Exploration of 3D Printing in Single-Hand Prosthetic Robotic Designs

Mahadevi K C[1], Smitha H.S[2], Pavitra S R[3]
[1]*Lecturer, Department of Electronics and Communication Engineering, Government Polytechnic, Nagamangala, Karnataka, India*
[2]*Lecturer, Department of Electronics and Communication Engineering, Government Polytechnic, Kushalnagara, Karnataka, India*
[3]*Lecturer, Department of Electronics and Communication Engineering, Government Polytechnic, Kushalnagara, Karnataka, India*

***Abstract*— Prosthetic arms serve as a foundation for creating robots that closely resemble living organisms, enhancing their lifelike appearance. These prosthetics utilize various power sources, such as pneumatics (compressed air), hydraulics (pressurized oil), and electricity, to drive their functions. To achieve realism, the design is meticulously tailored, replicating the precise measurements and ratios found in real-world organisms. Motion actuators are implemented to simulate muscle-like movements, enabling realistic limb motions. Furthermore, the prosthetic structure is enveloped in flexible skins and body shells composed of soft and hard plastics, enhancing its tactile authenticity. Additional details, such as colors, hair, and feathers, are incorporated to further refine the visual and tactile realism of the robotic figure. A significant focus of this design is the replication of human hand kinematics. The robotic hand mimics the range of motion in each joint, achieving movements that are nearly identical to those of a human hand. This includes complex actions like the palm flexion of the little finger, ensuring functionality comparable to human anatomy. By aligning mechanical performance with human biomechanics, this prosthetic arm design exemplifies a convergence of engineering precision and biological mimicry. The result is a highly realistic robotic hand that offers a compelling fusion of functionality, aesthetics, and lifelike motion, advancing the boundaries of robotic prosthetic development.**

***Index Terms*— Arduino, programming, servo drives, Flex sensors, power integrated circuit.**

I. INTRODUCTION

This work explores various topologies and designs related to developing an animatronic hand built on an Arduino platform. While more advanced and costly versions of this concept exist, this is an enjoyable project with diverse potential applications. The interactive control offered by this system has numerous uses, including medical research, industrial manufacturing, and other scenarios requiring precision in hazardous environments. The hand's core components include servos, an Arduino board, a glove, and flex sensors. Flex sensors, variable resistors that change their value when bent, are mounted on a glove. They are part of a voltage divider, paired with fixed resistors on the other side. When the sensors bend, the Arduino reads the voltage change and triggers the servos to move proportionately, pulling threads that act as tendons to facilitate finger movement.

Robotic arms, known for their precision and efficiency, have become essential in industries such as manufacturing and medicine. These machines excel at performing repetitive and precise tasks with unmatched consistency, making them invaluable in situations where human intervention is impractical or unsafe. Despite their benefits, traditional robotic arm control methods often demand significant expertise, posing a steep learning curve for many users. This challenge has driven the search for more intuitive control mechanisms that make robotic systems easier to operate and more accessible to a broader audience.

The development of humanoid robots has garnered significant attention in recent years due to their vast potential applications. This bachelor's thesis in mechatronics presents the creation of one such robotic system in the form of a hand. The primary goal was to determine how effectively the robotic hand could replicate the motions of a user-worn glove controller while gripping objects, using wireless communication. The project highlights the growing interest and advancements in humanoid robotic systems, emphasizing their practicality and future potential.

II. RELATED WORK

This section presents a concise review of advancements in printed prosthetic robotic technology, highlighting innovative approaches and methods in the field.

Kosuke Jin et al. [1] introduced a 3D-printed myoelectric prosthetic hand aimed at achieving stable prosthetic control during dual-arm operations. Their proposed system leverages a state-transition model designed for managing dual-arm tasks commonly performed in daily life. By combining Electromyography (EMG) signals with task classification results derived from posture data, the system ensures precise task execution. A recurrent probabilistic neural network is employed to discriminate tasks effectively, using posture information from both arms. This innovative approach enhances the control and functionality of prosthetic devices, addressing complex dual-arm coordination with improved accuracy and efficiency.

Arnav Jain et al. [2] explored the concept of transhumanism, where robotics and biomimetics are used to push beyond human physical and mental limits. Their work focuses on developing affordable, lightweight, and durable 3D-printed prosthetic arms, inspired by the biomechanical designs of human anatomy. Despite advancements in lower-extremity prosthetics enabling amputees to compete at professional levels, upper-limb prosthetics still fall short in replicating the functionality of real hands.

Syed Ammad Ali Haider et al. [3] highlighted the significance of prosthetics in improving the lives of individuals with physical disabilities. Their research involves designing and constructing a 3D-printed prosthetic hand equipped with flex sensors to emulate human hand functionality. The study also introduces radio frequency-based wireless control for positioning and operating the prosthetic hand, enhancing ease of use and functionality.

Divya Raut et al. [4] presented a functional prototype of an automated prosthetic arm. The paper emphasizes that while technological advancements have enabled prosthetics to function like real arms, the high costs make them inaccessible to the general population, particularly in developing nations. Their research aims to address this gap by designing cost-effective prosthetic solutions that meet functional needs.

Riccardo Galviati et al. [5] tackled the challenge of replicating the human upper limb due to its complex structure and control requirements. Their project focuses on creating an IMU-based control system for the Hannes ARM upper-limb prosthetic. This proof-of-concept introduces data-fusion techniques to enable adaptive control, inspired by natural human upper-limb regulation through multi-stimuli integration.

Charbel Tawk et al. [6] developed a 3D-printed soft robotic hand, 'ACES-V2,' with embedded soft sensors for prosthetic use. Designed for myoelectric control systems, it features a monolithic, low-cost structure with minimal post-processing. The hand is lightweight (313 grams), anthropomorphic, and includes position sensors to prevent self-collision. This design improves gesture transition speed and efficiency, while multi-stage grasping enhances dexterity for handling multiple objects.

David Lanigan et al. [7] presented a low-cost, 3D-printed robotic hand equipped with temperature and pressure sensors in the fingertips. With 15 degrees of freedom and five actuators, it grips household items. Controlled by an Arduino Mega, the hand uses sensor feedback for responsive interactions, making it suitable for mechatronics education.

Ali Bin Junaid et al. [8] proposed a bio-mechatronic design for an anthropomorphic robotic hand. Using forward kinematics and MATLAB® simulations, the system mimics natural finger movements. Camera-based gesture recognition and tactile sensors provide feedback for precise gripping, enabling handling of delicate objects. This research highlights the complexity of replicating human hand functionality.

III. MATERIALS AND METHODS

Figure 1 illustrates the block diagram of both the transmitter and receiver sides, offering a comprehensive overview of the entire system and the components utilized. The diagram is divided into two parts: the transmitter side and the receiver side. Movement signals are transmitted from the transmitter side, where flex sensors in the glove capture the hand's movements. These signals are then sent to the receiver side. On the receiving side, various components work together to process the signals. A microcontroller is used to interpret the flex sensor data from the glove and translate the movement information into commands for the robotic hand. The signals received from the transmitter side correspond to the bending or flexing of the fingers, which are relayed to the receiver. The microcontroller processes these signals and sends the appropriate commands to the robotic hand to replicate the movements of the user's hand.

In this setup, the transmitter side acts as the input source, capturing the user's hand movements through the flex sensors in the glove. The receiver side, equipped with a microcontroller and robotic hand, receives and processes these signals to control the robotic hand's motions. This system effectively allows the translation of human hand gestures into corresponding robotic actions, enabling a seamless interface between the user and the prosthetic device. The interaction between the transmitter and receiver sides is essential for achieving accurate and responsive control of the robotic hand.

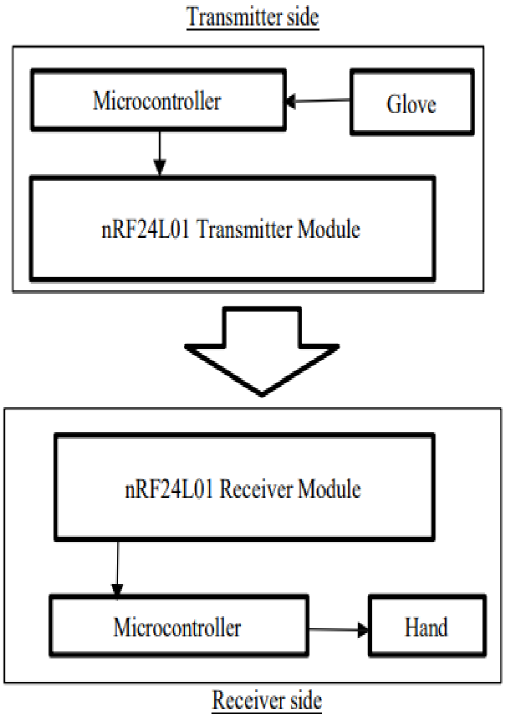

Fig.1 Block Diagram Transmitter and Receiver side

3.1 Arduino Uno

Developed by Arduino.cc, the Arduino Uno is an open-source microcontroller board that is based on the Microchip ATmega328P microcontroller. Sets of digital and analogy input/output (I/O) pins on the board allow it to be interfaced with other expansion boards (shields) and other circuits. The board may be programmed using the Arduino IDE (Integrated Development Environment) and a type B USB cable.

3.2 Servomotor (SG90)

A servo motor is a kind of motor that is driven by a DC source, which could be a controller or an external supply. The micro service motor sg90 is a compact, lightweight servo motor that has a high output power. This implies that the sg90 micro servo motor will only use as much force as necessary to finish the task at hand. There are many uses for SG90 servo motors, such as industrial automation, robotics, telescopes, cameras, and antennas.

3.3 Servomotor (MG996R)

The MG996R Digital Servo, which boasts metal gearing, can achieve an exceptionally high 10kg stalling torque inside a compact design. The MG996R servo is essentially an improved version of the well-known MG995 servo, with revised PCB and IC control system and improved shock- proofing. That compared to its predecessor, make it far more accurate.

3.4 Flex Sensors

Bend or flex sensors are sensors that measure the amount of bending or deflection. Usually, the surface has the sensor attached to it, and the surface can be bent to change the sensor element's resistance. Because the resistance is precisely proportional to the bend, it is also known as a flexible potentiometer and is utilized as a goniometer.

3.5 Accelerometer

An accelerometer is a tool used to measure acceleration and is frequently used to track and record changes in orientation and motion. These forces might be dynamic-arising from motion or vibrations-or static-like the force of gravity.

3.6 nRF24L01

The NRF24L01 is a wireless transceiver radio frequency module that has data sending and receiving capabilities. Nearly all countries have approved the technology for engineering purposes because it runs on the 2.4 GHz ISM band.

IV. DESIGN AND IMPLEMENTATION

An animatronic hand is a robotic system designed to mimic hand movements based on input from a glove equipped with flex sensors. These sensors detect bending movements of the glove fingers and send corresponding data to a servomotor. The servomotor then rotates at an angle based on the input it receives from the flex sensor. A string connects the servomotor to the robotic finger, allowing the finger to bend in synchronization with the motor's rotation. As the flex sensor bends, its resistance changes, which is processed by an Arduino microcontroller. The Arduino translates this change into signals for the servomotor, enabling precise rotation based on the detected resistance.

The linkage between the flex sensor and the servomotor is achieved through the Arduino, creating an interface that ensures smooth communication and operation. Additionally, a voltage divider circuit, requiring only a lower voltage, is integrated near the flex sensor to enhance efficiency. When the servomotor receives input, it generates rotational movement, which in turn moves the robotic fingers through the string connection. This design facilitates accurate replication of finger movements, making the animatronic hand an effective and responsive system.

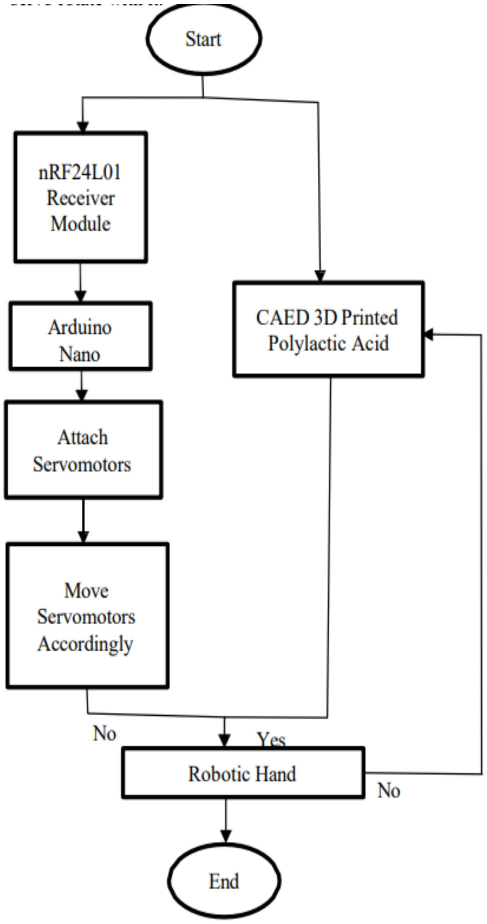

Fig 2. Flow Chart of the Glove

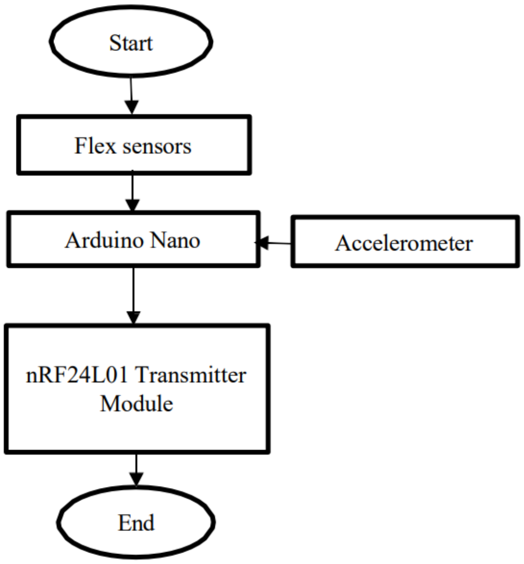

Fig 3. Flow Chart of the Robotic Hand

A. Implementation

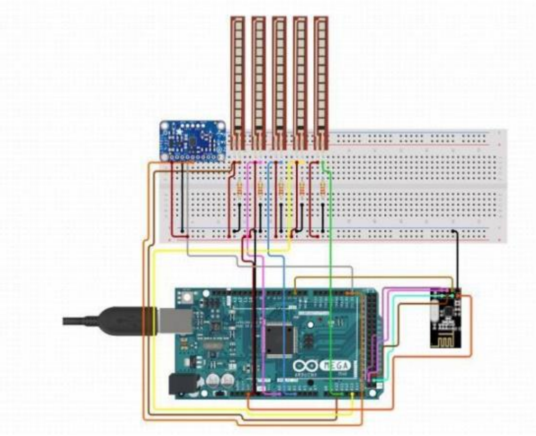

Fig 4. Circuit Connection of Glove

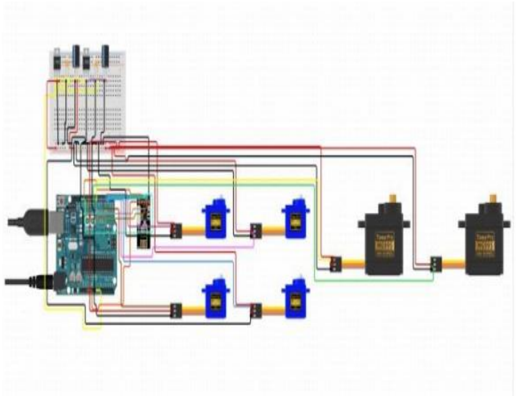

Fig. 5. Circuit Connection of Robotic Hand

These are the steps of implementation

4.1 Configure the Sensor Circuit

For the Flex sensors to work with the Arduino, a circuit is needed. It functions as a voltage divider because the flex sensors are variable resistors that, when combined with resistors of a static value, allow a change in resistance—in this example, bending the sensor—to be detected by measuring the difference in voltage between the resistors.

4.2 Mount the PCB on Gloves

The circuit was then put onto a tiny PCB. One that was simple to attach to the glove. Additionally, soldering the wires to the sensors was not too difficult for us, and we used heat shrink to ensure there were no shorts. In order to stabilize the sensors, we next applied super adhesive to the area where the wires are attached to the sensors.

4.3 Installation of Flex sensors

It's now time to attach the sensors to the glove and connect their circuit. With the help of super adhesive gum, the flex sensors are attached to the gloves. The adhesives are applied over top and bottom portion of flex sensors instead on the resistive material of the flex sensor which going to be bend.

4.4 Flex sensors, Accelerometer and nRF module connections with the Arduino

One of the two terminals of all the four flex sensors are provided 5V power supply via Arduino and other terminal of all four flex sensors which are connected via 10k ohm resistors are connected to analog pins of Arduino(A2-A5) and they are grounded as well. Accelerometer connections are such that X-in and Y-in Pins are connected to Analog pins (A0 & A1) of Arduino respectively. While Vcc and Ground have separate connections with Arduino extension. nRF module connections are such that CS, CE, MOSI, MISO, SCK are connected to digital pins of Arduino (D9-D13) in same order sequence. While Vcc and Ground have separate connections with Arduino extension.

4.5 Robot Claw Hand and Servo Motor Constructions

The 4 servo motors (SG90 Model) are clamped and adjusted at the back of the palm and are attached on the PCB with the help of hot glue gun. The other two servo motors (MG996R) are fixed on the stick with the help of L-Clamp at the wrist and elbow positions respectively.

4.6 Including the strings

The hardest and most painstaking part of this project is definitely adding the strings. It's easy to understand conceptually, but hard to carry out in practice. Keep in mind that threading the fingers requires patience. The one distinction between how I installed the strings. We configured the servo motor such that it could precisely and flexibly move our fingers.

4.7 Servo motor wiring with the Arduino

We used the Arduino PWM pins to connect the two servos that were placed on the elbow part and the other four servo motors that were put on the servo-bed. The PWM input wire (orange) for each servo would be attached to the Arduino pins as follows:

Servo One - PWM -> Digital 2 Servo Two - PWM -> Digital 3 Servo Three - PWM -> Digital 4 Servo Four - PWM -> Digital 5 Servo Five - PWM -> Digital 6 Servo Six - PWM -> Digital 7

4.8 nRF module connections with the Arduino

nRF module connections are such that CS, CE, MOSI, MISO, SCK are connected to digital pins of Arduino (D9-D13) in same order sequence. While Vcc and Ground have separate connections with Arduino extension.

4.9 Wiring the entire circuit and implementing

We built the primary circuit for execution by assembling all of the stationary circuits together after finishing the previously specified phases. We built the primary circuit for execution by assembling all of the stationary circuits together after finishing the previously specified phases. Uploading the Arduino sketch to our board is the last step. The hand should begin its calibration procedure by advancing each servo through its range of motion as soon as the Arduino resets. We put on the glove, plugged in the Arduino and servo battery, and then ran the program after downloading the file to the Arduino and verifying that all the connections to the glove and servos are right. putting on the glove and flexing the finger associated with the servo under repair. Next, we made servo ring adjustments. The servos turned based on the number of fingers.

IV. RESULTS AND DISCUSSIONS

The work focus with a security patrolling robot that uses night vision camera for securing any premises. The robotic vehicle moves at particular intervals and is equipped with night vision camera and sound sensors. It uses a predefined line to follow its path while patrolling. It stops at particular points and moves to next points if sound is detected. The system uses IR based path following system for patrolling assigned area. It monitors each area to detect any intrusion using 360degree rotating HD camera. It has the ability to monitor sound in the premises. Any sound after company is closed and it starts moving towards the sound on its predefined path. It then scans the area using its camera to detect any human faces detected. It captures and starts transmitting the images of the situation immediately on sound or human face detection. Here we use IOT gecko for receiving transmitted images and displaying them to user with alert sounds. Thus, we put forward a fully autonomous security robot that operates tirelessly and patrols large areas on its own to secure the facility.

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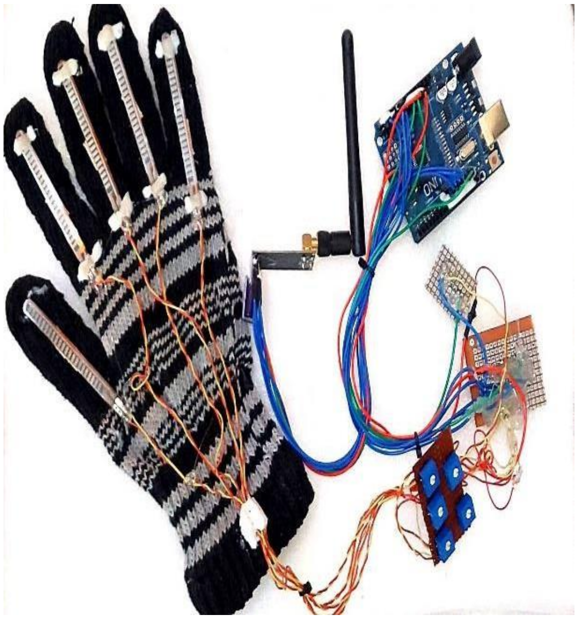

Fig 6: Glove

The grip test results demonstrated that the robotic hand could effectively handle only objects with some flexibility, such as soft to semi-soft items. It was capable of supporting a maximum weight of approximately 134 grams. While the hand could grasp various shapes, oblong and cylindrical objects were the easiest to hold, followed by lightweight spherical and rectangular items. This limitation arises from the robotic hand's restricted ability to execute a spherical volar grasp.

The robotic hand's ability to mimic and respond to operator movements was evaluated through three distinct test phases. In the first phase, each finger was contracted individually on the robotic hand using the operator glove. Wrist motion imitation was assessed by observing the glove's rotation corresponding to the wrist's rotation. In the second phase, several hand movements were performed while wearing the glove. During the third phase, the hand was continuously tested to perform combined finger and wrist motions.

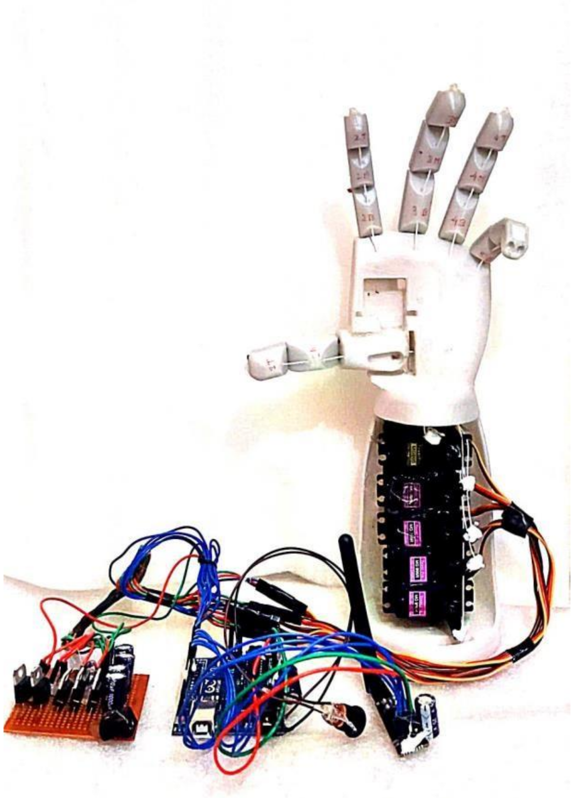

Fig 7: Robotic hand

V. CONCLUSION

Our model's primary development challenge is "latency," the delay between a surgeon's command and the robot's corresponding action. This limitation means the model is currently best suited for small-scale surgical procedures. However, given the state of current technology, the surgeon must remain in close proximity to the robot.

Robot control involves synchronizing a robot's sensory input with its actions. While robot control methods vary widely, each fit into a specific control framework, with no universally superior approach. Every method has distinct advantages and drawbacks. Robotics has brought remarkable improvements in surgical precision and efficiency, yet certain challenges persist. Ongoing research focuses on reducing latency, enhancing wireless communication, and enabling simultaneous movement of two servos. To address these issues, a user-provided flex sensor was implemented to wirelessly control a robotic arm.

The field of robotic hands continues to evolve rapidly. In the near future, robotic hands may perform tasks as effectively as human hands, if not more efficiently. The integration of brain-computer interfaces could revolutionize control systems, allowing the human brain to directly transmit signals to the robotic hand. This would enable the hand to mimic human functionality closely, creating a seamless interaction between human intention and robotic execution.

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