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Subject: **Introduction to Robotics**

Subject code: IE410

Project Part-B

Group-7

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Object Manipulation using a Robotic Arm

Objective:

This project presents a robotic arm system capable of autonomously identifying and relocating foam objects using computer vision and coordinate-based motion control. By leveraging a camera with ArUco marker tracking, the system detects target positions, calculates necessary joint movements, and executes precise pick-and-place actions.

System Components:

The solution integrates the following major parts:

Camera System with Marker Recognition:

A camera detects two sets of ArUco markers: one to define a work area and another to mark foam objects within that area. The first set (larger markers) sets a consistent reference square on the image, while the second set (smaller markers) identifies and locates movable objects.

Robotic Arm Controller:

The arm receives angle-based movement commands through serial communication. These commands are converted from spatial coordinates derived from the vision system. The robotic arm consists of six joints (base, shoulder, elbow, wrist, wrist rotation, and gripper), all of which can be individually or collectively positioned.

Inverse Kinematics Engine:

A mathematical model transforms 3D target coordinates into the joint angles necessary to reach those points. This calculation includes various physical compensations such as backlash, mechanical offsets, and positional adjustments for arm length variability and camera height.

Serial Communication Interface:

Commands from the control software are translated into string-based messages sent to the Arduino board, which interprets these instructions and moves the robotic arm accordingly. The Arduino also supports basic feedback and error handling for robustness.

Workflow:

1. Initialization:

   The robotic arm starts in a default (home) position. The camera system begins streaming video and initializes detection of ArUco markers in real-time.

2. Workspace Identification:

   Four reference markers are used to define the area of interest. Once all markers are detected, the region is geometrically transformed to normalize perspective, providing a consistent top-down view of the workspace.

3. Object Detection:

   A smaller marker is attached to a foam object. Once it is detected inside the defined workspace, its center is calculated and used to determine the object's coordinates in the image.

4. Coordinate Compensation:

   The image-based coordinates are adjusted to compensate for the camera's height, angle, and mechanical differences between visual and physical coordinates. This ensures accuracy when translating image data to physical motion.

5. Motion Planning:

   The compensated coordinates are processed through an inverse kinematics solver, which computes the precise angles needed for the robotic arm to reach the foam object.

6. Pick-Up Sequence:

   The arm opens the gripper, moves to the target location at a higher Z-level to avoid obstacles, then lowers to pick up the object, closes the gripper, and lifts the object.

7. Place Operation:

   After retrieval, the arm moves to a predefined drop location (such as a glass or container), lowers the object, releases it, and returns to the home position.

8. User Control:

   During operation, a keyboard input can be used to trigger object pickup manually, for demonstration or testing purposes.

Hardware Constraints:

Due to limited availability and high demand for the robotic arms during the project period, we had access to only two damaged models—one of which was nearly non-functional, and the other partially operational. While our system and code were fully functional, testing was constrained by these hardware limitations. The demonstration video below showcases the second model, which successfully performs all steps of the pick-and-place operation except for the rotation functionality due to mechanical issues.

VIDEO: Click here

Compensations & Enhancements

Backlash Compensation:

The base joint is adjusted for rotation slack based on the direction and magnitude of recent motion, minimizing positioning errors.

Mechanical Tuning:

Shoulder, elbow, and wrist angles are fine-tuned to account for servo misalignments and physical arm construction issues.

Camera Offset Handling:

Optical coordinates are re-aligned to real-world coordinates using a fixed transformation model that factors in camera height and foam thickness.

Conclusion

This system demonstrates an effective pipeline from camera-based detection to robotic manipulation using a combination of computer vision, inverse kinematics, and real-time motor control. It offers a scalable approach to pick-and-place robotics with a clear structure for future improvements, such as dynamic object tracking or machine learning-based vision enhancements.