ISSN: 2249-7196
IJMRR/July-September 2026/ Volume 16/Issue 3/48-56
P. Akshitha / International Journal of Management Research & Review

Arduino-Based Robotic Hand Using Flex Sensors

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Abstract

An Arduino-based robotic hand using flex sensors is an embedded system designed to replicate human hand movements through gesture control. Flex sensors mounted on a glove detect finger bending and send analog signals to the Arduino microcontroller. The controller processes these signals and controls servo motors that move the fingers of the robotic hand accordingly. The system enables real-time actions such as gripping, holding, and releasing objects with good accuracy.

The proposed system is simple, cost-effective, and easy to implement using an Arduino Uno, flex sensors, servo motors, and a wearable glove. It provides smooth and responsive gesture-based control without requiring complex image processing techniques. The robotic hand is suitable for applications in prosthetics, rehabilitation, industrial automation, educational robotics, and human–robot interaction. The implementation demonstrates reliable performance, accurate gesture replication, and efficient object handling, making it a practical solution for low-cost robotic hand development.

Keywords— *Arduino Uno, Robotic Hand, Flex Sensor, Servo Motor, Embedded System, Gesture Recognition, Human–Robot Interaction, Prosthetic Hand, Robotics, Automation.*

Introduction

This project focuses on the design and implementation of an **Arduino-based robotic hand using flex sensors** that can replicate the movements of a human hand in real time. The system uses an Arduino microcontroller as the main processing unit, flex sensors to detect finger movements, and servo motors to control the motion of the robotic fingers. Flex sensors are flexible electronic devices whose resistance changes when they are bent. In this project, the sensors are mounted on a wearable glove. When the user bends their fingers, the flex sensors bend accordingly, resulting in a change in resistance. These resistance variations are converted into voltage signals, which are read by the analog input pins of the Arduino microcontroller.

The Arduino processes the sensor data and converts it into corresponding control signals for the servo motors. Each servo motor is connected to one finger of the robotic hand. Based on the input received from the flex sensors, the

Arduino drives the servo motors so that the robotic fingers move in synchronization with the user's hand gestures, enabling accurate gesture replication.

The robotic hand is constructed using lightweight materials such as acrylic sheets or 3D-printed components. Strings or tendons connect the servo motors to the fingers, allowing smooth, precise, and natural finger movements while keeping the overall structure lightweight and durable.

This project has significant applications in various fields. It can be used in **prosthetic hand development** to assist physically challenged individuals in performing daily activities independently. It is also useful in **rehabilitation systems**, where patients recovering from hand injuries can improve their motor skills through assisted movement. In addition, robotic hands are widely used in **industrial automation**, **hazardous environments**, and **remote manipulation**, where direct human intervention is difficult or unsafe.

Furthermore, this project provides an excellent platform for understanding embedded systems, sensor interfacing, servo motor control, and human–machine interaction. The system can be further enhanced by integrating wireless communication technologies such as Bluetooth or Wi-Fi, implementing machine learning-based gesture recognition, and incorporating haptic feedback to improve functionality and user experience.

Literature Survey

The development of robotic hands has been an important area of research in robotics, biomedical engineering, and embedded systems. Initially, robotic hands were primarily designed as prosthetic devices to assist individuals with limb loss. These early systems were mainly mechanical and offered limited flexibility, movement, and functionality. As technology advanced, researchers focused on developing robotic hands capable of performing more natural and precise movements, making them suitable for a wide range of industrial, medical, and rehabilitation applications.

Various control techniques have been introduced to improve the performance of robotic hands. One widely used approach is based on **Electromyography (EMG)** signals, where electrical signals generated by human muscles are captured and processed to control the movement of the robotic hand. Although EMG-based systems provide accurate and natural control, they are relatively expensive, require complex signal processing, and involve sophisticated hardware. Another approach uses computer vision and image processing techniques to recognize hand gestures through cameras. While vision-based systems offer touch-free operation, they require high computational power and are often affected by lighting conditions, background noise, and camera positioning.

To overcome these limitations, **flex sensor-based robotic hand systems** have gained significant attention due to their simplicity, low cost, and ease of implementation. Flex sensors detect the bending of fingers by changing their electrical resistance, and these analog signals are processed by a microcontroller such as the Arduino to control servo motors attached to the robotic hand. This method provides real-time gesture replication with minimal hardware complexity and has become popular in educational projects, rehabilitation devices, prosthetic systems, and human–robot interaction applications.

Despite considerable progress, existing robotic hand systems still face several challenges, including limited movement accuracy, response delay, calibration issues, and high implementation costs in advanced designs. These factors can affect the overall performance and practical usability of the system. Therefore, there is a continuous need for developing robotic hands that are affordable, reliable, responsive, and easy to operate.

The proposed project addresses these challenges by developing an **Arduino-based robotic hand using flex sensors**. The system focuses on providing accurate real-time gesture replication through simple hardware and embedded programming. By combining flex sensors, servo motors, and an Arduino microcontroller, the proposed design offers a cost-effective, efficient, and user-friendly solution suitable for prosthetic assistance, rehabilitation, industrial automation, educational robotics, and research applications.

Existing and Proposed System

Existing System

Traditional robotic hand systems were developed using mechanical linkages, push buttons, joysticks, potentiometers, or pre-programmed controllers to operate the fingers. These systems required continuous manual control and were unable to replicate natural human hand movements in real time. As a result, finger movements were often slow, inaccurate, and lacked synchronization with the user's gestures. In prosthetic applications, many existing robotic hands provided only basic gripping functionality with limited control over individual fingers.

Several advanced robotic hand systems employ **Electromyography (EMG)** sensors to capture muscle signals for controlling hand movements. Although EMG-based systems provide accurate and natural motion, they require sophisticated signal processing, expensive hardware, and careful calibration, making them unsuitable for low-cost educational and research applications. Similarly, vision-based robotic hand systems rely on cameras and image processing algorithms, which demand high computational power and are affected by environmental conditions such as lighting and background noise.

Another limitation of conventional robotic hands is their high implementation cost, complex circuitry, bulky wired connections, and increased maintenance requirements. The absence of simple gesture-sensing devices such as flex sensors reduces user comfort and limits real-time interaction. Consequently, traditional robotic hand systems are less flexible, less portable, and not easily accessible for beginners or small-scale projects.

Proposed System

The proposed **Arduino-Based Robotic Hand using Flex Sensors** provides a simple, cost-effective, and efficient solution for real-time gesture-controlled robotic movement. The system uses flex sensors mounted on a wearable glove to detect the bending of each finger. The analog signals generated by the flex sensors are continuously read by the Arduino Uno microcontroller, which processes the sensor values and converts them into corresponding control signals for the servo motors. Each servo motor controls an individual robotic finger, allowing the robotic hand to accurately mimic the user's hand movements in real time.

The proposed system offers smooth, synchronized, and responsive finger movement with minimal delay, making it suitable for applications requiring precision and coordination. Since the design uses readily available and low-cost electronic components, it is economical, easy to assemble, and suitable for educational, rehabilitation, prosthetic, and industrial applications. The system is also flexible, allowing the number of flex sensors and servo motors to be modified according to application requirements. Software calibration can be performed to adjust sensor sensitivity and improve gesture accuracy for different users.

Compared to conventional robotic hand systems, the proposed design reduces hardware complexity, lowers implementation cost, improves reliability, and enhances user interaction. Furthermore, the system can be extended by incorporating wireless communication technologies such as Bluetooth or Wi-Fi for remote operation, pressure sensors for touch feedback, and machine learning algorithms for advanced gesture recognition. These enhancements make the proposed robotic hand a scalable and intelligent platform for future human–robot interaction applications.

Hardware Description and Working

The hardware section of the **Arduino-Based Robotic Hand Using Flex Sensors** consists of components that detect finger movements, process sensor data, and generate mechanical motion. The Arduino Uno serves as the central controller, receiving input signals from the flex sensors and controlling the servo motors according to the programmed instructions. Flex sensors are attached to the fingers of a wearable glove to detect finger bending. When a finger bends, the resistance of the corresponding flex sensor changes. This variation in resistance is converted into a proportional voltage signal using a voltage divider circuit and is transmitted to the Arduino Uno through its analog input pins.

The Arduino processes the received analog signals and generates Pulse Width Modulation (PWM) signals to control the servo motors. Each servo motor is connected to a finger of the robotic hand, allowing the robotic fingers to replicate the movements of the user's fingers accurately and in real time. The robotic hand is constructed using lightweight materials such as acrylic sheets, plastic, or 3D-printed components, with strings or tendons connecting the servo motors to the fingers for smooth movement. A regulated power supply provides the required electrical power to the Arduino Uno and servo motors, while jumper wires, resistors, and other electronic components establish reliable circuit connections and ensure proper signal conditioning. The integration of flex sensors, Arduino Uno, servo motors, and the robotic hand mechanism results in an efficient, low-cost, and responsive gesture-controlled robotic system.

Block Diagram

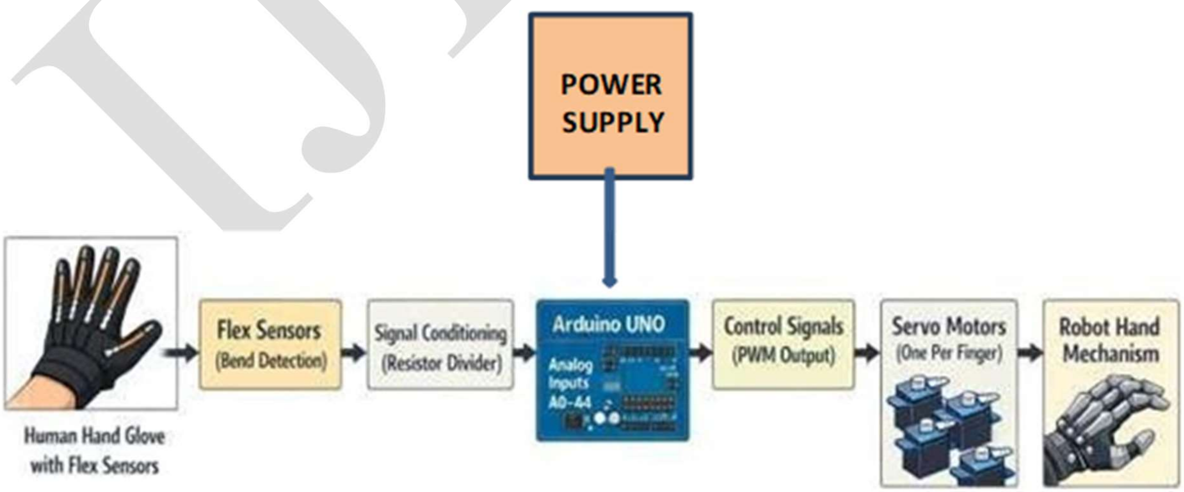

Figure 1; Block Diagram of Arduino-Based Robotic Hand Using Flex Sensors

Block Diagram Description

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The operation of the system begins with a wearable glove fitted with flex sensors, which detect the bending of the user's fingers. As each finger bends, the resistance of the corresponding flex sensor changes, producing an analog electrical signal. This varying resistance is converted into a proportional voltage through a voltage divider circuit, making the signal suitable for processing by the Arduino Uno microcontroller. The conditioned analog signals are applied to the Arduino's analog input pins (A0–A4), where they are continuously monitored and processed according to the embedded program.

Based on the sensor readings, the Arduino Uno generates appropriate Pulse Width Modulation (PWM) control signals to drive the servo motors. Each servo motor is assigned to a specific finger of the robotic hand and rotates to the required angle corresponding to the user's finger movement. As the servo motors operate, they pull the strings or mechanical linkages attached to the robotic fingers, enabling the robotic hand to accurately mimic the movements of the human hand in real time. A regulated power supply provides the necessary electrical energy to both the Arduino Uno and the servo motors, ensuring stable and reliable operation of the entire system. The coordinated operation of the flex sensors, Arduino Uno, servo motors, and robotic hand mechanism enables smooth, responsive, and real-time gesture-controlled finger movement.

Software Implementation

The software implementation of the **Arduino-Based Robotic Hand Using Flex Sensors** focuses on programming the Arduino Uno microcontroller to detect human finger movements and control the robotic hand accordingly. The application software is developed using the **Arduino Integrated Development Environment (IDE)**, where programs are written in **Embedded C/C++** and uploaded to the Arduino Uno. The software continuously acquires analog signals from the flex sensors attached to the user's fingers. These sensor values represent the degree of finger bending and are processed by the Arduino to determine the corresponding movement of each robotic finger.

The received analog values are calibrated, mapped to appropriate servo motor angles, and converted into Pulse Width Modulation (PWM) signals for precise motor control. The program continuously updates the servo positions in real time, enabling the robotic hand to accurately mimic the user's hand gestures. In addition, the software includes sensor calibration, angle limitation, and serial monitoring functions to improve system accuracy and facilitate testing and debugging. Thus, the software serves as the core of the system by coordinating sensor data acquisition, signal processing, and servo motor control to achieve smooth, responsive, and reliable robotic hand movement.

Software Requirement

Arduino IDE

The **Arduino Integrated Development Environment (Arduino IDE)** is an open-source software platform used to develop programs for Arduino microcontroller boards such as the Arduino Uno. It provides a simple and user-friendly interface for writing, editing, compiling, and uploading Embedded C/C++ programs to the microcontroller. The Arduino IDE includes essential features such as a source code editor, compile (Verify) option, Upload function, Serial Monitor, and library management, making it an ideal development environment for embedded system applications.

In the **Arduino-Based Robotic Hand Using Flex Sensors**, the Arduino IDE is used to develop the control program that continuously reads analog signals from the flex sensors, processes the sensor data, and generates PWM signals to control the servo motors. The Serial Monitor is used during testing and debugging to observe sensor values, verify system performance, and calibrate the flex sensors for accurate finger movement. Overall, the Arduino IDE provides an efficient platform for integrating software with hardware, enabling reliable real-time gesture recognition and robotic hand control.

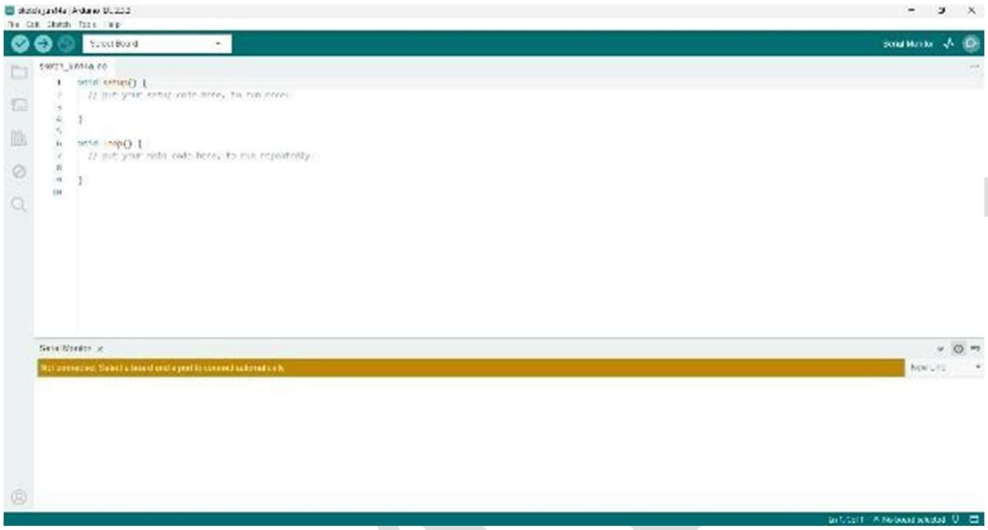

Figure 2; Arduino IDE

Results and Discussion

Results

The developed robotic hand successfully demonstrated real-time gesture-controlled operation using flex sensors and servo motors. The system accurately mapped human finger bending to the corresponding movement of the robotic fingers, with the servo motor angles closely matching the flex sensor input values. Experimental testing showed that small finger bends produced proportional low-angle servo movements, while larger finger bends resulted in greater angular displacement, indicating effective and nearly linear control.

The response time of the system was very low, enabling smooth and real-time synchronization between the human hand and the robotic hand. Repeated experiments confirmed consistent performance, with identical finger movements producing nearly identical servo positions during each trial. The robotic hand successfully performed various actions, including gripping small objects, holding lightweight items, and demonstrating simple hand gestures. Although minor fluctuations in servo position were observed due to analog signal noise, the overall system remained stable and reliable. The system also operated continuously without significant overheating or power-related issues when powered by a regulated supply. The achieved range of finger motion was sufficient for basic robotic manipulation, prosthetic assistance, educational demonstrations, and rehabilitation applications. Overall, the developed system provided good movement accuracy, depending on proper sensor calibration and component quality.

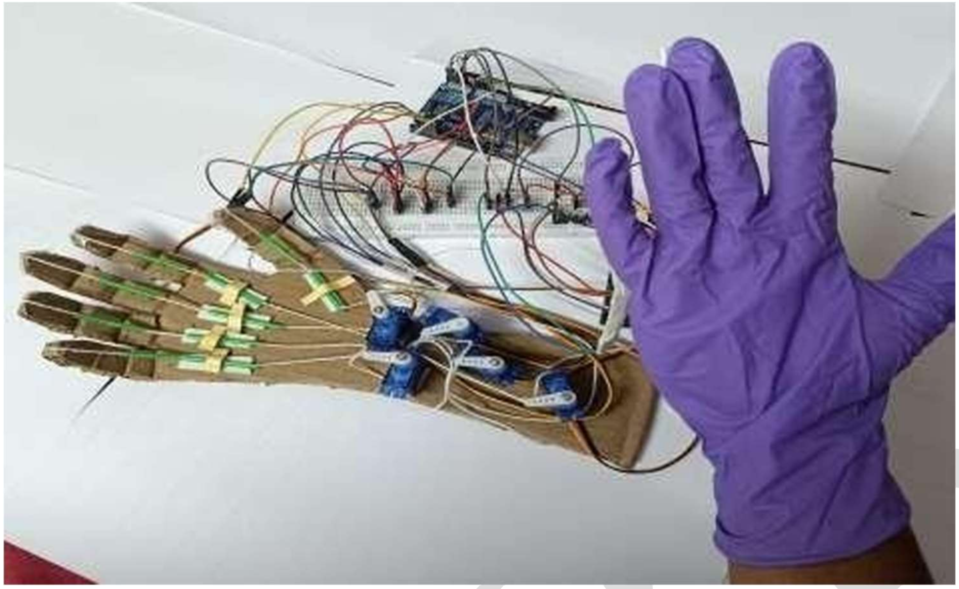

Figure 3; Flex Sensor Controlled Robotic Hand System

The output shown in the developed prototype demonstrates the successful operation of the Arduino-based robotic hand controlled by flex sensors. The flex sensors attached to the glove detect the bending of the user's fingers and convert the movements into analog electrical signals. These signals are processed by the Arduino Uno, which generates PWM control signals for the servo motors mounted on the robotic hand. As a result, the robotic fingers accurately mimic the movements of the user's fingers in real time. The experimental results confirm smooth, coordinated, and responsive gesture replication, demonstrating effective human–machine interaction.

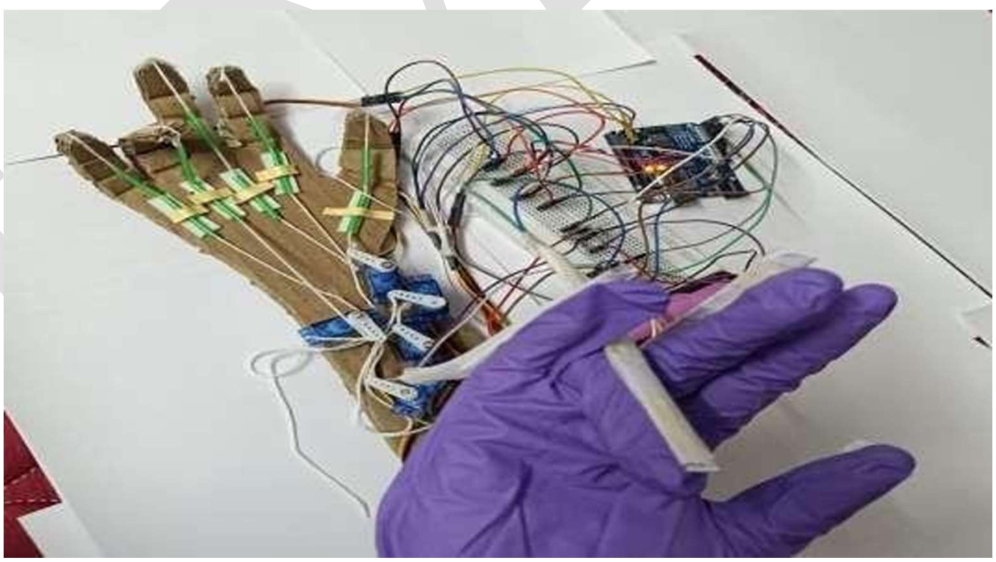

Figure 4; Working of Servo Motors Based on Flex Sensors

Discussion

The performance of the Arduino-based robotic hand depends primarily on the accuracy of flex sensor calibration, signal stability, and the mechanical design of the robotic hand. Proper calibration enables accurate mapping of flex sensor readings to servo motor angles, ensuring precise finger movement. Minor fluctuations caused by analog signal noise can affect servo positioning, but these can be reduced through filtering techniques and improved sensor calibration. The mechanical arrangement of the servo motors, strings, and finger joints also plays a significant role in determining the smoothness, flexibility, and range of motion of the robotic fingers.

The experimental results show that the system provides fast response, reliable gesture recognition, and smooth finger movement with minimal delay. Although the system operates as an open-loop controller without positional feedback, it performs effectively for basic gesture replication and object manipulation tasks. The use of low-cost components such as the Arduino Uno, flex sensors, and servo motors makes the system economical, easy to implement, and suitable for educational, rehabilitation, prosthetic, and research applications. Future improvements such as force feedback, closed-loop control, wireless communication, and machine learning-based gesture recognition can further enhance the accuracy, functionality, and practical usability of the robotic hand.

Conclusion

The **Arduino-Based Robotic Hand Using Flex Sensors** is a successful implementation of a real-time gesture-controlled robotic system that accurately replicates human hand movements. By integrating flex sensors for finger motion detection, an Arduino Uno microcontroller for signal processing, and servo motors for actuation, the system provides smooth, coordinated, and responsive finger movements. The project demonstrates that low-cost hardware components can be effectively combined to develop an efficient robotic hand suitable for educational, rehabilitation, prosthetic, and automation applications.

The developed system offers reliable performance with accurate gesture replication, simple hardware design, and easy implementation. It provides an excellent platform for understanding embedded systems, sensor interfacing, servo motor control, and human–machine interaction. Although the system operates as an open-loop controller and depends on proper sensor calibration for accurate movement, it performs efficiently for basic gripping, object handling, and gesture-based control. Overall, the project serves as a cost-effective and scalable solution that forms a strong foundation for future developments in robotics and assistive technologies.

Future Scope

The proposed robotic hand can be further enhanced by integrating **wireless communication technologies** such as Bluetooth or Wi-Fi, allowing the robotic hand to be controlled remotely without wired connections. This would improve user convenience, flexibility, and portability.

The system can also be improved by incorporating **force and pressure sensors** on the fingertips to provide better grip control and prevent damage to delicate objects. Implementing a **closed-loop feedback system** using position or angle sensors would enable automatic correction of finger movements, resulting in higher accuracy, precision, and reliability. Replacing the Arduino Uno with more advanced microcontrollers such as the **ESP32** or **Raspberry Pi** can provide faster processing, multitasking capabilities, and built-in wireless connectivity, making the system more powerful and scalable.

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Future research may also integrate **Machine Learning (ML)** and **Artificial Intelligence (AI)** techniques to recognize complex hand gestures, adapt to different users, and enable applications such as sign language recognition and intelligent robotic control.
The mechanical structure of the robotic hand can be further improved by using lightweight materials, flexible joints, and optimized linkage mechanisms to achieve smoother, faster, and more natural finger movements. In addition, the project can be extended to develop **advanced prosthetic hands** by integrating **Electromyography (EMG)** sensors, allowing the robotic hand to be controlled directly through human muscle signals. Such enhancements would significantly increase the system's practicality and expand its applications in healthcare, industrial automation, rehabilitation, research, and human–robot interaction.

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