Team Name

The Suctioneers

Background

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Students

- Andrew Weiler - CPE
- Andrew Whitmill – CS
- Jonathon Commarce – SE
- Samriddha Kharel – CS
- Seezayn Bishwokarma – CS

Abstract

This project integrates sensors, suction control, and automated motion planning to create a reliable, adaptable, and cost-efficient material-handling solution. Built around the UR20 robotic arm, the system is designed for palletizing tasks: detecting incoming boxes on a conveyor, lifting them using vacuum suction, and stacking them in a palletized arrangement. The goal is to demonstrate how a flexible and affordable robotic solution can streamline operations, reduce labor demands, and minimize human error in manufacturing, warehouse, and logistics settings.

Background

Many industries rely on repetitive manual tasks that involve picking up and moving objects as work that can lead to worker fatigue, injuries, and inconsistencies in production. To address these challenges, the team developed the Vacu-Arm, a suction-based robotic arm designed to automate object handling. Unlike traditional mechanical grippers, the Vacu-Arm uses suction technology, allowing it to lift a wide range of items such as boxes, circuit boards, and irregularly shaped components without requiring custom tools or risking damage.

Project Requirements

- PLC (Programmable Logic Controller): Serves as the central interface between all system layers. Programmed using URScript. Handles key functions including sensor control and the palletizing algorithm.
- UR20 Robot Arm: Composed of a robotic arm, vacuum gripper, and air compressor controller. Executes motion and gripper actions based on commands from the PLC.
- Vacuum Gripper: Designed for reliable box pickup. Must meet safety requirements for use with the UR20 collaborative robot.
- Safety Sensor: The DataLogic sensor is powered by the UR20 control box and provides two warning signals: Warning 1 (CI4) and Warning 2 (CI0). Configured to send a halt interrupt in the PLC to halt UR20 movement, permanently shutting down the program until restart.
- Conveyor Belt System: Motor-driven belt with two states: on or off. Equipped with a guide for box reorientation and a photo eye bracket.
- Photoelectric Sensor (Photo-eye): Detects incoming boxes at the stop point of the conveyor. Connected to a relay module to control conveyor start/stop.
- Solenoid for Air Valve: Connected to the control box to manage vacuum gripper operations. Enables on/off control for box grabbing and releasing during palletizing.
- Input Function Logic: Built into the PLC, processes inputs from both the photo eye and safety systems. Directs flow to box offset and position algorithms accordingly.
- Position and Offset Algorithms: Determine motion path for the UR20 to place boxes accurately on the pallet based on given pallet corner parameters.

Design Constraints

Laboratory equipment lockout/tagout (LOTO) procedure: Any fabrication equipment provided used in the development of the project shall be used in accordance with OSHA standard LOTO procedures. Locks and tags are installed on all equipment items that present use hazards, and ONLY the course instructor or designated teaching assistants may remove a lock. All locks will be immediately replaced once the equipment is no longer in use. Equipment usage, due to lock removal policies, will be limited to availability of the course instructor and designed teaching assistants. Occupational Safety and Health Standards 1910.147 – The control of hazardous energy (lockout/tagout).

National Electric Code (NEC) wiring compliance: Any electrical wiring must be completed in compliance with all requirements specified in the National Electric Code. This includes wire runs, insulation, grounding, enclosures, over-current protection, and all other specifications. High voltage power sources, as defined in NFPA 70, will be avoided as much as possible in order to minimize potential hazards.

RIA robotic manipulator safety standards: robotic manipulators, if used, will either housed in a compliant lockout cell with all required safety interlocks, or certified as a “collaborative” unit from the manufacturer. Collaborative robotic manipulators will be preferred over non-collaborative units in order to minimize potential hazards. Sourcing and use of any required safety interlock mechanisms will be the responsibility of the engineering team.

American National Standard for Industrial Robots and Robot Systems: Collaborative robots remain dangerous, and collaborators entering the work area of a Co-bot shall adhere to specific safety requirements in order to prevent bodily harm. The movement path of the collaborator(s) must be kept free of tripping or other movement hazards while the Cobot is powered on. A collaborator shall not enter the workspace with dangling jewelry, loose clothing, or long loose hair. Collaborator(s) must not enter the marked Cobot operating space while the Cobot is active. Those not adhering to the safety requirements listed in ISO/TS 15066 shall be prohibited from collaboration with the Cobot until adherence to the requirements resumes.

Collaborate robot workspace clearance requirements: The collaborative robot workspace should be clear of hazards that could impede the movement of the collaborator(s) or the Cobot itself. The collaborative space of the Cobot, where humans are safe to interact, must be visibly delineated from the operating space of the Cobot. The Cobot shall function with reduced force when a human is present. In calculating these reduced forces, the weight of the payload must be considered. The workspace of the Cobot must be kept free of blockages or other movement hazards while the Cobot is powered on. Possible locations of quasi-static contact (where a human may be clamped between any part of the Cobot and the working environment, including another part of the Cobot) must be identified and removed where possible. Possible locations of transient contact (where the Cobot or the environment may collide with a human) must be identified and removed where possible. The force of contact should also be considered.

International Organization for Standardization: Not all possible locations of contact will be removable. To account for this, dangerous areas must be delineated as part of the Cobot operating space. Risk of injury at these locations shall be minimized by calculating the reduced force used by the Cobot according to ISO 10218-1:2011.

Engineering Standards

Robotics & Safety Standards

- ISO 10218-1 — Safety Requirements for Industrial Robots
- ISO 10218-2 — Safety Requirements for Robot Systems and Integration
- ISO/TS 15066 — Collaborative Robot Safety
- ANSI/RIA R15.06 — Industrial Robot Safety
- IEC 60204-1 — Safety of Machinery: Electrical Equipment
- ISO 13849-1 — Safety-Related Parts of Control Systems

Software & Communication Standards

- POSIX (IEEE 1003) — Operating System Interface Standard
- ROS REP 103 — Standard Units of Measure
- ROS REP 105 — Coordinate Frames for Manipulators
- ROS REP 200 — Command-Line Conventions
- ROS REP 201 — Parameter Server Conventions
- IEEE 802.3 — Ethernet Communication Standard

Mechanical & Structural Standards

- ISO 4413 — Hydraulic (Vacuum Analog) System Safety
- ISO 9409-1 — Mechanical Interfaces for Robot End-Effectors
- ANSI MH29.1 — Industrial Manipulator Standards

Vacuum and Material Handling Standards

- ISO 15012-4 — Vacuum System Specifications
- ISO 4414 — Pneumatic System Safety
- ANSI/ASME B30.20 — Below-the-Hook Lifting Devices

Software Quality, Documentation, and Testing Standards

- IEEE 829 — Software Test Documentation
- IEEE 1016 — Software Design Description
- IEEE 12207 — Systems and Software Engineering Lifecycle Processes

Ethical & Professional Standards

- NSPE Code of Ethics for Engineers
- ACM Code of Ethics and Professional Conduct

System Overview

This project's goal is to program a collaborative palletizing robot intended for industrial use. The main component is PLC (programmable logic controller) designed for use with the UR20 cobot (collaborative robot) arm, and the secondary components will be the UR20 arm itself, a safety system and a conveyor belt with a sensor for new boxes. The intended product of the project will be a robot that can palletize boxes in a predetermined pattern, while being safe for humans to work around. The focus is the arm, but other requirements in the intended working environment (such as the conveyor belt system, boxes, and pallet) have been acquired or designed for testing.

The main component, the PLC, will be the control module for the entire system. All other components report back to and are controlled by the PLC. The second most important component is the UR20 arm, which is designed to work with the PLC controller. The arm will manipulate and palletize the boxes in response to the commands given by the PLC. The PLC will make decisions based on the safety sensor system, which detects human presence to keep the PLC informed on whether it is safe to operate the UR20 arm when a human is nearby. The conveyor belt is an external system. It constantly feeds boxes to the UR20 arm, with the intention of mimicking an industrial environment. It continuously operates until a box is in the correct position for pick-up, then stops and notifies the arm.

Results

The palletizing program successfully uses the predetermined grid patten layout to locate the placement of each box. The arm successfully picks up the boxes on the moving conveyor belt using the vacuum gripper. One more key feature implemented was the freedrive switch, allowing the user to only hold the 3PE yellow button on the PLC while putting the arm into freedrive for arm locations in movements.

Future Work

For future teams, another way to develop programs is using the PLC script function. The user can send over a c code with the raspberry pi over network for the PLC to follow the code and do tasks. This will allow for more freedom in your choices for the arm rather than the specific functions in URscript. Another project is to redesign the Vacuum gripper for more suction through surface tensions instead of the small vacuum cups. This will allow for heavier objects to be carried. Or completely change the vacuum gripper into a claw and pick up items in a game.

Project Files

Provided in the closeout materials
Demo video (link)

References

[1] Md Abdullah-Al-Noman, Anika Nawer Eva, Tabassum Binth Yeahyea, and Riasat Khan. Computer vision-based robotic arm for object color, shape, and size detection. Journal of Robotics and Control (JRC), 3, 2022.

[2] Yi Deng, Tao Zhou, Guojin Zhao, Kuihu Zhu, Zhaixin Xu, and Hai Liu. Energy saving planner model via differential evolutionary algorithm for bionic palletizing robot. Sensors, 22, 2022.

[3] Vehbi C. Gungor and Gerhard P. Hancke. Industrial wireless sensor networks: Challenges, design principles, and technical approaches. IEEE Transactions on Industrial Electronics, 56, 2009.

[4] Robotiq. Automated palletizing with robotiq palletizers, 2024.

[5] Junjie Xu, Long Xiao, Muquan Lin, and Xiaojing Tan. Application of fuzzy pid position control algorithm in motion control system design of palletizing robot. Security and Communication Networks, 2022, 2022.