Robotics Programming Project

Draft Flow & Literature Review

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1. Project Overview

This project focuses on developing a fully functional handling robot that operates as part of a coupled industrial robotic system. The robot's primary task is to manage cut pieces from a production line by picking them up and transporting them. Using a suction-based end effector, the robot will handle both the finished parts and any scrap material, ensuring an efficient workflow. The simulation, carried out in CoppeliaSim using a URDF model, will serve as a digital twin of the hardware. This integration will allow for seamless transition from the virtual environment to the real-world system, ensuring accurate synchronization and control between simulation and hardware.

2. Literature Review

1. Types of Robotic Arms and Their Applications

In the article *Robotic Arms: Different Types and When to Use Them* by Catherine Bernier, various types of robotic arms are discussed, including articulated, SCARA, Cartesian, and collaborative robots (cobots). Articulated arms, with their multiple joints, offer maximum flexibility and are used in industries like automotive, aerospace, and pharmaceuticals for tasks requiring high dexterity and reach. Six-axis robots, a type of articulated arm, are particularly versatile for complex operations. SCARA robots are suitable for high-speed, low-flexibility tasks such as pick-and-place operations.

Cobots, designed to work alongside humans, are becoming increasingly popular in industries that require close human-robot collaboration. These robots prioritize safety and flexibility, allowing for seamless integration into workspaces where human interaction is necessary. For our project, articulated robotic arms are the most applicable due to their flexibility in performing handling tasks.

2. Robotic Arms in Industry 4.0

The article *The Transformative Power of Industrial Robot Arms in Industry 4.0* highlights how robotic arms contribute to the development of smart factories by integrating digital technologies with physical production. In Industry 4.0, robot arms equipped with sensors and software can communicate with other machines, gather real-time data, and optimize production processes autonomously. This integration helps reduce human error, improve productivity, and ensure consistent product quality.

Robotic arms are pivotal in predictive maintenance, enabling real-time monitoring and fault detection to minimize downtime. Additionally, emerging technologies such as augmented reality (AR) and virtual reality (VR) are enhancing the programming and simulation of robots, allowing operators to interact with machines in a more immersive way. This concept is directly relevant to the project's digital twin approach, where the simulated robot's performance will mirror the hardware in real-time, ensuring seamless synchronization.

3. Design and Control of Pick-and-Place Robots

The article *Robot Arm for Pick and Place Process* presents the design and control of a 4-degree-of-freedom (DOF) robotic arm intended for autonomous pick-and-place operations. This arm, controlled via an Arduino microcontroller, uses a Proportional-Integral-Derivative (PID) controller to regulate the joints' movement, ensuring smooth and precise handling. The robot's kinematic model includes both forward and inverse kinematics, allowing for accurate end-effector positioning.

The application of such control systems aligns with our project, where precise movement and grip control are critical for handling cut materials. By simulating similar control systems in CoppeliaSim, we ensure the robot can perform complex handling tasks with minimal error, an essential aspect of optimizing real-world industrial processes.

4. Industrial Robotics and Smart Manufacturing

The *Pick and Place Robotic Arm: A Review Paper* further explores the impact of AI and machine learning on robotics, transforming them from static machines into adaptive systems. These technologies enable robots to continuously learn and improve workflows, leading to increased efficiency and reduced costs. Industrial robots, particularly those used for material handling, benefit from innovations such as AI-powered data analytics, which allow for real-time decision-making and process optimization.

This insight reinforces the importance of incorporating AI into robotics, potentially enabling future iterations of our project to improve through machine learning. As robotic arms evolve, their ability to dynamically adjust to new tasks and environments will further enhance automation in smart factories.

5. Selected Application: Handling Robot for Cut Materials

Other articles discuss the coordinated use of robotic arms for cutting and handling materials. In this selected application, one robot equipped with a cutting tool precisely cuts materials such as cardboard or wood. A second robot, equipped with a suction-based end effector, picks up the cut materials and transports them for further processing or packaging. By automating both the cutting and handling processes, the system enhances efficiency and accuracy.

For our project, we are tasked with simulating the second robot, which handles the cut pieces using a suction-based end effector. This robot must carefully pick up and transport the cut material without damaging it, ensuring that both the blank and scrap materials are handled appropriately. The use of articulated arms and the integration of a suction-based end effector are central to this task, as they provide the flexibility and precision needed to optimize the handling process.

Conclusion

The reviewed literature provides a comprehensive overview of the current state of industrial robotics, particularly focusing on robotic arms and their applications in smart manufacturing environments. The selected application of handling cut pieces using a robotic arm with a suction end effector corresponds directly to the insights gained from these articles. By integrating articulated robotic arms with advanced control systems, sensors, and predictive maintenance capabilities, we aim to simulate a highly efficient and flexible robot in CoppeliaSim that can later be synchronized with its real-world counterpart.

3. Draft Flow

1. **URDF Model Import and Configuration**
   - The first step is to import the URDF model of the handling robot into CoppeliaSim.
   - The robot's joints and degrees of freedom (DoF) will be verified to ensure accurate movement and flexibility.
   - The suction-based end effector will be assigned to the robot for handling tasks.

2. **Environment Setup**
   - A simulation environment resembling the production line will be created, including a conveyor belt for cut materials.
   - Racks for scrap materials will also be included to ensure proper handling of both reusable and scrap pieces.
   - Workspace boundaries will be defined to prevent collisions and ensure safe robot movement.

3. **End-Effector Configuration**
   - The suction gripper will be calibrated to securely pick up cut materials.
   - Vacuum sensors will be integrated to monitor grip strength, ensuring the materials are held securely without damage.

4. **Task Programming (Pick and Place Operations)**
   - The robot will be programmed to perform pick-and-place operations, including picking up cut materials and placing them on the conveyor belt or designated area.
   - The robot will differentiate between scrap and usable materials, handling both appropriately.
   - A separate sequence will handle scrap collection, placing it into designated racks.

5. **Feedback Control System**
   - A PID control system will regulate the robot's movements, ensuring precision and correct grip pressure during handling.
   - Proximity sensors and force sensors will monitor movement and material handling to prevent damage.

6. **Simulation Testing in CoppeliaSim**
   - Multiple simulation tests will be run to validate grip strength, movement accuracy, and placement efficiency.
   - Simulations will include testing with different material sizes and orientations to optimize the robot's handling capabilities.

7. **Performance Tuning**
   - The robot's parameters, such as grip pressure and movement speed, will be fine-tuned based on simulation results.
   - Issues like material slippage or delays in the pick-and-place cycle will be addressed through iterative tuning.

8. **Fault Handling and Error Management**
   - The robot will be programmed to handle faults, such as unsuccessful picking attempts, with retries or alerts for manual intervention.
   - An error-detection mechanism will pause operations if issues with grip or movement occur.

9. **Digital Twin Integration with Hardware**
   - The simulation in CoppeliaSim will be merged with the physical hardware to create a **digital twin**. This will ensure the simulation mirrors the hardware's real-time operations.
   - Data from the physical robot, such as joint positions, force feedback, and sensor readings, will be integrated into the simulation to maintain synchronization.
   - The digital twin will allow us to monitor the system in real-time, test scenarios virtually, and transfer improvements from the simulation directly to the hardware.
   - The hardware will be controlled by the same algorithms used in the simulation, ensuring that changes made in the simulation are immediately applicable to the physical system.

10. **Final Validation**
- After confirming the synchronization between the simulation and hardware, we will conduct final tests to ensure smooth operation of the digital twin.
- The handling robot's performance will be validated across various production scenarios, ensuring reliable operation within the coupled system.
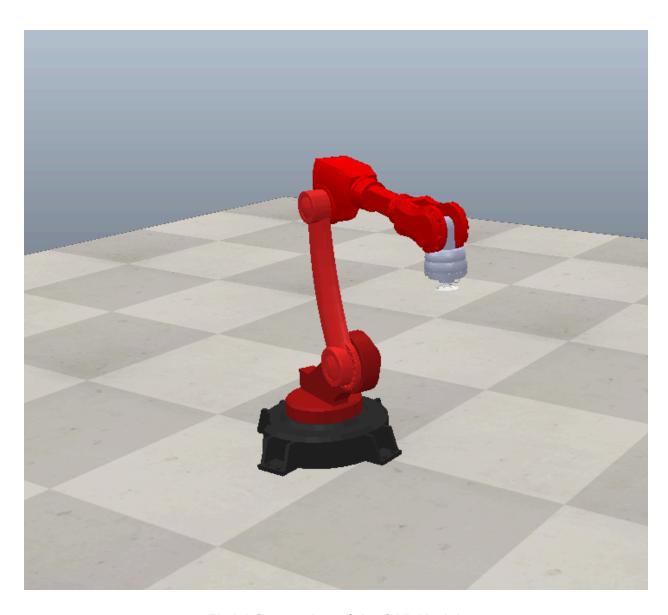
Fig1.1 Screenshot of the CAD Model

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