directions, and in some cases, proper orientation of the containers before placing them.

However, manual handling of such tasks can result in inconsistent performance due to human factors. Differences in speed, coordination, and fatigue can affect both efficiency and standardization. As production demand increases, maintaining uniform cycle time and high accuracy becomes more difficult with manual systems.

To overcome these challenges, this project focuses on designing an automated pick-and-place robotic system for handling cylindrical containers. The system combines linear motion for positioning, rotary motion for orientation, and a vacuum-based gripping mechanism to ensure secure and accurate handling. Proper design considerations are taken to achieve stable and repeatable operation.

The main aim of this project is to develop a reliable and cost-effective automation solution that improves efficiency, reduces manual effort, and ensures consistent performance in repetitive packaging operations.

II. BACKGROUND OF THE SYSTEM

Pick-and-place mechanisms are commonly used in industrial environments to move objects from one position to another. These systems are often connected with conveyor lines, where products move continuously and need to be arranged or packed in a specific pattern. The overall performance of such systems depends on how accurately the objects are positioned, how consistent the cycle time is, and how safely the objects are handled during the process.

Handling cylindrical containers comes with its own challenges because of their curved shape and possible orientation requirements. In many cases, containers are picked in one position and need to be placed in a different orientation. This means the system must not only move in straight directions but also have controlled rotational motion to properly align the containers before placing them.

When this process is done manually, it often leads to variations in placement accuracy and cycle time. Human factors like speed, coordination, and fatigue can affect the consistency of the operation. Over time, repetitive lifting and positioning also increase the chances of errors such as misalignment or improper placement. Automated pick-and-place systems help overcome these issues by combining mechanical design, motion control, and effective gripping mechanisms. Linear motion ensures accurate positioning, while rotary motion helps in adjusting orientation when required. The gripping system must be strong enough to hold the containers securely without damaging them. In this project, a robotic system is designed by integrating linear movement, rotary control, and a vacuum-based gripping mechanism. The goal is to achieve efficient, accurate, and repeatable handling of cylindrical containers within a defined working area.

III. CURRENT SCENARIO (EXISTING SYSTEM)

In the current setup, the pick-and-place operation is carried out manually by workers. Cylindrical containers move along a conveyor and need to be arranged in a fixed grid pattern inside cardboard boxes. Each box contains multiple containers, and proper alignment is important to ensure good packaging quality.

At present, four workers are involved in this process. They pick the containers from the conveyor, adjust their orientation if needed, and place them into the boxes. On average, it takes around 23 to 25 seconds to complete the packing of one box.

While the system works, several issues can be observed. Since each worker operates at a slightly different speed, the cycle time is not consistent. Some boxes are filled quickly, while others take more time, which leads to an uneven production flow. This makes it difficult to maintain a steady and predictable output.

Another challenge is the physical effort involved. Continuous lifting and placing of containers over long hours leads to fatigue. As workers get tired, the chances of errors such as misalignment, incorrect placement, or even dropping containers increase. This directly affects both the quality of packaging and overall efficiency.

The system also relies completely on human coordination. During high production demand, it becomes difficult to maintain both speed and accuracy consistently. So, even though the manual system is simple, it lacks consistency, scalability, and overall efficiency.

IV. PROBLEM IDENTIFICATION

Based on the analysis of the existing manual system, several technical and operational issues have been identified. These problems directly affect productivity, consistency, and system efficiency.

1) Inconsistent Cycle Time: The time required to complete one packaging cycle varies between workers. Since each individual operates at a different speed, the overall output rate is not standardized. This variability makes it difficult to maintain a fixed production schedule.
2) Lack of Placement Accuracy and Uniformity: Manual placement may result in slight misalignment of containers inside the box. Improper alignment can affect packaging stability and stacking performance during transportation.
3) Worker Fatigue and Physical Strain: The repetitive nature of picking, lifting, and placing containers leads to physical fatigue. Over extended periods, this reduces efficiency and increases the likelihood of errors.
4) Higher Probability of Human Error: Fatigue and repetitive motion can cause accidental dropping, incorrect orientation, or improper arrangement of containers. These errors impact quality and may lead to product damage.
5) Difficulty in Handling Increased Production Demand: During periods of high demand, maintaining consistent speed and accuracy becomes challenging in a manual system. Scaling the process requires additional manpower, which increases operational cost.
6) Recurring Labor Cost: The manual system requires continuous labor expenditure. This results in high long-term operational cost compared to a one-time investment in automation.

V. NEED FOR AUTOMATION

1) Considering the limitations of the existing manual system, automation becomes a necessary step to improve overall efficiency and reliability. Repetitive pick-and-place operations are well-suited for robotic automation because they require consistent motion, fixed positioning, and predictable cycle time.

2) One of the primary reasons for automation is to achieve standardized cycle time. Unlike manual operations, an automated system operates with a programmed sequence, ensuring that each cycle is completed within a fixed and repeatable time interval. This improves production planning and ensures a steady output rate.
3) Automation also significantly improves placement accuracy and repeatability. Robotic systems follow precise positional commands along defined axes, ensuring uniform arrangement of containers inside each box. This eliminates misalignment and improves packaging consistency.
4) Another important factor is the reduction of human fatigue and errors. By replacing repetitive lifting and placement tasks with a robotic mechanism, physical strain on workers is minimized. Human involvement can then be shifted toward supervision and quality control rather than manual handling.
5) From an economic perspective, automation converts recurring labor expenses into a one-time capital investment. Although the initial setup cost may be higher, long-term operational savings and increased productivity make the system financially beneficial.
6) Furthermore, automation allows easy scalability. If production demand increases, the robotic system can operate continuously with minimal performance variation, unlike manual systems that depend on workforce availability and stamina.
7) Therefore, implementing an automated pick-and-place system is a logical and efficient solution to overcome the identified challenges of the existing manual operation.

VI. PROJECT OBJECTIVES

The primary objective of this project is to design and develop an automated pick-and-place mechanism capable of handling cylindrical containers efficiently and accurately. The specific objectives of the project are as follows:
1) To Reduce Manual Handling: To replace repetitive manual pick-and-place operations with an automated robotic system, thereby minimizing physical effort and reducing dependency on human labor.
2) To Achieve Standardized Cycle Time: To design a system that operates with a fixed and consistent cycle time, eliminating variability caused by manual operation.
3) To Improve Placement Accuracy and Uniformity: To ensure precise positioning and uniform arrangement of containers inside packaging boxes using controlled linear and rotary motion.
4) To Integrate Linear and Rotary Motion Mechanisms: To design a hybrid robotic structure capable of performing both linear positioning (X-Y-Z movement) and angular orientation adjustment.
5) To Develop a Reliable Vacuum-Based Gripping System: To calculate and implement the required vacuum pressure for safe lifting and stable handling of containers.
6) To Improve Overall System Efficiency and Productivity: To enhance throughput, reduce errors, and improve operational reliability through automation.
7) To Provide a Cost-Effective Automation Solution: To design a system that is economically feasible compared to long-term manual operation costs.

VII. MECHANICAL STRUCTURE

The mechanical structure is based on a Cartesian configuration, which provides linear motion along defined axes. Linear guideways and actuators are used to move the gripper assembly in vertical and horizontal directions.

In addition to linear motion, a rotary joint is incorporated into the link mechanism to allow angular movement. This enables orientation adjustment of containers when required before placement.

The rigid frame supports all mechanical components and ensures structural stability during operation.

A. *Motion System*

The motion system includes:
1) Linear actuators for X, Y, and Z movement
2) A rotary actuator for angular orientation
3) Motor drives for controlled motion

The combination of linear and rotary motion allows the system to:
- Move to the pickup position
- Lift the containers
- Rotate them if orientation change is required

- Move to the placement location
- Lower and release them accurately

B. Gripping Mechanism
A vacuum gripper is selected as the end-effector due to its suitability for handling cylindrical containers. The suction cups create negative pressure between the cup and the container surface, generating sufficient holding force.

The required vacuum pressure is calculated based on container weight and suction area to ensure safe lifting with an appropriate safety factor.

C. Control System
The system is controlled using a programmable controller that coordinates:

1) Sensor input
2) Motor actuation
3) Valve switching
4) Vacuum activation

The control sequence ensures synchronized operation between motion and gripping actions.

D. Working Principle
The system operates in the following sequence:

1) Sensors detect the presence of containers at the pickup position.
2) The robotic arm moves to the pickup location.
3) The vacuum gripper activates and lifts the containers.
4) Rotary motion adjusts orientation if required.
5) The arm moves to the box location.
6) The containers are lowered and released.
7) The cycle repeats.

VIII. ROBOT SELECTION AND JUSTIFICATION
The selection of an appropriate robot configuration is a critical step in the design of an automated pick-and-place system. After evaluating different robotic structures such as SCARA, articulated (6-axis), and delta robots, a **hybrid Cartesian robot with rotary** motion has been selected for this project.

A. Suitability for Linear Pick-and-Place Operations
The primary motion required in this application is straight-line movement between fixed pickup and placement positions. A Cartesian robot provides controlled linear motion along perpendicular axes, which is ideal for grid-based placement inside packaging boxes. The rectangular work envelope of a Cartesian structure perfectly matches the arrangement pattern required for box filling.

B. Requirement of Rotary Motion
In addition to linear positioning, orientation adjustment is required before placement. Instead of using a fully articulated robotic arm, a rotary actuator is integrated into the link mechanism. This allows angular motion only where needed, reducing unnecessary complexity.

This hybrid design combines:

- Linear positioning accuracy
- Controlled angular orientation
- Mechanical simplicity

C. Comparison with Other Robot Types
- SCARA Robot: Although SCARA robots are fast and suitable for assembly tasks, they involve multiple rotary joints and more complex kinematics. For a fixed grid placement task, this level of flexibility is unnecessary.

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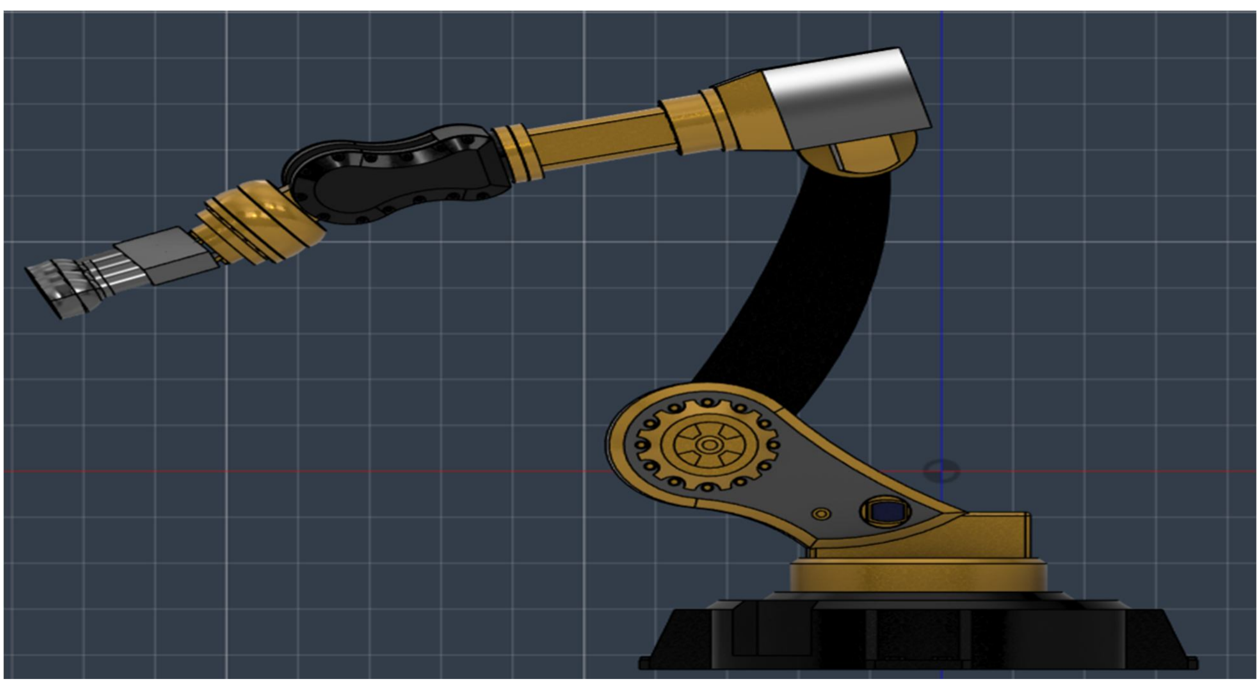
- Delta Robot: Delta robots are suitable for lightweight, high-speed operations but are less rigid for heavier loads and orientation control.
- Articulated (6-Axis) Robot: Articulated robots provide maximum flexibility but are expensive and overly complex for repetitive linear packaging tasks.

D. Advantages of Hybrid Cartesian Configuration
- High structural rigidity
- Accurate and repeatable positioning
- Simpler control algorithms
- Lower cost compared to articulated robots
- Easy integration with conveyor systems
- Stable handling of multiple containers

Therefore, the hybrid Cartesian configuration offers the best balance between performance, simplicity, cost, and design feasibility for this application.

IX. DESIGN OF THE SYSTEM
The design of the automated pick-and-place system is carried out based on the functional requirements of handling cylindrical containers efficiently and accurately. The system is developed by considering factors such as load capacity, workspace requirement, motion type, and gripping mechanism.
The overall design consists of a hybrid robotic structure that combines linear motion along the X, Y, and Z axes with a rotary mechanism for orientation control. The linear motion ensures precise positioning of the end-effector, while the rotary motion allows adjustment of container orientation before placement.
The mechanical design includes a rigid frame that supports all components and maintains structural stability during operation. The arm links and joints are designed to handle the required load of multiple containers while minimizing vibration and deformation.
The end-effector is designed using a multi-cup vacuum gripper, which enables simultaneous handling of multiple containers. The size and arrangement of suction cups are selected based on the container dimensions to ensure proper contact and stable gripping.
The motion system is designed using servo motors and actuators, which provide controlled and accurate movement. The selection of motors is based on torque requirements calculated from the load and arm length.
The design also considers safety and reliability by including proper alignment, smooth motion control, and adequate safety factors in calculations. The overall system is designed to be simple, cost-effective, and suitable for industrial implementation.



X. TECHNICAL CALCULATIONS

A. Load Calculation

To design the gripping system, the force required to lift one cylindrical container must be calculated.

Given:

Mass of one container,

$m = 0.65$ kg

Gravitational acceleration,

$g = 9.81\ m/s^2$

Force Required:

$F = m \times g$

$F = 0.65 \times 9.81$

$F = 6.38$ N

Therefore, the minimum lifting force required to hold one container is 6.38 N.

B. Suction Area Calculation

Diameter of container (outer diameter),

$d = 10.5$ cm $= 0.105$ m

Area of suction surface:

$A = \pi d^2 / 4$

$A = \pi(0.105)^2 / 4$

$A = 0.00865\ m^2$

C. Required Vacuum Pressure

Vacuum pressure is calculated using:

$P = F / A$

$P = 6.38 / 0.00865$

$P = 737$ Pa

$P \approx 0.74$ kPa

This is the theoretical minimum vacuum pressure required.

D. Applying Safety Factor

In industrial applications, a safety factor of 3 is commonly used to account for:

- Leakage
- Surface roughness
- Dynamic motion
- Sudden acceleration

Design pressure:

$P_{design} = 0.74 \times 3$

$P_{design} \approx 2.2$ kPa

E. Final Design Requirement

To safely lift one container, a vacuum pressure of approximately **2–3 kPa (negative pressure)** is required.

If multiple containers are lifted simultaneously, the total force increases proportionally, and the vacuum system must be designed to supply adequate pressure and flow rate.

F. Consideration of Dynamic Effects

During motion, additional forces may act due to acceleration. Therefore, motor selection and structural design must consider:

- Gravitational load
- Inertial force during acceleration
- Factor of safety

XI. COMPONENTS DESCRIPTION

The proposed automated pick-and-place system consists of mechanical, pneumatic, and electronic components working together to achieve controlled motion and reliable gripping.

A. Linear Motion Actuators

Linear actuators are used to provide controlled movement along the required axes. These actuators move the gripper assembly in horizontal and vertical directions.
Function:

- Positioning at pickup location
- Movement toward placement position
- Vertical lifting and lowering

These actuators ensure accurate and repeatable motion along defined paths.

B. Rotary Actuator

A rotary actuator is integrated into the link mechanism to provide angular motion.
Function:

- Orientation adjustment of containers
- Controlled rotation before placement

This eliminates the need for complex multi-joint robotic arms while providing necessary angular flexibility.

C. Vacuum Gripper

The vacuum gripper acts as the end-effector of the robotic system. It consists of suction cups that create negative pressure to hold containers securely.
Function:

- Safe lifting without mechanical clamping
- Even force distribution
- Reduced surface damage

The required vacuum pressure is calculated to ensure stable gripping with safety margin.

D. Vacuum Pump

The vacuum pump generates the negative pressure required by the suction cups.
Function:

- Maintain required vacuum level
- Supply sufficient flow rate
- Ensure stable suction during motion

The pump is selected based on calculated vacuum pressure and number of suction cups.

E. Solenoid Valves

Solenoid valves control the airflow between the pump and suction cups.
Function:

- Turn vacuum ON during pickup
- Release vacuum during placement
- Synchronize gripping with robot motion

They are electrically controlled by the main controller.

F. Sensors

Sensors detect the presence and position of containers.
Types Used:

- Proximity sensors

- Position sensors
- Limit switches

Function:

- Detect pickup position
- Confirm placement
- Ensure safety and accuracy

G. Control System

The control system coordinates all mechanical and pneumatic operations.

Function:

- Control actuator movement
- Activate valves
- Monitor sensors
- Maintain programmed sequence

A programmable controller ensures synchronized and repeatable operation.

H. Rigid Frame Structure

The rigid frame supports all mechanical components and ensures structural stability.

Function:

- Provide vibration-free operation
- Maintain alignment of axes
- Support actuators and motors

XII. COST ANALYSIS AND ECONOMIC FEASIBILITY

To evaluate the feasibility of the proposed automated system, a comparison between the existing manual operation cost and the estimated automation cost is performed.

A. Existing Manual System Cost

In the current setup, four workers are engaged in the pick-and-place operation.

Assuming:

- Wage per worker per day = ₹475
- Monthly wage per worker ≈ ₹14,225
- Yearly wage per worker ≈ ₹1,70,000

Total yearly cost for four workers:

Total = 1,70,000 × 4

Total ≈ ₹6,80,000 (approx.)

This cost is recurring and continues every year.

B. Estimated Automation System Cost

The proposed automated system requires the following major components:

- Vacuum gripper system
- Vacuum pump and accessories
- Linear actuators
- Rotary actuator
- Sensors
- Control system
- Electrical components
- Rigid structural frame

The total estimated cost of the system is approximately:

₹2,50,000 – ₹3,00,000 (one-time investment)

C. Cost Comparison

Manual system yearly cost ≈ ₹6,80,000
Automation system cost ≈ ₹2,75,000 (average)
This shows that the automation cost is significantly lower than one year of manual labor expense.

D. Payback Period

Payback period is calculated as:
Payback Period = Automation Cost / Annual Labor Cost
= 2,75,000 / 6,80,000
≈ 0.4 years
This means the system can recover its cost in less than one year of operation.

E. Long-Term Benefit

After cost recovery:

- Labor dependency reduces
- Operational cost decreases
- Productivity increases
- System operates with consistent performance

XIII. ADVANTAGES AND LIMITATIONS OF THE PROPOSED SYSTEM

A. Advantages

1) Standardized Cycle Time: The automated system operates with a programmed sequence, ensuring consistent and repeatable cycle time for each pick-and-place operation.
2) Improved Placement Accuracy: Linear and rotary motion control ensures precise positioning and uniform arrangement inside packaging boxes.
3) Reduced Manual Effort: The system eliminates repetitive manual lifting, reducing physical strain and improving workplace safety.
4) Higher Productivity: Continuous and controlled operation increases overall throughput compared to manual handling.
5) Reduced Human Error: Automation minimizes misalignment, dropping, or incorrect orientation of containers.
6) Cost Savings in Long Term: A one-time investment reduces recurring labor costs, improving long-term economic efficiency.
7) Scalability: The system can operate continuously and handle increased production demand without performance variation.
8) Improved System Reliability: Fewer moving joints compared to articulated robots result in lower maintenance and higher reliability.

B. Limitations

1) Initial Investment Cost: The automation system requires upfront capital investment.
2) Limited Flexibility: The system is designed for specific container dimensions and arrangement patterns.
3) Maintenance Requirement: Regular maintenance of mechanical and pneumatic components is necessary for reliable performance.
4) Power Dependency: The system requires continuous electrical power supply for operation.
5) Design Constraints: Workspace dimensions limit the maximum operating range of the robotic structure.

XIV. FUTURE SCOPE

Although the proposed automated pick-and-place system improves efficiency and consistency, several enhancements can be implemented in the future to further increase system capability and performance.

1) Integration of Vision Systems: A machine vision system can be added to detect object position and orientation automatically. This would allow the system to handle objects even if their position on the conveyor is slightly irregular.
2) Handling of Multiple Object Sizes: The current design is optimized for a specific container size. Future improvements may include adjustable gripper mechanisms that can accommodate containers of different diameters and heights.

3) Advanced Motion Control: Implementation of advanced motion control algorithms can improve speed, reduce cycle time, and ensure smoother acceleration and deceleration of the robotic system.
4) IoT-Based Monitoring: The system can be connected to industrial monitoring platforms using IoT technology. This would allow real-time monitoring of system performance, predictive maintenance, and remote diagnostics.
5) Energy Optimization: Future designs may include energy-efficient actuators and vacuum generation systems to reduce power consumption during operation.

XV. CONCLUSION

This project presents the design of an automated pick-and-place system for handling cylindrical containers using a hybrid Cartesian robotic mechanism integrated with a vacuum-based gripping system. The proposed system aims to replace manual handling operations with an efficient automated solution capable of performing repetitive tasks with higher accuracy and consistency.

The study analyzed the limitations of manual operations, including inconsistent cycle time, worker fatigue, and higher probability of human errors. Based on these challenges, an automated solution was proposed that integrates linear motion mechanisms, rotary orientation control, vacuum gripping technology, and an electronic control system.

Technical calculations were performed to determine the required vacuum pressure for safely lifting the containers. The design ensures stable gripping and reliable operation while maintaining safety factors for real operating conditions. The selection of a hybrid Cartesian configuration provides a balance between mechanical simplicity, structural rigidity, and precise positioning capability.

Economic analysis shows that the proposed system is financially feasible, as the automation cost can be recovered within a short period when compared with recurring manual labor expenses. Additionally, the automated system improves productivity, reduces operational variability, and ensures consistent performance.

Overall, the proposed design demonstrates a practical and efficient approach for automating repetitive pick-and-place operations, offering improved reliability, accuracy, and long-term cost benefits.

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