Development of a Robotic Arm with Vision-Based Pick and Place Functionality

Girish Kumar[1], Sandesh Satish Hegde[1], Rochan A Ritti[1], Jayanthi K Murthy[2]

[1]Student, Electronics and Communication Engineering, BMS College of Engineering, Bangalore, India
[2]Associate Professor, Electronics and Communication Engineering, BMS College of Engineering, Bangalore, India

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Abstract - In this paper, we present the design and implementation of a robotic arm system equipped with both manual and automated control capabilities, facilitated by an Arduino Uno microcontroller and various peripheral modules. The robotic arm is constructed using three SG90 and three MG996R servo motors, providing multi-degree-of-freedom movement for precise manipulation tasks. Integration of an HC-05 Bluetooth module enables wireless communication, allowing remote control and programming flexibility. A key feature of our system is its vision-based pick and place functionality, enabled by the inclusion of an OV7670 camera module. Utilizing image processing algorithms, the camera captures real-time footage of the arm's surroundings, facilitating object recognition and localization. This enables autonomous operation, where the arm can identify and manipulate objects based on predefined criteria. The versatility of our robotic arm system makes it suitable for a wide range of applications, including industrial automation, educational purposes, and research endeavours. By combining mechanical design, electronics, and software development, we demonstrate a comprehensive approach to the creation of intelligent robotic systems.

Key Words: Robotic Arm, 6-DOF, Image Recognition

1.INTRODUCTION

Robotic arms have emerged as indispensable tools in various fields, ranging from industrial manufacturing to medical surgery, owing to their ability to execute precise and repetitive tasks with efficiency and accuracy. With advancements in technology, the integration of sophisticated control systems and sensory capabilities has further enhanced the functionality and versatility of these robotic systems. In this work, we embark on the development of a robotic arm equipped with vision-based pick and place functionality, aiming to combine mechanical dexterity with intelligent automation.

The core of the robotic arm system is built around an Arduino Uno microcontroller, providing a flexible and programmable platform for control and coordination of the arm's movements. Comprising a combination of SG90 and MG996R servo motors, the mechanical structure of the arm enables multi-axis articulation, facilitating complex manipulation tasks. Additionally, the inclusion of an HC-05 Bluetooth module offers wireless communication capabilities, enabling remote control and interaction with the arm.

A distinguishing feature of the system is the integration of an OV7670 camera module, which serves as the sensory apparatus for vision-based perception. By capturing real-time visual data of the arm's surroundings, the camera facilitates object recognition and localization through image processing algorithms. This enables the arm to autonomously identify and manipulate objects based on predefined criteria, thereby augmenting its capabilities for automation and adaptability to dynamic environments.

Through the convergence of mechanical design, electronics, and software development, the work aims to showcase a holistic approach to the creation of intelligent robotic systems. The resulting robotic arm not only demonstrates proficiency in performing designated tasks but also serves as a platform for experimentation and exploration in the realm of robotics and automation. With its potential applications spanning industrial automation, educational endeavors, and research initiatives, the work underscores the significance of integrating advanced technologies to advance the capabilities of robotic systems in addressing real-world challenges.

2. LITERATURE SURVEY

Different types of robotic arm designs have distinct functions, such as helping visually impaired individuals by responding to voice commands, supporting stroke patients in regaining limb movement through Surface Electromyography, and providing affordable solutions for agricultural activities like pruning and fruit harvesting in underdeveloped areas [1]. The paper introduces a robotic arm grasping system that utilizes the OpenMV module for both image recognition and positioning. It employs a normalized cross-correlation template matching algorithm. Integrated with an embedded microprocessor and stepper motor driver, the system showcases precise object recognition and successful grasping. This project received support from the Guangdong Province Special Fund for Modern Agricultural Industry Common Key Technology R&D Innovation Team [2]. The development process of robotic systems involves coordinating programming, mechanical, sensor, actuation, and supervision components, customizing configurations such as SCARA and DELTA robots for fast and accurate tasks such as pick-and-place and assembly operations. This underscores the vital importance of precision and efficiency across various industries [3]. [4] In investigations of neural interfaces facilitating somatosensory feedback, illusions induced by muscle vibration, and techniques for reinstating natural sensory feedback in hand prostheses. It also encompasses studies on generating force and angular sensations through nerve stimulation, as well as approaches such as tendon vibration and skin stretching for proprioceptive feedback. These findings have implications for enhancing the control of robotic arms and limb prostheses. The paper[5] outlines the development of a robotic hand employing Arduino Uno, flex sensors, and servo motors to replicate human hand movements. It highlights the hand's versatility across various fields such as space exploration, manufacturing, household tasks, and remote control driven by IoT. Furthermore, it suggests enhancing its functionalities by incorporating it into mobile robotic systems for expanded utility . The paper[6] presents an innovative technique for operating a primary robotic arm from a distance using a small-scale arm outfitted with potentiometers and Bluetooth technology. This method replicates human motions, facilitating accurate manipulation for activities like medical procedures and managing dangerous substances. The system framework encompasses signal gathering from potentiometers, data processing through Arduino, and wireless communication via Bluetooth [6].

3. PROPOSED WORK

3.1 Mechanical Design

The mechanical design of the robotic arm focused on achieving a balance between structural stability, flexibility, and weight optimization. Utilizing Computer-Aided Design (CAD) software, a 6-degree-of-freedom (DOF) arm structure was meticulously crafted, comprising interconnected joints, links, and an end effector. The arm's geometry was carefully designed to maximize space utilization within the 3D printed framework while considering the 25-30 cm range of motion needed for different manipulation tasks..

During the design phase, material selection was crucial. To reduce inertia and improve agility, lightweight yet robust components were used. Every joint was designed such that it will allow for enough articulation while preserving structural integrity when under stress. In addition, care was taken to reduce friction and backlash in the joints to guarantee accurate and seamless movement across the arm's range.

Careful alignment and calibration were required during the mechanical component assembly process to maximize the arm's functionality. The arm construction was designed to accommodate two servo motors (SG90 and MG996R), each of which is in charge of driving a distinct degree of freedom. To keep things neat and tidy, wiring harnesses were routed via the hollow tubes in the arm.

3.2 Electronics Integration

In order to ensure a seamless conversation and management, the integration of electronic components into the robot arm system has evolved into an orchestrated process. A careful consideration of electricity requirements, signal compatibility and noise reduction was involved when interfacing servo motors with Arduino Uno microcontrollers. Each servo motor changed into related to man or woman PWM pins at the Arduino, bearing in mind precise manage over role and velocity.

The HC-05 Bluetooth module has been integrated seamlessly into the device, providing a wireless communication interface for remote control and programming. To allow real-time control of the robot arm, a serial conversation protocol may be used to transmit commands and instructions from outside devices such as smartphones into the Arduino.

With the integration of the OV6707 camera module, the robot arm's imaginative and prescient abilities have been enhanced, allowing item reputation and localization. The camera module has been connected to the Arduino Uno, and the picture data has been processed in real time for the use of onboard algorithms. It made it easier for the arm to operate independently, allowing it to perceive and control objects entirely on the basis of visible signals.

3.3 Software Development

The development of control algorithms, communication protocols and user interfaces has been part of software development for the robot arm system. In order to manage the movement of the servo motors in the arm, control algorithms have been designed that take account of Kinematic and Operational Requirements.

To facilitate a seamless interaction between the robotic arm and external devices, Bluetooth communication protocols have been developed. In order to ensure robust communication and user feedback mechanisms have been introduced for handling commands and parsing errors.

In order to analyze the data captured by an OV7670 camera module, image processing algorithms have been designed that allow object recognition and localization. In order to identify objects in the arm's field of view, techniques such as edge detection, color segmentation and template matching have been applied.

For manual operation and autonomous mode operation, user interfaces have been designed to provide intuitive controls and feedback mechanisms. Graphical interfaces allowing users to monitor arm status, issue commands and view captured images in real time have been developed for mobile platforms.

4. HARDWARE REQUIREMENTS

The hardware infrastructure of the embedded project encompasses a diverse array of components, each serving a distinct purpose in achieving the desired functionality. This section delineates the specific hardware requirements crucial for the successful implementation of the project.

4.1 Arduino Uno

The Arduino Uno acts as the central control unit for the robotic arm system, overseeing motor control, Bluetooth communication for remote operation, and integration with the OV7670 camera module for vision-based functionalities. It processes sensory inputs, facilitates decision-making, and hosts the user interface for manual or autonomous control, serving as the core component for orchestrating the arm's movements and interactions..

4.2 OV7670 Camera Module

The OV7670 camera module serves as the visual sensory component of the robotic arm system. It captures real-time images of the arm's surroundings, enabling vision-based functionalities such as object recognition and localization. The Arduino Uno interfaces with the camera module to receive image data, processes it using image processing algorithms, and makes decisions based on the visual information, facilitating tasks such as pick and place of objects with precision and accuracy.

4.3 Servo Motors(MG996R and SG90)

The MG996R and SG90 servo motors provide multi-degree-of-freedom movement, precise positioning, and smooth motion control for the robotic arm. Interfaced with the Arduino Uno, they enable the arm to articulate its joints with accuracy, perform delicate manipulations, and execute tasks such as picking and placing objects with stability and reliability, essential for the project's success.

4.4 HC-05 Bluetooth Module

The HC-05 Bluetooth module facilitates wireless communication between the robotic arm and external devices like smartphones, enabling remote control and programming flexibility. It allows users to interact with the arm wirelessly, sending commands or instructions for specific actions, enhancing accessibility and usability. Additionally, it enables integration with other Bluetooth-enabled devices or systems, expanding the range of potential applications and interactions for the robotic arm.

Table -1: Arduino pin mapping

Arduino board	Connections
VCC	HC-05 VCC, To all the servos (VCC)
GND	HC-05 (GND), To all the servos (GND)
GPIO3	HC-05 Tx
GPIO4	HC-05 Rx
GPIO5	Servo motor 1 (MG996R)
GPIO6	Servo motor 2 (MG996R)
GPIO7	Servo motor 3 (MG996R)
GPIO8	Servo motor 4 (SG90)
GPIO9	Servo motor 5 (SG90)
GPIO10	Servo motor 6 (SG90)

External power supply connected to all servos (VCC and GND)

Table -2: Material used to build Robotic

Arduino board	1 – Arduino UNO
Servo Motors	3 – MG996R (4.8 – 7.2V DC) 3 – SG90 (4.8 – 6V DC)
Resistor	1 – 1k ohm 1 – 2.2k ohm
Camera Module	1 – OV7670 (3.3V, 640x480 resolution)
Bluetooth Module	1 – HC-05 (3.3V to 6V, range up to 100m)
Jumper Wires	As per the requirement
Bolts and Nuts	As per the requirement

5. RESULTS AND CONCLUSIONS

The creation and application of a Bluetooth-controlled robot arm with vision-based picking and positioning capabilities represents a major advancement in robotic system technology. The project has created a versatile and adaptive robot platform that, because of the smooth integration of mechanical, electrical, and software components, is capable of carrying out complex manipulation tasks by itself. The use of robotic arms in several industries creates new opportunities for invention and discovery. Because to its versatile and straightforward design, as well as its user-friendly control interfaces, it may be used by a broad spectrum of users, from beginners to experts. Through further arm performance optimization and refinement, it may be able to expand its capacity and range of applications in the future. Additionally, by investigating collaboration and interactive capabilities, new avenues for human robot interaction and partnership may be opened up. The Bluetooth controlled robotic arm essentially serves as an example of the strength of interdisciplinary collaboration and creativity, which will pave the way for future advancements in robotics and automation.

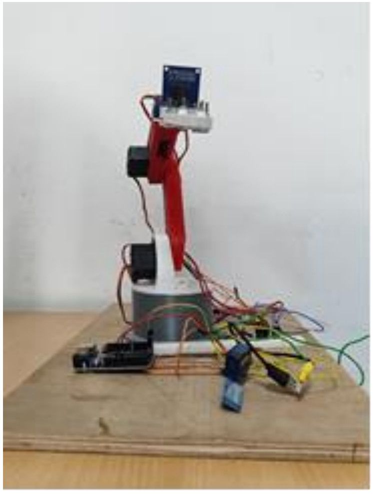

Fig -1: Robotic ARM model

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