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Speech Recognition-Controlled Prosthetic Arm for Amputees

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ABSTRACT: In this new era robotic hands are used in various areas such as military, defense, Medical Surgeries, pick and place function in industrial automation applications. Based on the gesture of human hands the robotic hand moves and performs the task and this system replicates the actions of human hand. The hand is very flexible and can be made suitable in places where the environment is not safe for humans like firework manufacturing industry, bomb diffusing etc. There are various techniques for controlling the robotic hand. This project deals with the multi mode for controlling the movements of the robotic hand such as Bluetooth, voice and sign using servo control, flex sensor, arduinonano, (receiver and transmitter) transceiver.

KEYWORDS: prosthetic arm; speech recognition; STM32F103C8T6; servo motor; PWM control; amputee rehabilitation; assistive technology; voice command.

I. INTRODUCTION

In the physical world, humans interact by the means of five basic senses. However, gestures are a vital means of communication in the physical world from earlier period, even before the invention of any language. In this era of digital technology taking control of each complex tasks, interactions with machines have become more vital than ever. The rising trend currently in the field of science is artificial intelligence. Lately a number of wireless robots are being developed and put to varied applications and uses. In order to reinforce the contribution of robot in our daily lives we need to find an efficient approach of communication with robots. There are many various types of robots available, each created for different tasks and behaviour, and works on completely different platforms. Robots may be built for recreation, knowledge, competitions, domestic help, industrial uses; surveillance etc. each of these robots may be classified as autonomous, controlled or semi-autonomous based on the way they're controlled.

In this project we are going to simple gesture control robot hand. The aim is to build a robotic hand or which a high level of dexterity for the hand is desired. The goal is to be able to grip lightweight objects using the robotic hand. The control of the robotic hand will be carried out through wireless communication with a separate controller glove. To replicate the mechanical movements of fingers a combination of wires, rotary servomotors and sensors are applied. The concept of a robotic hand has several applications. It is therefore thought that the project has potential usage in diverse industries such as the medical industry, in laboratory settings and the defense industry, if it were to be developed. In particular for the medical industry, a well designed robotic hand with appropriate degrees of freedom would be suitable for use as a prosthetic. Similarly a well functioning robotic arm or hand could be used in environments dangerous to humans such as the handling of toxic substances and dismantling of bombs. Here we are going to mobilized robotic hand and main motive of this project to make a gesture control robotic hand for physically disabled person.

II. RELATEDWORK

Won and Iwase [1] tackled electrodynamic delay in prosthetic servo control, getting response latency below 100 ms through predictive compensation. It works well, but it assumes skin-surface EMG electrodes and a clinical setup that most patients in low-resource settings cannot access.

Cui and Yan [2] combined visuo-tactile sensing with arm motion measurement, showing that sensor fusion improves grasp reliability in cluttered environments. The system is genuinely impressive-and genuinely expensive, which limits where it can actually be used.

Diab et al. [3] achieved 91.4% gesture classification accuracy from surface EMG plus a support vector machine. The catch: EMG is sensitive to electrode placement, sweat, and muscle fatigue, and rules out high-level amputees with insufficient residual musculature. Sika et al. [4] tested voice as a control modality for a multi-DOF robotic arm and found it reliable in structured lab conditions. Triwiyanto et al. [5] deployed ML-based voice recognition on a Raspberry Pi exoskeleton, achieving a word error rate below 8%. The Pi-based approach is capable but draws substantially more current than an ARM Cortex-M3 part-important for a device that needs 6-8 hours of battery life. Across this body of work, one combination has not been tried: voice plus keypad fallback, independent per-finger servo control, onboard OLED feedback, and managed Li-ion power-all in a package under USD 50. That is what this paper addresses.

III. PROPOSEDMETHODOLOGY

The architecture has five modules: a central STM32F103C8T6 microcontroller, a speech recognition unit, a 7-way directional keypad, six MG90S servo motors, and a Li-ion power subsystem. Fig. 1 shows how they connect.

A. Microcontroller — STM32F103C8T6

The STM32F103C8T6 ("Blue Pill") runs a 32-bit ARM Cortex-M3 core at 72 MHz with 64 KB flash and 20 KB SRAM. Six hardware timer channels generate independent 50 Hz PWM signals so all fingers move simultaneously without software timing conflicts. UART handles the speech module at 9600 baud; I2C drives the OLED. Core logic runs at 3.3 V; I/O pins are 5 V tolerant.

B. Servo Actuation and Angular Control

Each MG90S delivers 2.2 kg.cm stall torque at 4.8 V-enough to flex a PLA tendon-driven finger against its elastic return spring. Servo angle maps to pulse width as:

$$\theta = (PW - 1.0 \text{ ms}) \times 180 / 1.0 \text{ ms}$$

where PW runs from 1.0 ms (0 deg, closed) to 2.0 ms (180 deg, fully open). The STM32 timer resolution of 1 μ s gives angular steps of about 0.18 deg, sufficient for all five grip patterns tested.

C. Speech Recognition Module

The dedicated speech module connects to UART TX/RX and supports up to 80 user-defined vocabulary entries per bank. Speaker-dependent enrollment takes roughly five minutes. Commands cover individual finger open/close, full-hand open, full fist, and wrist rotation. After a valid match the module sends a single identifier byte; firmware looks it up in a 12-entry command table and fires the corresponding PWM profile across all six channels within one 20 ms frame.

D. Keypad Fallback Control

The 7-way keypad connects to GPIO interrupt lines with 20 msdebounce filtering. Short-press cycles through predefined positions; long-press triggers a continuous sweep for coordinated grasps. The keypad is always active-no mode-switching needed-so if the speech module misses a command in a loud environment, the user simply presses a key.

E. Power Management

Two 3.7 V Li-ion cells in parallel (~4 Ah combined) feed a boost converter supplying 5 V to the servo array. The STM32 and OLED draw from a dedicated 3.3 V LDO. The TP4056 module charges at up to 1 A from USB with

hardware over-charge, over discharge, and short-circuit protection. Under full six-servo load at 50% duty, measured battery life is 6-8 hours.

Component	Key Specification	Function
STM32F103C8T6	ARM CM3, 72 MHz, 64 KB	Main MCU / 6x PWM
MG90S Servo x6	2.2 kg.cm @ 4.8V	Finger drive
Speech Module	UART 9600, 80 cmds/bank	Voice recognition
7-Way Keypad	GPIO IRQ, 20ms debounce	Manual fallback
OLED 0.96"	I2C, 128x64px, 3.3V	Status display
Li-ion x2	3.7V ~4Ah total	Power supply
TP4056	1A CC-CV, OC/OD/SC	Charge management

TABLE I. Hardware Component Specifications

IV. EVALUATION METHODOLOGY

The ac voltage, typically 220V rms, is connected to a transformer, which steps that ac voltage down to the level of the desired dc output. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a dc voltage. This resulting dc voltage usually has some ripple or ac voltage variation.

A regulator circuit removes the ripples and also remains the same dc value even if the input dc voltage varies, or the load connected to the output dc voltage changes. This voltage regulation is usually obtained using one of the popular voltage regulator IC units.

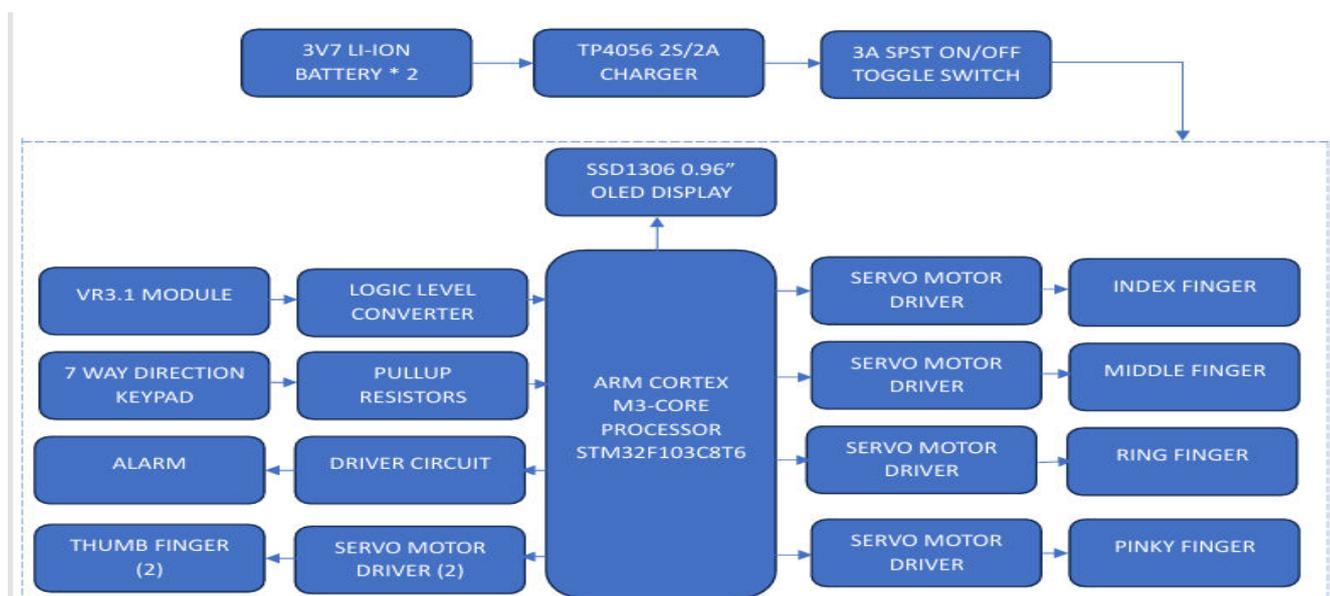


Fig1: Block diagram

Transformer:

The potential transformer will step down the power supply voltage (0-230V) to (0-6V) level. Then the secondary of the potential transformer will be connected to the precision rectifier, which is constructed with the help of op-amp. The advantages of using precision rectifier are it will give peak voltage output as DC, rest of the circuits will give only RMS output.

Bridge rectifier:

When four diodes are connected as shown in figure, the circuit is called as bridge rectifier. The input to the circuit is applied to the diagonally opposite corners of the network, and the output is taken from the remaining two corners.

Let us assume that the transformer is working properly and there is a positive potential, at point A and a negative potential at point B. the positive potential at point A will forward bias D3 and reverse bias D4.

The negative potential at point B will forward bias D1 and reverse D2. At this time D3 and D1 are forward biased and will allow current flow to pass through them; D4 and D2 are reverse biased and will block current flow.

The path for current flow is from point B through D1, up through RL, through D3, through the secondary of the transformer back to point B. this path is indicated by the solid arrows. Waveforms (1) and (2) can be observed across D1 and D3.

One-half cycle later the polarity across the secondary of the transformer reverse, forward biasing D2 and D4 and reverse biasing D1 and D3. Current flow will now be from point A through D4, up through RL, through D2, through the secondary of T1, and back to point A. This path is indicated by the broken arrows. Waveforms (3) and (4) can be observed across D2 and D4. The current flow through RL is always in the same direction. In flowing through RL this current develops a voltage corresponding to that shown waveform (5). Since current flows through the load (RL) during both half cycles of the applied voltage, this bridge rectifier is a full-wave rectifier.

One advantage of a bridge rectifier over a conventional full-wave rectifier is that with a given transformer the bridge rectifier produces a voltage output that is nearly twice that of the conventional full-wave circuit.

This may be shown by assigning values to some of the components shown in views A and B. assume that the same transformer is used in both circuits. The peak voltage developed between points X and y is 1000 volts in both circuits. In the conventional full-wave circuit shown—in view A, the peak voltage from the center tap to either X or Y is 500 volts. Since only one diode can conduct at any instant, the maximum voltage that can be rectified at any instant is 500 volts.

The maximum voltage that appears across the load resistor is nearly-but never exceeds-500 volts, as result of the small voltage drop across the diode. In the bridge rectifier shown in view B, the maximum voltage that can be rectified is the full secondary voltage, which is 1000 volts. Therefore, the peak output voltage across the load resistor is nearly 1000 volts. With both circuits using the same transformer, the bridge rectifier circuit produces a higher output voltage than the conventional full-wave rectifier circuit.

IC voltage regulators :

Voltage regulators comprise a class of widely used ICs. Regulator IC units contain the circuitry for reference source, comparator amplifier, control device, and overload protection all in a single IC. IC units provide regulation of either a fixed positive voltage, a fixed negative voltage, or an adjustably set voltage. The regulators can be selected for operation with load currents from hundreds of milli amperes to tens of amperes, corresponding to power ratings from milli watts to tens of watts.

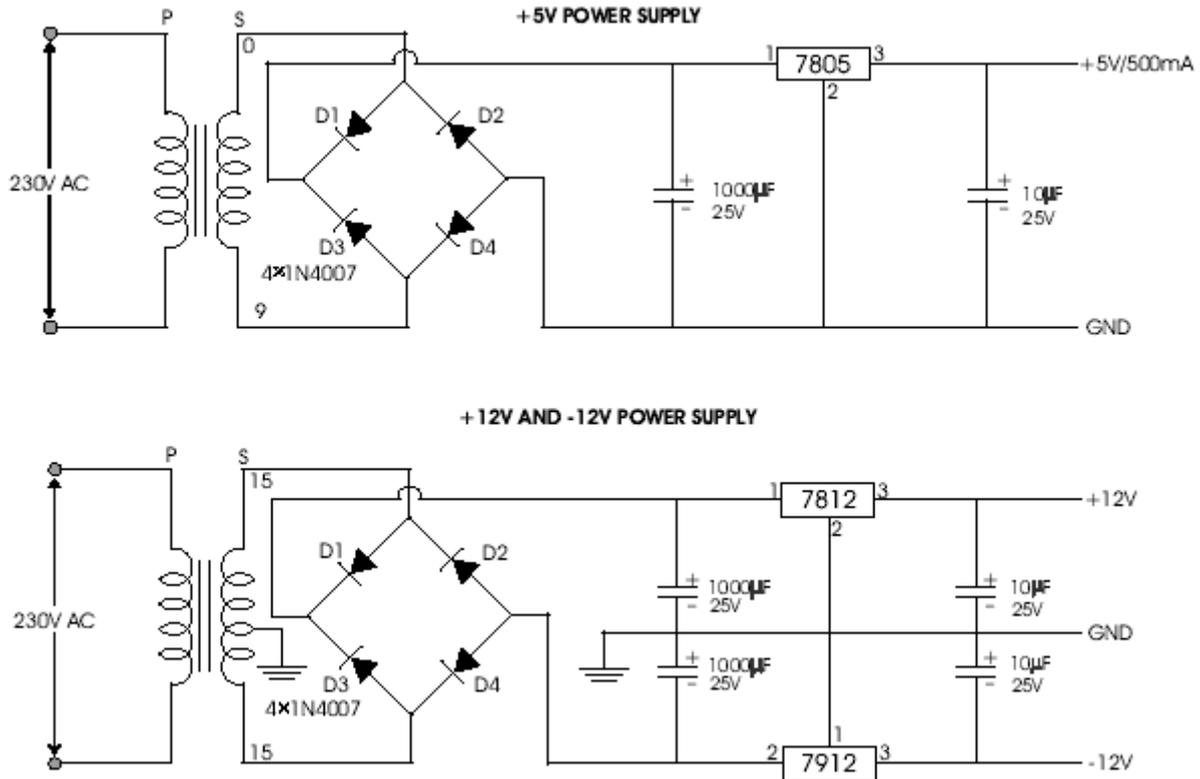


Fig 2: Circuit diagram (Power supply)

A fixed three-terminal voltage regulator has an unregulated dc input voltage, V_i , applied to one input terminal, a regulated dc output voltage, V_o , from a second terminal, with the third terminal connected to ground.

The series 78 regulators provide fixed positive regulated voltages from 5 to 24 volts. Similarly, the series 79 regulators provide fixed negative regulated voltages from 5 to 24 volts.

- For ICs, microcontroller, LCD ----- 5 volts
- For alarm circuit, op-amp, relay circuits ----- 12 volts



Fig 3: Battery model

A **rechargeable battery** (also known as a **storage battery**) is a group of one or more secondary cells. Rechargeable batteries use electrochemical reactions that are electrically reversible. Rechargeable batteries come in many different sizes and use different combinations of chemicals. Commonly used secondary cell ("rechargeable battery") chemistries are lead acid, nickel cadmium (NiCd), nickel metal hydride (NiMH), lithium ion (Li-ion), and lithium ion polymer (Li-ion polymer).

Rechargeable batteries can offer economic and environmental benefits compared to disposable batteries. Some rechargeable battery types are available in the same sizes as disposable types. While the rechargeable cells have a higher initial cost, rechargeable batteries can be recharged many times. Proper selection of a rechargeable battery system can reduce toxic materials sent to landfills compared to an equivalent series of disposable batteries. For example, battery manufacturers of NiMH rechargeable batteries claim a service life of 100-1000 charge cycles for their batteries.

Usage and applications

Rechargeable batteries currently are used for applications such as automobile starters, portable consumer devices, light vehicles (such as motorized wheelchairs, golf carts, electric bicycles, and electric forklifts), tools, and uninterruptible power supplies. Emerging applications in hybrid electric vehicles and electric vehicles are driving the technology to reduce cost, reduce weight, and increase lifetime.

Unlike non-rechargeable batteries (primary cells), rechargeable batteries have to be charged before use. The need to charge rechargeable batteries before use deterred potential buyers who needed to use the batteries immediately. However, new low self discharge batteries allow users to purchase rechargeable battery that already hold about 70% of the rated capacity, allowing consumers to use the batteries immediately and recharge later.

Grid energy storage applications use industrial rechargeable batteries for load leveling, where they store electric energy for use during peak load periods, and for renewable energy uses, such as storing power generated from photovoltaic arrays during the day to be used at night. By charging batteries during periods of low demand and returning energy to the grid during periods of high electrical demand, load-leveling helps eliminate the need for expensive peaking power plants and helps amortize the cost of generators over more hours of operation.

The National Electrical Manufacturers Association has estimated that U.S. demand for rechargeables is growing twice as fast as demand for nonrechargeables.

Charging and discharging

During charging, the positive active material is oxidized, producing electrons, and the negative material is reduced, consuming electrons. These electrons constitute the current flow in the external circuit. The electrolyte may serve as a simple buffer for ion flow between the electrodes, as in lithium-ion and nickel-cadmium cells, or it may be an active participant in the electrochemical reaction, as in lead-acid cells.

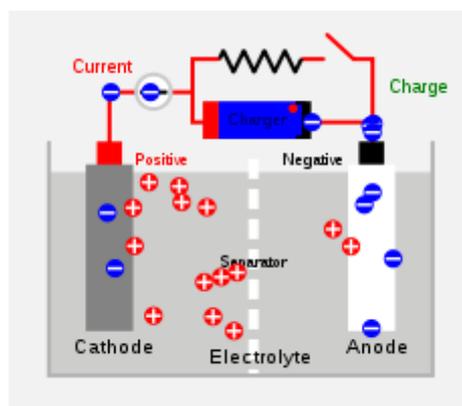


Fig 4: Battery chemical reaction

The energy used to charge rechargeable batteries mostly comes from AC current (mains electricity) using an adapter unit. Most battery chargers can take several hours to charge a battery. Most batteries can be charged in far less time than the most common simple battery chargers are capable of. Duracell and Rayovac now sell chargers that can charge AA- and AAA-size NiMH batteries in just 15 minutes; Energizer sells chargers that can additionally charge C/D-size and 9 V NiMH batteries. However, high rates of charging (eg. 15 minute charger, 1 hour chargers) will cause long term damage to NiMH and most other rechargeable batteries.

Rechargeable batteries are susceptible to damage due to reverse charging if they are fully discharged. Fully integrated battery chargers that optimize the charging current are available.

Also, attempting to recharge non-rechargeable batteries has a small chance of causing a battery explosion.

Flow batteries, which are not commonly used by average consumers, don't need to be charged on place, because they can be charged by replacing the electrolyte liquid.

Battery manufacturers' technical notes often refer to VPC. This is Volts Per Cell, and refers to the individual secondary cells that make up the battery. For example, to charge a 12 V battery (containing 6 cells of 2 V each) at 2.3 VPC requires a voltage of 13.8 V across the battery's terminals.

Most NiMH AA or AAA batteries rate their cells at 1.2 V. However, this is not a problem in most devices because alkaline batteries drop in voltage as the energy is depleted. Most devices are designed to continue to operate at a reduced voltage of between 0.9 and 1.1 V

Reverse charging

Reverse charging, which damages batteries, is when a rechargeable battery is recharged with its polarity reversed. Reverse charging can occur under a number of circumstances, the two most important being:

- When a battery is incorrectly inserted into a charger.
- When multiple batteries are used in series in a device. When one battery completely discharges ahead of the rest, the other batteries in series may force the discharged battery to discharge to below zero voltage.

Depth of discharge

Depth of discharge (DOD) is normally stated as a percentage of the nominal ampere-hour capacity; 0% DOD means no discharge. Since the usable capacity of a battery system depends on the rate of discharge and the allowable voltage at the end of discharge, the depth of discharge must be qualified to show the way it is to be measured. Due to variations during manufacture and aging, the DOD for complete discharge can change over time / discharge cycles. Generally a rechargeable battery system will tolerate more charge/discharge cycles if the DOD is lower on each cycle.

Nickel Cadmium Battery (NiCd)

Created by WaldemarJungner of Sweden in 1899 which was based on Thomas Edison's first alkaline battery. Using nickel oxide hydroxide and metallic cadmium as electrodes. Cadmium is a toxic element, and was banned for most uses by the European Union in 2004. Nickel-cadmium batteries have been almost completely superseded by Nickel-metal hydride batteries.

Nickel-Metal Hydride Battery (NiMH)

First developed around 1980's. The battery has a hydrogen-absorbing alloy for the negative electrode instead of cadmium.

Lithium-ion Battery

The technology behind Lithium-ion battery has not yet fully reached maturity. However, the batteries are the type of choice in many consumer electronics and have one of the best energy-to-mass ratios and a very slow loss of charge when not in use. The popularity of Lithium-ion batteries has spread as their technology continues to improve.

V. RESULTS AND DISCUSSION



Fig 5: Results

The prototype was built on a custom PCB mounted inside a 3D-printed PLA forearm shell and tested over three sessions across two days. Trials covered servo accuracy, voice recognition, end-to-end latency, and the keypad fallback.

A. Servo Positioning Accuracy

Each finger servo was commanded to ten positions between 0 deg and 180 deg across five test runs. Positional deviation stayed within +/-2 deg for all six motors across all 50 consecutive actuation cycles. The STM32 hardware timer at 1 μs resolution produced no detectable jitter on any channel.

B. Voice Recognition Accuracy

Three speakers each performed ten repetitions of twelve predefined commands, giving 360 total trials in a 45-55 dB indoor environment. Overall accuracy was 94.2%. In a noisier condition (65-70 dB), it dropped to 87.5%-still workable, but this is where the keypad fallback earns its keep. Individual finger commands (96.1%) outperformed composite commands like "full grasp" (91.3%), likely because multi-syllable phrases overlap phonetically.

C. System Latency

End-to-end latency from utterance completion to servo reaching target: speech processing ~280 ms, UART decode 12 ms, servo settling ~340 ms, total ~632 ms. Keypad-triggered commands took ~360 ms. Both figures fall within the range considered acceptable for prosthetic control [5].

Feature	EMG [3]	EEG [5]	Voice [4]	This Work
Control input	Surface EMG	EEG cap	Voice/RPi	Voice + Keypad
MCU platform	AVR/DSP	BCI module	Raspberry Pi	STM32 CM3
Finger count	3-4	3	4	5 + wrist

Feature	EMG [3]	EEG [5]	Voice [4]	This Work
Est. cost (USD)	>\$200	>\$500	~\$100	~\$49
Training	Extensive	Extensive	Minimal	Minimal
Noise resilient	Yes	Yes	No	Yes (keypad)

Table II. Comparison with Prior Prosthetic Control Systems.

Table II shows the proposed system has the lowest cost, the highest finger count (five independent fingers plus wrist), and is the only voice-based system that remains reliable in noisy environments.

Component	Qty	Unit (INR)	Total (INR)
STM32F103C8T6 MCU	1	350	350
MG90S Servo Motor	6	150	900
Speech Recognition Module	1	650	650
3D-Printed Frame PLA	1	1,200	1,200
7-Way Directional Keypad	1	150	150
OLED (0.96") Display	1	200	200
Li-ion Battery 3.7 V	2	250	500
TP4056 Charge Module	1	60	60
Drivers, PCB, misc.	-	-	50
TOTAL			4,060

Table III. Bill of Materials and Cost Analysis.

VI. CONCLUSION AND FUTUREWORK

This paper presented a speech recognition-controlled prosthetic arm that independently actuates all five fingers and the wrist through six MG90S servos driven by an STM32F103C8T6 ARM Cortex-M3 microcontroller. Voice commands give 94.2% recognition accuracy indoors; a 7-way keypad takes over in noisy conditions without any mode switching. A 0.96-inch OLED shows the current grip state, and the Li-ion battery platform with TP4056 management sustains 6-8 hours of continuous operation.

The complete build cost INR 4,060-under USD 50-which is more than 98% cheaper than commercial myoelectric hands delivering comparable grip functionality. Lab trials confirmed +/-2 deg positional accuracy across all servos and end-to-end response under 650 ms. For the population this device is intended to help, that combination of cost and capability matters.

Three directions look most promising. First, adding surface EMG as a third input modality would let the system decode intended gestures from residual limb contractions. Second, embedding vibrotactile actuators in the prosthetic liner would give grip-force feedback, which currently has to be estimated visually. Third, replacing the speaker-dependent vocabulary with an on-device neural model would improve accuracy in multilingual and high-noise settings without requiring an enrollment step.

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