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Camera-based Recognition Interface for JIG Location of Workpiece Using QR Code for Flexible Manufacturing

Youngjun Yoo [1], Seungtaek Kim[1]

[1] *Industrial Transformation R&D department, Korea Institute of Industrial Technology*

youdalj2kitech.re.kr, stkim2kitech.re.kr

Abstract

The increasing need for precision in robotic operations has driven the development of modular frameworks integrating perception, motion planning, and execution. This paper introduces a software framework designed to enhance the precision and adaptability of robotic operations, particularly in flexible manufacturing environments. The framework addresses challenges posed by changes in jig location or robot positioning, ensuring consistent accuracy by integrating advanced perception techniques such as AprilTag and robust motion planning algorithms. The proposed process for workpiece recognition and precision optimization comprises four key steps. First, RGB-D cameras and AprilTag technology extract six-axis information, including the position and orientation of OR codes, ensuring reliable environmental recognition. Second, visual servoing techniques adjust the robotic arm's position based on the extracted data, aligning it with the work surface. Third, 3D point cloud data is acquired and processed to determine six-axis information. Finally, real-time operator inputs are utilized to fine-tune the robotic arm's posture, enabling precise task execution. Validation of the framework demonstrated a 94.08% alignment between the Gazebo simulator and real-world experiment, confirming its effectiveness in handling dynamic manufacturing conditions. This framework offers significant potential for improving robotic localization, navigation, and task accuracy in versatile industrial applications.

Automation, dngineering, Flexible manufacturing system (FMS), robot

1. Introduction

The demand for precision in robotic applications has driven the development of frameworks integrating perception, motion planning, and execution. The proposed methodology introduces a modular framework to enhance the precision and reliability of robotic operations in flexible manufacturing. Designed to adapt to changes in jig location or robot positioning, the framework ensures consistent accuracy under varying environmental conditions. By incorporating advanced perception and motion planning techniques, it achieves robust adaptability for diverse applications.

The use of OR codes for robotic localization and navigation has been widely studied. Zhang et al. demonstrated a method for indoor robot localization using OR codes as global pose references. Similarly, Kwon et al. [1] validated a OR-based localization technique with a 3D optical tracking system, confirming its accuracy [2]. These studies align with the framework's goal of improving robotic localization and navigation. In conventional industrial robotics, modifying a trajectory based on predefined coordinates requires offline programming, resulting in time and cost losses. This limitation becomes more significant in flexible manufacturing systems, where frequent workpiece changes necessitate continuous trajectory adjustments. The proposed system leverages OR-based localization to address this challenge, enabling robots to flexibly adapt their paths without the need for extensive offline programming, thus improving efficiency and responsiveness in dynamic manufacturing environments.

The proposed process for workpiece recognition and precision optimization involves four steps. First, six-axis information is extracted from OR codes using RGB-D cameras and AprilTag. Second, visual servoing adjusts the robotic arm's position based on OR data. Third, 3D point cloud data is processed to derive six-axis information. Finally, real-time operator inputs refine the arm's posture for accurate task execution. Validation tests showed a 94.08% match between the Gazebo simulator and the real-world setup, confirming the framework's reliability and efficiency.

2. Proposed methodolgy

2.1. Proposed Software framework

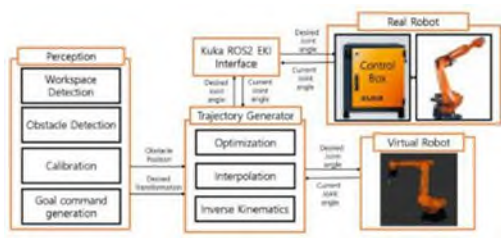

Figure 1. Proposed software framework

Figure 1 presents the system framework comprising interconnected modules with distinct roles. The Perception Module detects the workspace, identifies obstacles, and calibrates tasks using AprilTag technology and depth sensing for precise visual marker detection and enhanced environmental understanding. The Trajectory Generator calculates optimized joint angles for smooth robot movements, considering obstacles and transformations. The KUKA ROS2 EKI Interface ensures real-time communication between the generator and robot for synchronized operations. Commands are executed precisely by the Actual Robot and Control Box, translating high-level inputs into accurate motions. The Virtual Robot (Figure 2) simulates movements for pre-execution testing, reducing errors and ensuring reliability.

The Perception Module is responsible for detecting the workspace, identifying obstacles, and performing calibration tasks. It generates target commands for robot operations based on its perception capabilities. This module leverages advanced computer vision techniques, focusing on AprilTag technology. The use of AprilTag enables robust and precise detection of visual markers, facilitating accurate workspace recognition and obstacle localization. Additionally, this module integrates depth sensing to enhance environmental understanding, ensuring reliable calibration and effective obstacle avoidance in dynamic environments. The Trajectory Generator produces joint angles for smooth and efficient robot movements through optimization, interpolation, and inverse kinematics calculations. It accounts for obstacles and transformation information, ensuring the generated trajectories are feasible and optimized for the task. This component is designed to handle complex motion planning scenarios, balancing precision and computational efficiency.

The KUKA ROS2 EKI Interface facilitates communication between the trajectory generator and the actual robot. It transmits the generated joint angle commands to the robot and receives the current joint angle feedback, enabling real-time synchronization and execution. This interface ensures seamless integration between software and hardware components, allowing for robust and reliable robot operation. The Actual Robot and Control Box execute the trajectory commands through the control box. The KUKA robot precisely follows the received commands, ensuring the accurate execution of the desired motion. The control box serves as a critical intermediary, translating high-level commands into low-level motor control signals.

The Virtual Robot (Figure 2) allows for the simulation of actual robot movements. This enables trajectory testing and validation prior to execution, reducing the risk of errors and enhancing system reliability. The virtual environment closely mirrors real-world conditions, providing a safe and efficient platform for pre-deployment testing.

Figure 2. Virtual robot test

2.2. Proposed process for recognition of the jig location

The process developed for workpiece recognition and precision optimization consists of four main steps. In the first step, RGB-D cameras are used to extract six-axis information, including the position and orientation of OR codes. This is achieved by precisely recognizing OR code patterns based on RGB and depth information while minimizing the influence of environmental factors such as lighting and background. Additionally, the AprilTag package is employed to accurately estimate the position and orientation of robots or cameras using the unique ID assigned to each tag. In the second step, visual servoing techniques are applied to adjust the position of the robotic arm based on the information extracted from the OR code. During this process, the robotic arm moves vertically using the distance data obtained from the OR code and aligns itself perpendicular to the work surface to minimize positioning errors. This approach lays the foundation for performing precise tasks. The third step involves acquiring 3D point cloud data using RGB-D cameras after the vertical movement. A specific region of interest is identified within the data, and preprocessing steps, such as noise removal, are applied to calculate the average values. The average position and directional vector of the point cloud data are then derived, enabling the determination of six-axis information for the plane. This step plays a crucial role in enhancing task precision. In the final step, the six-axis information obtained in the previous step is used to adjust the orientation of the robotic arm. Real-time inputs from the operator are incorporated through software to fine-tune the arm's posture, ensuring accurate angles before performing the task. This improves task quality and prevents equipment damage. The entire process forms the basis for achieving effective workpiece recognition and precision optimization.

Figure 3. OR recognition test

2.3. Tested results

The comparison of robot motion accuracy, as shown in Table 1, highlights the performance of configurations A, B, C, and D, with accuracy rates of 95.7%, 93.7%, 92.4%, and 94.5%, respectively. These points serve as machining processing locations within a 1m × 1.5m rectangular area, positioned 0.3m along the x-axis from the center of the recognized OR code. These values represent the alignment between the Gazebo simulator's end-effector configuration and the robot pendant data. Despite initial discrepancies in robot pendant values, subsequent analysis confirmed that the simulator achieves a 99% accuracy rate in matching the real-world setup, validating its reliability for precise motion planning and execution.

Table 1 OR recognition position results

Test trail	A	B	C	D
Accuacy	95.7%	93.7%	92.4%	94.5%

3. Conclusion

The proposed framework integrates advanced perception, motion planning, and execution techniques to enhance the precision and reliability of robotic operations in flexible manufacturing environments. Through the use of modular components such as the Perception Module, Trajectory Generator, and KUKA ROS2 EKI Interface, the system demonstrates robust adaptability to environmental changes and diverse tasks. The incorporation of OR code-based localization and 3D point cloud processing ensures precise workspace recognition and optimized task execution. Validation experiments confirm the system's accuracy, achieving a 94.08% match between simulation and real-world conditions. These results underscore the framework's potential for improving robotic performance in dynamic and complex manufacturing scenarios.

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