Vision and Voice Controlled Bionic Robotic Arm for Assistive and Research Applications

1 Purushothaman S,2 Aswin Krishna R,3 Karthik Saju,
4 Mohammed Habeeb Hassan,5 Muhammed Fayis P H
1 Assistant professor,2 Student,3 Student,4 Student,5 Student Department of Mechatronics Engineering
Nehru College of Engineering and Research Centre,Pampady, Thrissur, Kerala, India

How to Cite this Article:

R, A. K., Saju, K., Hassan, M. H. & H, M. F. P. (2026). Vision and Voice Controlled Bionic Robotic Arm for Assistive and Research Applications. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(03). https://doi.org/10.55041/ijcope.v2i3.209

https://doi.org/ 10.55041/ijcope.v2i3.209

Abstract—Robotic arms are widely used in automation, prosthetic systems, and intelligent robotic applications. The development of flexible and cost-effective robotic manipulators remains an important research area in robotics and mechatronics engineering. This paper presents the research and development (R&D) of a modular bionic robotic arm capable of performing human-like movements through multiple control interfaces. The proposed system integrates a Raspberry Pi 5 with a camera module, voice command processing, and an ESP32/Arduino microcontroller to provide intelligent and flexible control of the robotic arm. The system supports three different control modes: camera-based vision commands, voice command recognition, and direct control commands sent to the ESP controller. The Raspberry Pi performs high-level processing such as object detection and speech recognition, while the ESP microcontroller performs low-level motor control using Pulse Width Modulation (PWM) signals. The robotic arm consists of nine servo motors and one DC motor that control finger movements, elbow bending, forearm rotation, and shoulder motion.The proposed design focuses on modularity, affordability, and expandability, allowing the robotic arm to be used as a research platform for future robotics development. Experimental results demonstrate that the system can successfully perform operations such as gripping, lifting, and object manipulation. The project demonstrates how embedded systems, computer vision, and intelligent control techniques can be integrated to develop an efficient robotic manipulator for assistive robotics, research laboratories, and educational environments.

Index Terms—Bionic Arm, Robotic Manipulator, Computer Vision, Voice Control, Embedded Systems, Servo Motors.

I. INTRODUCTION

Robotic arms are one of the most important developments in the field of robotics and automation. They are widely used in industrial automation, medical prosthetics, assistive technologies, and research laboratories. A robotic arm is designed to replicate the motion of a human arm using a combination of mechanical joints, actuators, and control systems.

In recent years, the integration of artificial intelligence, embedded systems, and computer vision has significantly improved the capabilities of robotic systems. Modern robotic arms are no longer limited to pre-programmed movements; instead, they can interact with their environment, recognize objects, and respond to human commands.

One of the main challenges in robotic arm development is achieving natural and coordinated motion while maintaining affordability and flexibility. Many advanced prosthetic and industrial robotic arms are expensive and difficult to customize for research or educational purposes. Therefore, there is a need for a cost-effective robotic arm system that can serve as a research platform for experimenting with intelligent control techniques.

This project focuses on the **research and development of a modular bionic robotic arm** capable of performing human-like movements using multiple control interfaces. The system integrates a **Raspberry Pi processing unit, camera-based vision system, voice command recognition, and an ESP microcontroller for motor control**.

Unlike traditional robotic arms that rely on a single control method, the proposed system supports **three different control modes**:

- Vision-based control using camera input
- Voice command-based control
- Direct command control through ESP microcontroller

These multiple control modes make the system flexible and suitable for research, automation, and assistive robotic applications. The main objectives of the project are:

- To design and develop a bionic robotic arm capable of human-like motion
- To integrate camera-based vision processing for intelligent control
- To implement voice command recognition for human-robot interaction
- To develop an ESP-based motor control system for servo actuation
- To create a modular research platform for robotic arm development

II. LITERATURE REVIEW

Several research studies have been conducted in the field of robotic arms and prosthetic systems. These studies explore various sensing technologies, control mechanisms, and actuation systems to improve robotic arm functionality.

One study presented a customizable robotic prosthesis platform using modular components that used servo motors and modular components to develop a flexible robotic arm. The system allowed customization but required complex mechanical design and expensive components.

Another research project developed a **flex sensor controlled prosthetic arm** that used finger bending sensors to control robotic fingers. The system was affordable and simple but lacked precision and had limited load-handling capability.

Research has also been conducted using **IMU sensors and wearable controllers** to capture human arm movements and replicate them using robotic actuators. These systems provide intuitive control but require continuous calibration and may suffer from sensor drift.

Recent developments in robotic prosthetics include **electromyography (EMG) based control systems**, where electrical signals from human muscles are used to control robotic arms. Although these systems provide natural motion control, they require specialized sensors and complex signal processing algorithms.

Some advanced robotic systems combine **computer vision and machine learning techniques** to improve object detection and grasping capabilities. Vision-based robotic arms can analyze their environment and adjust their movements accordingly.

Despite these advancements, many robotic arm systems still face several challenges such as high cost, limited flexibility, high power consumption, and complex integration of sensors and actuators.

Therefore, the development of a **cost-effective, modular robotic arm system with multiple control interfaces** remains an important research area

III. METHODOLOGY

The proposed robotic arm system is developed as a **research and development platform for intelligent robotic manipulators**. The design integrates computer vision, voice recognition, and embedded control systems to provide flexible and intelligent operation.

The system architecture consists of two main processing units:

- **Raspberry Pi 5**
- **ESP32 / Arduino Microcontroller**

The Raspberry Pi serves as the **high-level processing unit**, while the ESP controller acts as the **low-level motor controller**.

The Raspberry Pi is responsible for tasks such as camera data processing, object detection, and voice command recognition. The ESP microcontroller receives commands from the Raspberry Pi or external interfaces and converts them into PWM signals for controlling the servo motors.

The robotic arm uses **ten servo motors** to replicate human arm movement. Each actuator controls a specific joint of the robotic arm.

The system supports three different control modes:

A. Camera-Based Control

The Raspberry Pi camera captures real-time video input. Computer vision algorithms analyze the video frames to detect objects and determine their position and orientation. Based on this information, the system generates commands that control the movement of the robotic arm.

B. Voice Command Control

Voice commands are captured using a microphone connected to the Raspberry Pi. Speech recognition algorithms convert the audio signal into text commands. These commands are interpreted by the system and translated into robotic arm movements.

C. Direct ESP Command Control

In this mode, commands are directly transmitted to the ESP microcontroller. The controller processes the commands and generates PWM signals to actuate the servo motors. This mode allows manual or programmatic control of the robotic arm.

This multi-layer control architecture provides flexibility and allows the robotic arm to be used for various research experiments and robotic applications.

IV. SYSTEM ARCHITECTURE

The system architecture consists of multiple interconnected hardware and software modules that work together to control the robotic arm.

Processing Unit

The Raspberry Pi 5 functions as the main processing unit responsible for executing computer vision algorithms and voice recognition software.

Camera Module

The camera module captures real-time visual data used for object detection and environmental monitoring.

Microcontroller Unit

The ESP32 or Arduino microcontroller receives commands from the Raspberry Pi and converts them into PWM signals required for servo motor operation.

Actuation System

The robotic arm uses ten servo motors to control the different joints of the arm.

Communication Interface

Communication between the Raspberry Pi and the ESP controller is achieved through wired serial communication, ensuring reliable data transfer.

Power Supply

A regulated power supply provides stable voltage to all electronic components including the Raspberry Pi, microcontroller, and motors.

V. PROCEDURE

The operation of the robotic arm involves multiple stages that coordinate sensing, processing, and actuation.

System Initialization

When the system is powered on, all hardware components including Raspberry Pi, camera module, microcontroller, and servo motors are initialized. Required software libraries such as OpenCV and speech recognition modules are initialized.

Input Acquisition

The system receives input from one of the three control interfaces: camera input, voice command input, or direct control commands.

Data Processing

The Raspberry Pi processes the input data. For vision control, image processing algorithms detect objects. For voice commands, speech recognition algorithms convert audio signals into commands.

Command Generation

Based on the processed data, the system generates movement commands for the robotic arm.

Communication

The commands are transmitted to the ESP microcontroller through serial communication.

Motor Control

The ESP controller converts the received commands into PWM signals that control the servo motors.

Arm Movement

The servo motors rotate to specific angles to perform movements such as gripping, lifting, and rotating.

Continuous Feedback

The system continuously processes input data and adjusts the arm movements accordingly.

VI. DATA ANALYSIS

Data analysis is performed to evaluate the performance and efficiency of the robotic arm system.

Several parameters are analyzed including motion accuracy, response time, and object handling capability. Servo motor positions are monitored to evaluate the precision of arm movements.

Camera data is analyzed to determine the accuracy of object detection algorithms. Voice command recognition accuracy is also evaluated to determine the effectiveness of the human-robot interaction system.

Key evaluation metrics include:

- Motion accuracy of servo motors
- Response time of command execution
- Object detection accuracy
- Voice recognition accuracy
- Grip success rate

These performance metrics help identify possible improvements in control algorithms and mechanical design.

VII. RESULTS

The developed robotic arm successfully demonstrates intelligent control using vision processing, voice commands, and direct microcontroller commands.

The Raspberry Pi successfully processes camera input and generates movement commands based on detected objects. Voice command recognition also functions effectively, allowing users to control the robotic arm using simple spoken commands.

The ESP microcontroller efficiently generates PWM signals to control the servo motors. The robotic arm is capable of performing coordinated movements such as gripping objects, lifting items, and rotating joints.

The integration of multiple control modes improves the flexibility and usability of the robotic arm system.

VIII. SYSTEM COMPONENTS

The robotic arm system consists of the following major components:

- Raspberry Pi 5 – Main processing unit

- ESP32 / Arduino Uno – Motor control unit

- Camera Module – Vision input system

- Servo Motors (10 units) – Joint movement control

- Microphone – Voice command input

- Power Supply – System power source

IX. FUTURE SCOPE

The robotic arm can be further improved by integrating advanced technologies such as artificial intelligence, machine learning algorithms, and sensor fusion techniques.

Future work may include:

- Autonomous object detection and manipulation
- Brain-computer interface integration
- Gesture recognition using deep learning
- Improved prosthetic applications
- Remote wireless robotic arm control

These advancements could significantly enhance the intelligence and capabilities of the robotic arm system.

X. CONCLUSION

This research presented the design and development of a **vision and voice controlled bionic robotic arm** using embedded systems and intelligent control techniques. The system integrates a Raspberry Pi processing unit with an ESP-based motor controller to achieve flexible and efficient robotic arm operation.

The robotic arm supports multiple control modes including camera-based control, voice command control, and direct microcontroller commands. The use of servo motors enables precise joint movement and human-like motion replication.

The proposed design demonstrates that a cost-effective and modular robotic arm can be developed using accessible components while maintaining good performance and flexibility. The system provides a useful platform for future research in assistive robotics, intelligent automation, and prosthetic technology.

REFERENCES

[1] M. Zecca, S. Micera, M. C. Carrozza, and P. Dario, “Control of multifunctional prosthetic hands by processing the electromyographic signal,” *Critical Reviews in Biomedical Engineering*, vol. 30, no. 4–6, pp. 459–485, 2002.

[2] C. Cipriani, J. L. Segil, J. A. Birdwell, and R. F. Weir, “Dexterous control of a prosthetic hand using fine-wire intramuscular electrodes,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 22, no. 4, pp. 828–836, 2014.

[3] J. T. Belter, J. L. Segil, A. M. Dollar, and R. F. Weir, “Mechanical design and performance specifications of anthropomorphic prosthetic hands: A review,” *Journal of Rehabilitation Research and Development*, vol. 50, no. 5, pp. 599–618, 2013.

[4] L. Resnik, S. L. Klinger, and K. Etter, “The DEKA arm: Its features, functionality, and acceptance,” *Journal of Rehabilitation Research and Development*, vol. 51, no. 4, pp. 451–462, 2014.

[5] M. Asghari Oskoei and H. Hu, “Myoelectric control systems—A survey,” *Biomedical Signal Processing and Control*, vol. 2, no. 4, pp. 275–294, 2007.

[6] M. Ortiz-Catalan, B. Håkansson, and R. Brånemark, “An osseointegrated human-machine gateway for long-term sensory feedback and motor control of artificial limbs,” *Science Translational Medicine*, vol. 6, no. 257, 2014.

[7] A. Fougner, Ø. Stavdahl, P. J. Kyberd, Y. G. Losier, and P. A. Parker, “Control of upper limb prostheses: Terminology and proportional myoelectric control—A review,” *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 20, no. 5, pp. 663–677, 2012.

[8] C. Castellini and P. van der Smagt, “Surface EMG in advanced hand prosthetics,” *Biological Cybernetics*, vol. 100, no. 1, pp. 35–47, 2009.

[9] C. Antfolk, M. D’Alonzo, B. Rosén, G. Lundborg, F. Sebelius, and C. Cipriani, “Sensory feedback in upper limb prosthetics,” *Expert Review of Medical Devices*, vol. 10, no. 1, pp. 45–54, 2013.

[10] K. Kim, J. E. Colgate, J. J. Santos-Munné, A. Makhlin, and M. A. Peshkin, “On the design of miniature haptic devices for upper extremity prosthetics,” *IEEE/ASME Transactions on Mechatronics*, vol. 17, no. 1, pp. 28–38, 2012.

[11] B. Peerdeman et al., "Myoelectric forearm prostheses: State of the art from a user-centered perspective," *Journal of Rehabilitation Research and Development*, vol. 48, no. 6, pp. 719–738, 2011.

[12] P. J. Kyberd and W. Hill, "Survey of upper-limb prosthesis users in Sweden and the United Kingdom," *Journal of Prosthetics and Orthotics*, vol. 23, no. 2, pp. 56–60, 2011.

[13] L. J. Hargrove, A. M. Simon, A. J. Young, R. D. Lipschutz, S. B. Finucane, D. G. Smith, and T. A. Kuiken, "Robotic leg control with EMG decoding in an amputee with nerve transfers," *New England Journal of Medicine*, vol. 369, no. 13, pp. 1237–1242, 2013.

[14] E. Biddiss and T. Chau, "Upper-limb prosthetics: Critical factors in device abandonment," *American Journal of Physical Medicine & Rehabilitation*, vol. 86, no. 12, pp. 977–987, 2007.

[15] L. Zollo, S. Roccella, E. Guglielmelli, M. C. Carrozza, and P. Dario, "Biomechatronic design and control of an anthropomorphic artificial hand for prosthetic and robotic applications," *IEEE/ASME Transactions on Mechatronics*, vol. 12, no. 4, pp. 418–429, 2007.