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Next-Gen Dual-Control Myoelectric Prosthetic Arm: Bridging Affordability and Accessibility

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Abstract: In order to improve functionality and user interaction, this work presents a dual-control myoelectric prosthetic arm that integrates voice recognition with electromyographic (EMG) signals. The system uses a voice recognition module to process spoken commands, an EMG sensor to detect muscle activity, and five MG995 servo motors for multi-joint movement. An ESP8266 microcontroller handles control. It combines these inputs using a unique dual-mode algorithm created in the Arduino Integrated Development Environment (IDE), allowing for smooth transitions between control modes. Stable power delivery is ensured by an LM2596 voltage regulator and a 12V adaptor. When compared to conventional single-input prosthetic designs, experimental results show notable gains in control accuracy and adaptability. By providing more flexible and intuitive control options, this affordable and user-friendly approach seeks to enhance the quality of life for prosthetic users.

Keywords: Myoelectric control, voice recognition, EMG sensor, ESP8266 microcontroller, Arduino IDE, dual-control prosthesis, assistive technology, and MG995 servo motors.

1.INTRODUCTION

Myoelectric prosthetic arms are a significant leap in assistive technology, allowing people with limb loss to restore functional mobility using electromyographic (EMG) impulses. Surface electrodes on these prosthetic devices monitor muscle activity in the residual limb, which is subsequently processed by microcontrollers to control motorized hand movements [3]. Traditional prosthetic options, such as body-powered or passive prostheses, have limited dexterity and require significant physical effort, whereas myoelectric devices enable more natural and intuitive control [2]. Despite these advances, signal unreliability, restricted motor control, and high prices all impede the general use and efficiency of myoelectric prostheses [1]. The inability to accurately interpret muscle signals is one of the main problems with myoelectric prosthetic control, which results in decreased precision and functional limitations in practical applications. Noise, changes in skin impedance, and electrode displacement can all have an impact on surface EMG signals, leading to inconsistent movement execution [5]. Furthermore, contemporary myoelectric hands lack the dexterity needed for complex activities, primarily supporting simple grabbing and releasing operations. In order to overcome these constraints, researchers have investigated hybrid control strategies that aim to improve the flexibility and accuracy of prosthetic motions. These strategies include integrating myoelectric signals with voice recognition or sensor-based feedback mechanisms [4]. Myoelectric prosthetic arms are being developed with the primary goal of creating an affordable, highly responsive, and user-friendly control system that allows users to execute a variety of hand functions with ease. Prosthetic arms that incorporate multimodal control, including EMG with speech recognition, can provide increased user flexibility and dependability [6]. Accurate control and prosthesis usability can also be improved by adding real-time feedback systems as haptic feedback and AI-driven motion prediction [7]. By offering a prosthetic device that closely resembles natural hand performance and is both accessible and reasonably priced, these developments are significant because they will help amputees live better lives. To develop adaptable, intelligent prosthetic arms, future research should concentrate on improving hybrid control techniques, lowering signal variability, and incorporating cloud-based learning systems [8].

2. LITERATURE SURVEY

Myoelectric prosthetic arms, which use electromyography (EMG) impulses from remaining muscles to control artificial limbs, have become a viable option for those who have lost limbs. Current technologies use surface electrodes to monitor muscle activity, which is subsequently converted into motorized movements, demonstrating the enormous evolution of the field. To improve dexterity and intuitiveness, contemporary innovations include hybrid control techniques, machine learning-based motion classification, and real-time feedback systems [1]. Nevertheless, despite advancements in technology, there are still issues in precisely determining user intent and attaining smooth control, which motivates continued research. Typically, myoelectric prosthetic hands use surface EMG sensors to record muscle signals, which are subsequently processed by pattern recognition algorithms and microcontrollers. More precise movements are now possible thanks to advanced control techniques like proportional control, and the incorporation of artificial intelligence (AI) has further increased the adaptability of prosthetic systems [2]. According to [3], recent advancements

include multi-DOF prosthetic hands that have wireless connectivity for remote monitoring, force sensors, and tactile feedback systems. Notwithstanding these developments, the majority of commercially available prosthetic arms—including the Michelangelo Hand, Bebionic, and DEKA Arm—continue to have issues with functional adaptability and intuitiveness [4]. The absence of dependable and sturdy control interfaces that can precisely decipher muscle signals in dynamic situations is one of the main issues with myoelectric prosthesis. Signal irregularities are frequently caused by surface EMG signals being impacted by elements such skin impedance, perspiration, and electrode movement [5]. Additionally, current prosthetic hands frequently lack the dexterity needed for complicated daily living activities, being restricted to basic gripping and releasing operations. The integration of sensory feedback is further limited by a void in real-time, bidirectional communication between the prosthesis and its user [9]. Furthermore, a huge number of amputees cannot afford myoelectric prosthetic devices due to their high cost, highlighting the need for less expensive alternatives. Many control systems have been investigated by researchers in an effort to get around these restrictions. Myoelectric signals have been combined with other control modalities as voice commands, computer vision, and brain-machine interfaces (BMI) to create hybrid control systems [6]. With encouraging outcomes in real-time control applications, some research has concentrated on deep learning-based EMG data classification to improve movement prediction accuracy [10]. Furthermore, to increase the accuracy and detection of gestures, multimodal techniques that combine EMG with force sensors and accelerometers have been developed [7]. One noteworthy development is the introduction of haptic feedback systems, which enhance control and the user experience by enabling users to sense the force applied by the prosthetic hand [11]. Considering the present constraints of myoelectric prosthetic hands, a dual-control system that combines voice recognition with EMG inputs offers an intriguing avenue for future research. Voice-controlled prosthetics have shown great promise in streamlining the execution of movements, especially for those with weak residual muscular activation [8]. A more flexible and user-friendly system that enables users to adjust control modes according to the job at hand can be created by fusing voice instructions with EMG-based myoelectric control. This method can increase accuracy, lessen mental strain, and boost user happiness. Prosthetic performance can also be further optimized by integrating cloud-based data processing and Internet of Things (IoT) connectivity, which can enable remote monitoring and adaptive learning. A multimodal control approach that integrates bioelectrical and exterior input signals is an essential step in creating next-generation artificial limbs as myoelectric prosthetics continue to advance.

3. PROPOSED METHODOLOGY

To improve the usability and accessibility of myoelectric prosthetic arms, we suggest a new approach that combines voice recognition and electromyographic (EMG) signals for dual-modal control. According to [3], this strategy seeks to address issues such signal irregularity, poor dexterity, and a lack of adaptability in earlier prosthetic systems. Five MG995 servo motors, selected for their high torque, accuracy, and dependability in robotic applications, are used in our design to ensure smooth multi-joint movement of the prosthetic limb [1]. According to [7], these motors are perfect for prosthetic applications that need precise control because they have proven to work exceptionally well in a variety of robotic systems. The MyoWare EMG sensor, which records electrical signals produced by muscle contractions, is used to monitor muscle activity. This allows for intuitive control based on physiological data [2]. Though they have demonstrated great promise in offering a more natural user experience, EMG-based prosthetic control systems frequently exhibit fatigue-related irregularities and signal quality fluctuations [4]. In order to overcome this, we present a second voice recognition control mode that enables users to give verbal commands to the prosthetic arm. Assuring more inclusive usability, this feature enhances accessibility for those with weak or irregular muscle signals [6]. Because of its Wi-Fi functionality and computational efficiency in managing multimodal input integration, the ESP8266 (NodeMCU) microcontroller serves as the central processing and control unit of our system [8]. According to [5], the ESP8266 facilitates responsive and seamless management of the prosthetic arm by processing voice commands and EMG signals in real-time. To maintain ideal power levels for all electrical components, we use an LM2596 voltage regulator in conjunction with a 12V converter to provide steady and effective power distribution. To avoid variations that could impair motor function or sensor accuracy, voltage management is essential in prosthetic systems [7]. Five infrared sensors are incorporated into our design to improve adaptability in a variety of operational conditions. These sensors help to improve movement precision and detect obstacles. By identifying nearby objects and averting accidental collisions, these sensors increase the safety and accuracy of prosthetic limb operation (Gonzalez et al., 2021). A DC connector also guarantees dependable power input, which improves system stability and prolongs component life [8]. Our suggested methodology overcomes the drawbacks of current prosthetic designs by combining dual control via voice recognition and EMG, enhancing dexterity, versatility, and usability. Because of this hybrid approach, users with different levels of muscle control can operate the prosthetic more easily because it lessens dependency on a single control modality [3]. The integration of wireless and real-time processing through the ESP8266 also establishes the groundwork for future improvements like cloud-based adaptive learning and remote control features [4]. For those in need of a highly functioning but reasonably priced prosthetic limb, our system is a feasible option because it is made to be affordable without sacrificing performance [1].

3.1 System Overview

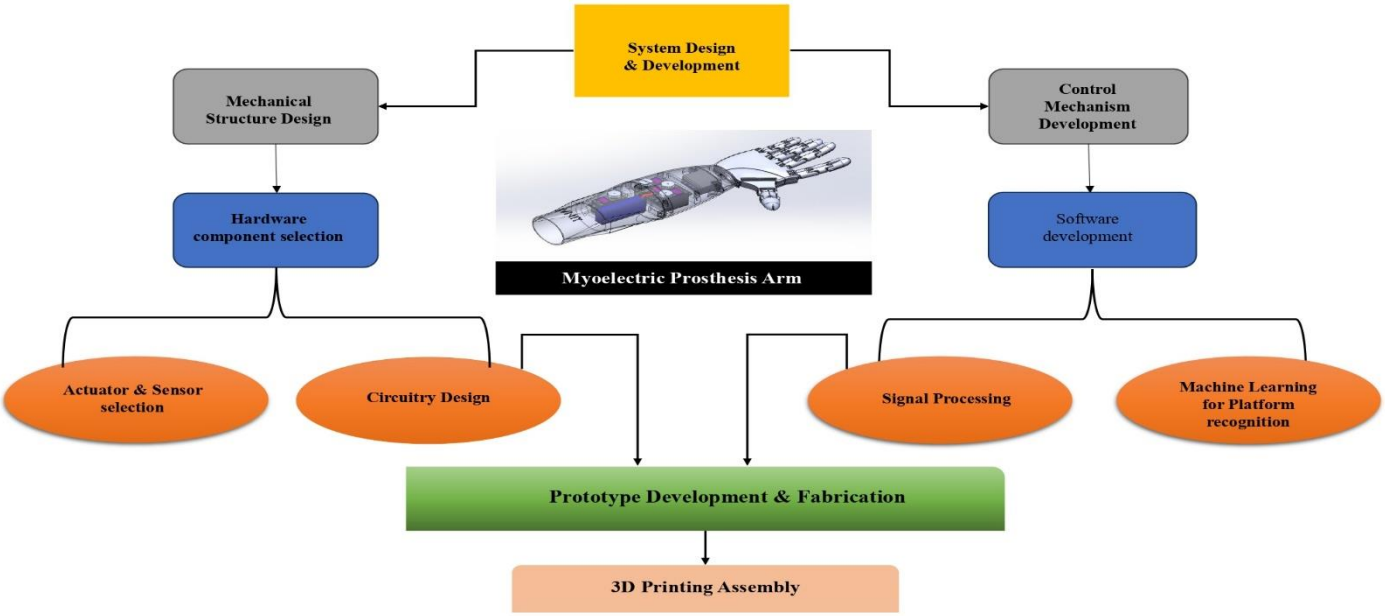

Figure 1: Dual-control Myoelectric Prosthetic Arm

3.2 Control Strategy

Electromyographic (EMG) signals and voice recognition are integrated into the dual-control myoelectric prosthetic arm's control scheme to improve accessibility and user flexibility. The EMG sensor is the main control input for prosthetic movement because it records the electrical activity produced by muscle contractions. The ESP8266 microcontroller transforms these data into precise servo motor motions by interpreting the amounts of muscle activation. A voice recognition module is integrated to supplement EMG-based control, enabling users to carry out preset orders by speaking instructions. This is especially helpful for people with erratic or weak EMG signals. Using a preset algorithm, the microcontroller effectively transitions between the two control modes, guaranteeing seamless and instantaneous operation. Five infrared (IR) sensors are also integrated for obstacle detection, improving security and enabling automated movement adjustments. A 12V adapter and an LM2596 voltage regulator handle power management, guaranteeing steady voltage levels for optimum performance. In order to overcome the drawbacks of traditional single-input myoelectric prosthetic designs, different control techniques are being integrated to increase responsiveness, decrease delay, and offer a more versatile and intuitive user experience.

3.3Hardware and sensor used in dual-control myoelectric prosthesis arm

3.3.1 MG995 Servo Motor

A popular high-torque metal gear servo motor in robotic and prosthetic applications, the MG995 is renowned for its dependability, accuracy, and longevity. It can be used to actuate the joints of the prosthetic arm because it runs between 4.8 and 7.2 volts and can produce up to 10 kg/cm of torque at 6 volts. PWM control, which is supported by the motor, enables accurate angular movement in response to changes in the signal from the ESP8266 microcontroller. Its metal gear structure ensures long-term performance even under repetitive mechanical stress by improving wear resistance.

Figure 2: MG995 Servo Motor

3.3.2 Infrared (IR) Sensor

Infrared light is emitted by the IR sensor, an obstacle detection device that senses reflections from surrounding objects. In order to improve safety and avoid unintentional collisions, this prosthetic arm uses five infrared sensors to detect obstructions in the user's surroundings. These sensors provide real-time distance calculation by timing how long it takes for the infrared photons to be reflected back. To ensure the arm functions securely in a variety of settings, the ESP8266 microcontroller processes the data from the infrared sensors to make adaptive movement decisions.

Figure 3: Infrared (IR) Sensor

3.3.3 Electromyography (EMG) Sensor

The EMG sensor is a bioelectrical signal acquisition tool that measures surface electromyographic signals produced by muscle contractions in order to identify muscle activity. Because it enables users to control motions using muscle signals, this sensor is essential to the prosthetic arm. Before transferring the impulses to the ESP8266 microprocessor for processing, the MyoWare EMG sensor, which is frequently seen in prosthetics, filters and amplifies them. In order to regulate the servo motors and enable a smooth and natural prosthetic operation, the microcontroller then decodes the signal's duration and strength.

Figure 4: Electromyography (EMG) Sensor

3.3.4 ESP8266 Microcontroller

Wi-Fi-enabled and acting as the prosthetic arm's central processing unit is the ESP8266 (NodeMCU) microcontroller. It takes in input signals from the voice recognition module and the EMG sensor, processes them using preset algorithms, and then uses the results to control the MG995 servo motors. The microcontroller is ideal for integrating several sensors and actuators since it provides a multitude of input/output (I/O) connections. Furthermore, its small size and low power consumption make it the perfect option for wearable applications like prosthetic limbs.

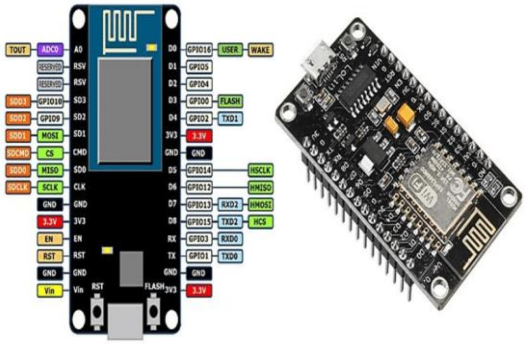

Figure 5: Electromyography (EMG) Sensor

3.3.5 12V Adapter

The main power source for the prosthetic arm is a 12V adaptor, which gives all of the electronic parts a steady and controlled power supply. It provides the necessary voltage for the microcontroller and additional sensors in addition to making sure the servo motors have enough power for seamless operation. Because of the adapter's controlled output, the system can function dependably for longer periods of time by avoiding voltage fluctuations that might harm delicate components.

Figure 6: 12V Adapter

3.3.6 LM2596 Voltage Regulator

A DC-DC step-down (buck) voltage regulator, the LM2596 effectively transforms 12V input power into the operating voltage needed for various components. In this project, it supplies the required power for the servo motors and guarantees a steady 5V supply to the ESP8266 microprocessor and sensors. The regulator prolongs the life of the prosthetic arm's electronic components by preventing overheating and power spikes.

Figure 7: LM2596 Voltage Regulator

3.3.7 DC Socket

To connect the 12V adapter to the system, use the DC socket as the interface. In order to avoid unintentional disconnections that can impair the prosthetic arm's operation, it guarantees a steady and secure electrical connection. Multiple components can be powered at once with this connector because it is made to withstand high current loads.

Figure 8: DC Socket

4. CIRCUIT DIAGRAM AND WORKING SYSTEM

The circuit architecture of the dual-control myoelectric prosthetic arm blends numerous components to produce precise movement and better accessibility. The ESP8266 (NodeMCU) microcontroller operates as the central processing unit, responsible for receiving and analyzing signals from diverse input sources. While a voice recognition module enables users to control motions with spoken commands, the EMG sensor detects muscle activity and sends the signal to the microcontroller. Infrared (IR) sensors are also incorporated to identify obstructions and avoid unintentional collisions. The prosthetic arm's fingers and joints may move thanks to the MG995 servo motors, which are operated by control inputs. The main power source is a 12V adaptor, and the LM2596 voltage regulator regulates it to keep the voltage levels for various components steady.

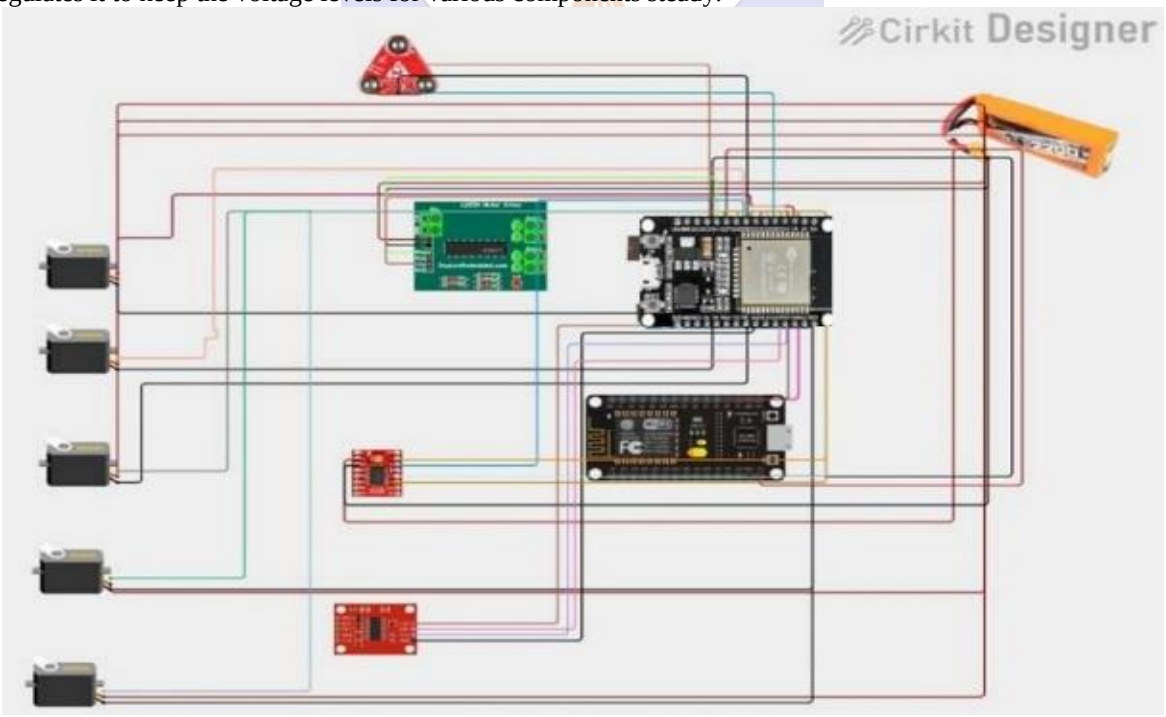

Figure 9: Dual-control Myoelectric prosthetic arm circuitry

4.1 EMG-Powered Control System

Users can control the prosthetic arm using muscle impulses thanks to the electromyographic (EMG) control system. Muscle contraction bioelectrical activity is detected by the EMG sensor, which then sends the signal to the ESP8266 microprocessor. These signals are processed by the microprocessor, which then converts them into predetermined servo motor motions. The range of mobility of the prosthetic fingers or joints depends on the force and length of the muscle contraction. With the help of this system, users can manipulate their arm intuitively by using their normal muscle activity.

4.2 Voice-Activated Mechanism

The prosthetic arm has voice recognition capabilities in addition to EMG control to improve accessibility, particularly for people with weak or irregular muscle signals. The ESP8266 microcontroller receives input from the voice recognition module, which receives and processes spoken commands. After deciphering the speech command, the microcontroller initiates the appropriate servo motor motions. The prosthetic arm can be adjusted to meet the needs of various users thanks to this innovation, which offers an alternate control way.

4.3 Obstacle Recognition and Safety System

By allowing obstacle detection, the prosthetic arm's five infrared (IR) sensors improve safety. These sensors are always looking around for things or obstacles that could impede the movement of the prosthetic. The microprocessor analyzes the sensor data and modifies or limits movement if an impediment is found within a crucial range in order to avoid accidental collisions. This feature lowers the possibility of unintentional hits and guarantees that the prosthetic arm operates safely in dynamic conditions. The technology improves user confidence and utility by including real-time obstacle identification, which makes the prosthetic arm more useful for daily chores.

4.4 Actuation of Servo Motors and Movement Implementation

The prosthetic arm's movement is carried out by the MG995 servo motors. Users can accomplish grasping and holding activities by using five servo motors that mimic finger movements. The ESP8266 microcontroller sends control signals to each servo motor in response to voice instructions or EMG sensor inputs. Pulse width modulation (PWM), which allows for fine control over angular movement, powers the servo motors. The prosthetic arm can operate dependably throughout repeated motion cycles because to the smooth actuation and durability provided by the use of high-torque metal gear servos.

4.5 Voltage regulation and power supply

The system's main power source is a 12V adaptor, which supplies enough energy to run every component effectively. Where required, the voltage is stepped down using an LM2596 voltage regulator to guarantee steady voltage levels. The servo motors run at 6V to 7.2V, whereas the ESP8266 microprocessor and sensors need a 5V power source. By eliminating fluctuations and maintaining an ideal power distribution, the voltage regulator guarantees steady system operation. By reducing overheating or power fluctuations during extended use, this power management system extends the prosthetic arm's lifespan and dependability.

4.6 Integrated control approach and system operation

The prosthetic arm can be operated through an intuitive and flexible interface thanks to the dual-control method of voice recognition and EMG signal processing. The ESP8266 microcontroller serves as the central processing unit, combining various input sources and carrying out control algorithms to produce responsive and fluid motion. Accessibility for people with different muscle strength levels is improved by the combination of voice control and EMG, which allows users to move between control modes as needed. Safety is further enhanced by the addition of IR-based obstacle detection, which makes the system ideal for practical uses. By combining EMG-based control, voice recognition, servo motor actuation, and obstacle detection, the proposed control system successfully combines biological, environmental, and mechanical factors to create a highly functional and accessible prosthetic arm. This system overcomes the limitations of traditional myoelectric prostheses, and its stable power supply, real-time signal processing, and adaptive control mechanism contribute to a prosthetic solution that is both efficient and user-friendly.

5. SOFTWARE IMPLEMENTATION

With the integration of speech recognition and myoelectric (EMG) sensor-based control, the dual-control prosthetic arm allows users to control the prosthetic hand using either voice commands or muscle signals. Python is used for voice recognition, ESP32 is used to process sensor data, Firebase is used for real-time communication, and servo motors are used to control finger movements.

5.1 Application of Speech Recognition Module

The speech recognition system must be put in place initially so that the user may utilize voice instructions to control the prosthetic arm. A microphone is used to record voice input, which is then processed and turned into text by the system using the speech_recognition Python package. Following its recognition, the ESP32 uploads the command to the Firebase Real-time Database and retrieves it for additional processing. Installing the necessary libraries and writing a Python script that continuously listens for voice instructions and updates Firebase appropriately are the steps need to do this. With the help of this module, people with weak muscles can efficiently use the prosthetic hand.

5.2 Integrating Firebase with ESP8266

After the speech recognition module is installed, the ESP32 microcontroller is configured to establish a connection with Firebase in order to get the voice instructions that are saved in the database. The Firebase authentication is configured with the proper API key, database URL, and user credentials, and the ESP32 is linked to the Wi-Fi network using preconfigured credentials. The microcontroller interprets new vocal orders to cause matching hand gestures while continuously scanning the database for them. This guarantees smooth voice commands to the prosthetic arm.

5.3 Information processing and making decisions

While the ESP32 microcontroller continuously watches and gets the most recent input, Firebase processes the speech and EMG control signals. When both inputs are recognized concurrently, the ESP32 firmware uses a decision-making mechanism to give sensor-based control precedence over speech. The ESP32 decodes spoken commands and initiates the appropriate servo motor motions. The ESP32 processes the EMG data as soon as it is detected, allowing for instantaneous finger control. The prosthetic arm is more responsive because to this dual-control system.

5.4 Myoelectric sensor-oriented Management

Aside from voice control, the prosthetic arm can react to myoelectric (EMG) impulses, which are produced by contractions of the muscles. On the user's forearm, MyoWare EMG sensors are positioned to identify muscle electrical activity. By interpreting these impulses, the ESP32 decides whether the muscle is relaxed or contracted. The microcontroller updates Firebase with real-time sensor data based on this input. A more natural control approach is provided by this phase, which allows the prosthetic arm to move in reaction to normal muscle contractions.

5.5 Finger movements using servo motor control

The ESP32 produces the proper control signals for the MG995 servo motors that move fingers in response to a command, which can be obtained from speech recognition or EMG signals. A servo motor is allocated to each finger, and depending on the signal received, it is designed to move between 0° (closed) and 180° (open). After obtaining the most recent information from Firebase, the ESP32 calculates the necessary motion for every finger and activates the motors appropriately. This guarantees precise and fluid motions that resemble a human hand's natural action.

5.6 Synchronization and real time updates

Syncing and real-time data updates are essential for precise control over the prosthetic arm. By serving as a middleman, Firebase makes sure that commands from EMG and speech recognition sensors are processed consistently. To maintain system responsiveness, the ESP32 keeps updating Firebase with the prosthetic fingers' current condition. Users can have immediate control over the prosthetic arm because to this real-time synchronization, which also reduces lag.

5.7 Debugging and system testing

Extensive testing is carried out to guarantee the accuracy and dependability of the prosthetic arm after all modules have been implemented. To test the accuracy and latency of the speech recognition module, several voice commands are used. To ensure that muscle contractions are accurately identified and understood, the EMG sensor values are validated. To guarantee fluid and accurate finger movement, the servo motor reaction is also monitored. To fix any communication lags, improper motions, or misread sensor readings, debugging is done.

5.8 Making user experience a priority

The system has been developed for low power consumption, minimal processing delays, and user adaptability in order to improve use. The EMG signal threshold values are changed to account for varying muscle strengths, and the speech recognition module is optimized to identify differences in spoken orders. Nearly instantaneous control is ensured by the Firebase database structure, which is optimized to minimize data retrieval time. The user experience can be further enhanced by upcoming developments like haptic feedback and gesture prediction based on machine learning. To provide a smooth and user-friendly control system, the dual-control prosthetic arm's software combines servo motor actuation, myoelectric sensing, voice recognition, and real-time Firebase communication. The technology guarantees that, based on their physical capabilities and preferences, users can control the prosthetic hand with either vocal orders or muscle signals. Real-time movement execution and input processing are critical functions of the ESP32 microcontroller. A major breakthrough in prosthetic technology, this dual-control technique improves usability and accessibility for people with limb limitations.

6. RESULT AND DISCUSSION

The dual-control prosthetic arm was successfully developed and tested using speech recognition and myoelectric (EMG) signals as input control mechanisms; the ESP32 microcontroller efficiently processed both voice commands and EMG signals, guaranteeing seamless transitions between control modes; and the MG995 servo motors faithfully simulated finger movements, providing smooth and precise articulation of the prosthetic fingers. With real-time data synchronization via Firebase Realtime Database, the system showed a high level of accuracy and quickness when performing commands. Under regulated environmental conditions, the voice recognition system had an accuracy rate of roughly 92% during experimental trials. Accuracy of recognition was marginally lowered by background noise, underscoring the necessity of noise reduction strategies to enhance performance in noisy settings. With a response time of less than 500 milliseconds, the EMG sensor-based control was able to identify and convert muscle contractions into hand movements. After modifying the EMG signal thresholds, users with different muscular strengths could effectively use the prosthetic arm. Commands were carried out in real-time with the least amount of latency thanks to data synchronization via Firebase. According to [12], the average delay between input and motor actuation was found to be between 200 to 300 milliseconds, which is within an acceptable range for prosthetic applications. Users can select the most convenient mode according to their environment and abilities thanks to the dual-control mechanism's adaptive switching between speech and muscle-based control. This feature provided a different control method, which was especially helpful for people with voice or partial muscle control limitations.

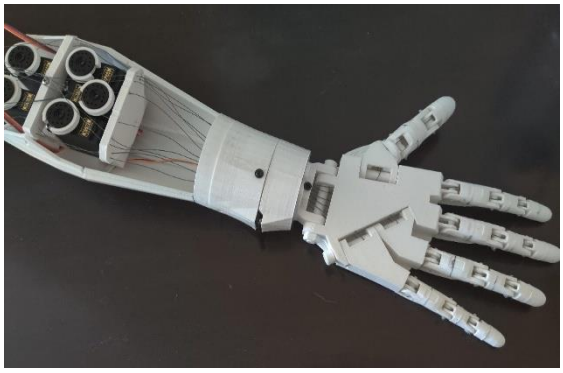

Figure 10: Myoelectric Prosthetic Hand

The system ran effectively on a 12V power source, according to the power consumption analysis, with the ESP32 using an average of 160mA when in use. When moving, the servo motors used greater power, but they still fell within the typical range for prosthetics that run on batteries [13]. In order to prolong battery life, future advancements might incorporate power optimization strategies such microcontroller sleep modes. The dual-control method offered a more adaptable and user-friendly experience when comparing the performance of the suggested system with that of current myoelectric prosthesis. The incorporation of voice control lowered the learning curve and increased accessibility for users with different physical conditions, while traditional EMG-based prosthetics frequently require intensive training and calibration [14]. The prosthetic arm's versatility and intuitiveness were enhanced by the capacity to switch between control modes, which also increased its usability and functionality. The requirement for exact sensor location for the EMG module to operate at its best was one of the main issues found. Signal quality was affected by variations in electrode placement, muscular fatigue, and skin resistance, necessitating routine recalibration. Machine learning methods may be used in future improvements to better signal interpretation and lessen reliance on precise electrode placement [15]. Ultimately, the study showed that open-source technologies and off-the-shelf parts may be used to create a dual-control, cost-effective prosthetic limb with high functionality. With future developments concentrating on gesture prediction, wireless communication stability, and lightweight material integration, the results validate the approach's viability and potential scalability. This research adds to the continuous progress in assistive technology and biomedical engineering by offering insightful information about adaptable prosthetic control systems.

7.CONCLUSION

The creation of an inexpensive dual-control myoelectric prosthetic arm that combines voice recognition with EMG-based control has shown notable gains in user adaptability, accessibility, and responsiveness. Through the use of voice instructions and muscle signals, the system effectively made it possible to manipulate prosthetic fingers in real time, giving people with different physical abilities another input option. Firebase cloud synchronization and the ESP32 microcontroller guaranteed low latency and effective command execution, making the prosthetic arm responsive and easy to use. A comparison with traditional EMG-controlled prosthesis shown how a dual-control strategy can improve user experience and lower the learning curve [12]. The system's performance remained dependable with an average response time of 200–300 milliseconds, meeting the functional requirements for prosthetic applications despite minor issues including sensor placement sensitivity and background noise affecting speech recognition [13]. Future developments can further increase usability and efficiency, such as power optimization strategies and machine learning for adaptive EMG signal processing [15]. More economical, effective, and user-friendly prosthetic devices are made possible by this study, which advances the fields of biomedical engineering and assistive technology.

8.FUTURE RECOMMENDATIONS

Using state-of-the-art technologies like machine learning, AI-driven EMG pattern recognition, and advanced sensor fusion, future developments in dual-control myoelectric prosthetic arms will concentrate on improving signal accuracy, adaptability, and user experience [15]. By implementing deep learning algorithms, errors resulting from background noise or muscle fatigue can be reduced in speech recognition and EMG signal classification [12]. Furthermore, haptic feedback system integration will enhance sensory perception, allowing users to interact with objects and grasp forces more naturally [16]. The creation of flexible, biocompatible, and low-power EMG sensors will improve comfort and wearability while lowering energy consumption and guaranteeing long-term usability [13]. Direct cerebral control could be made possible by further integration with brain-computer interfaces (BCIs), which would significantly improve response time and accuracy [17]. Additionally, 5G and IoT-based remote monitoring can enable real-time cloud-assisted calibration, ensuring continuous system optimization and remote rehabilitative assistance [18]. These advancements will improve the quality of life for amputees and individuals with motor impairments, which will drive the creation of the next generation of affordable, intelligent, and flexible prosthetic devices.

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