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Oralink: Tongue Controlled Multi Assistive System Universal Tongue-Driven Control System for Mobility and Smart Environments for the Completely Paralyzed

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Abstract:
ORALINK is a tongue-controlled multi-assistive smart wheelchair system designed to enhance independence and quality of life for individuals with severe motor impairments such as tetraplegia and advanced neuromuscular disorders. The system integrates wheelchair mobility control, a custom 3D-printed robotic arm, computer interaction via Bluetooth HID, and wireless home automation through a Telegram Bot — all driven by a custom capacitive intra-oral mouthpiece. Tongue movements detected by an MR121 sensor array are processed by an Arduino Nano master and relayed wirelessly via HC-05 Bluetooth to an Arduino UNO slave driving the actuators. A dedicated ESP32 module performs real-time health monitoring using the MAX30100 optical sensor (heart rate + SpO_2), uploads data to Firebase, and activates vibration therapy motors on abnormal readings. An Android health dashboard provides a live vitals interface and home automation control panel. User surveys at the Vocational Rehabilitation Centre for Handicapped, Thiruvananthapuram, confirmed 100% willingness to adopt the system. Expected performance shows command response times below 0.2–0.5 s with >95% reliability across all modules.

Keywords — Assistive Technology, Tongue Drive System, Tetraplegia, ESP32, Wheelchair Control, Robotic Arm, Home Automation, Health Monitoring, Human–Machine Interface.

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I. INTRODUCTION

The fundamental human desire for autonomy becomes profoundly significant for individuals facing severe physical disabilities. Assistive technology has opened new frontiers in restoring functional capabilities, yet a critical gap remains: most existing systems are standalone, addressing only a single function such as mobility or environmental control. Users with tetraplegia — partial or total loss of function in all four limbs — must manage multiple disparate interfaces, which is inefficient, costly, and cognitively burdensome.

Tetraplegia typically results from traumatic cervical spinal cord injury (SCI) or from conditions such as ALS, Multiple Sclerosis, or brainstem strokes. The World Health Organization estimates 250,000–500,000 new SCI cases annually worldwide [1]. The inability to perform Activities of Daily Living (ADLs) leads to overwhelming dependence on caregivers, eroding self-esteem and reducing quality of life.

The human tongue, innervated by the hypoglossal nerve which typically remains intact in high-level SCI, offers a remarkable control resource. With a large motor cortex representation, the tongue executes fine, voluntary movements with high precision and speed [4]. Tongue-based interfaces exploit this to provide high-bandwidth, reliable, hands-free control. This paper presents ORALINK — a tongue-controlled multi-assistive system integrating wheelchair mobility, robotic arm operation, computer access, home automation, and real-time health monitoring into one unified, low-cost platform.

II. Related Works

A. Eye-Controlled Wheelchair System

Eye-tracking systems allow wheelchair control using eye movements and blinking. Sensors detect eye gestures and translate them into navigation commands. While providing independence, these systems cause eye fatigue with extended use and require consistent lighting conditions. ORALINK's tongue control is inherently more robust to environmental variation and less fatiguing over prolonged periods.

B. Brain–Computer Interface (BCI) Wheelchair

BCI wheelchairs decode EEG signals in real-time to generate navigation commands. These systems show promise but suffer from low information transfer rates, high equipment cost, complex setup procedures, and susceptibility to noise [9]. ORALINK provides a simpler, significantly lower-cost alternative while maintaining fully hands-free control.

C. Tongue Drive System — Georgia Tech

The Tongue Drive System (TDS) by Georgia Tech [1] uses a small permanent magnet on the tongue and magnetic sensors on the cheeks to detect tongue position. ORALINK extends this concept by replacing the magnet attachment with a capacitive touch pad embedded in a standard mouthpiece, and augments the platform with a robotic arm, real-time health monitoring, and home automation not addressed by TDS (see Fig. 1).

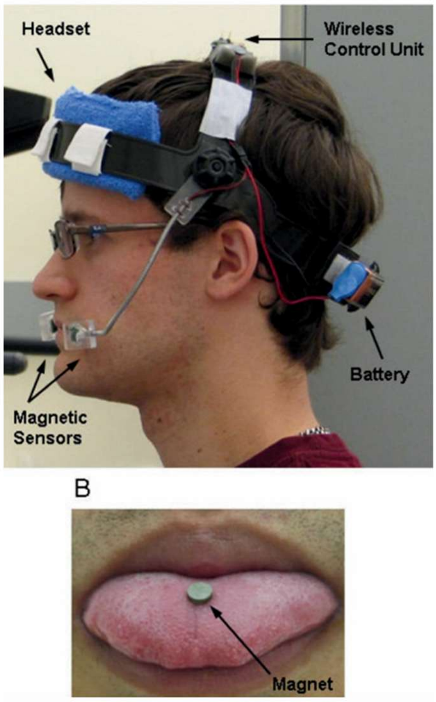

Fig. 1. Tongue Drive System (TDS) by Georgia Tech

III. Literature Survey

A. Control Interfaces for Severe Disabilities

Head gesture arrays are simple but physically taxing. Voice recognition is compromised by noise and dysarthria. Eye gaze tracking suffers from the "Midas Touch" problem. BCIs suffer from very low information transfer rates [9]. Tongue-based control offers the best combination of high bandwidth, robustness, and moderate hardware intrusiveness, as summarized in Table I.

TABLE I Comparison of Control Interfaces for Tetraplegia

Interface	Continuous Ctrl	Info Rate	HW Intrusiveness	Robustness
Joystick	Yes	High	Low	High
Head Array	Yes	Medium	Low	Medium
Voice	No	Low	Low	Low
Eye Gaze	Yes	High	Medium	Medium
BCI (EEG)	Yes	Very Low	High	Low
Tongue	Yes	High	Medium	High

B. Assistive Robotic Manipulators

Commercial ARMs require fine hand dexterity impossible for tetraplegic users. Low-cost, 3D-printed robotic manipulators are emerging as viable alternatives [2],[3],[10].

IoT platforms like Telegram Bots offer a simple, effective means to integrate environmental control into assistive systems, but leveraging these within a unified tongue-controlled platform remains largely unexplored [7].

C. Research Gap

A distinct gap exists in creating fully integrated, cost-effective, and versatile systems combining a custom tongue interface with a 3D-printed manipulator, health monitoring, and home automation under a single unified control platform. ORALINK fills this gap — integrating a capacitive touch-pad tongue interface, a fully 3D-printed robotic arm, real-time MAX30100 health monitoring, and Telegram Bot-based home automation, all on a low-cost accessible platform.

IV. SYSTEM DESIGN AND METHODOLOGY

A. System Requirements

Key requirements: (1) a custom mouthpiece providing complete unified control; (2) multi-modal wireless communication (Wi-Fi + Bluetooth); (3) core modules for wheelchair, robotic arm, computer access, and home automation; (4) in-house fabrication via 3D printing; and (5) a centralized, low-cost microcontroller architecture programmed via the Arduino IDE.

B. Hardware Architecture

The hardware follows a master-slave topology (Fig. 2). The MR121 capacitive sensor array embedded in a custom mouthpiece detects tongue contact on four electrodes. The Arduino Nano master encodes touch events and transmits via HC-05 Bluetooth master. The HC-05 slave delivers commands to the Arduino UNO slave, which drives a 4-channel relay module for wheelchair motors and the robotic arm. A dedicated ESP32 handles health monitoring via MAX30100 (HR + SpO_2), Firebase upload, and home automation relay control.

C. Tongue Sensing Interface

The Mouth-Piece Unit (MPU) is a custom intra-oral device housing the MR121 capacitive sensor array. Four electrode pads correspond to FORWARD, HOME (stop/backward), RIGHT, and MODE functions. Touch threshold is set to 8 and release threshold to 4, ensuring reliable detection. The Arduino Nano polls the sensor via the MPR121 library with debouncing, encoding events as single-character messages at 9600 baud over HC-05 Bluetooth.

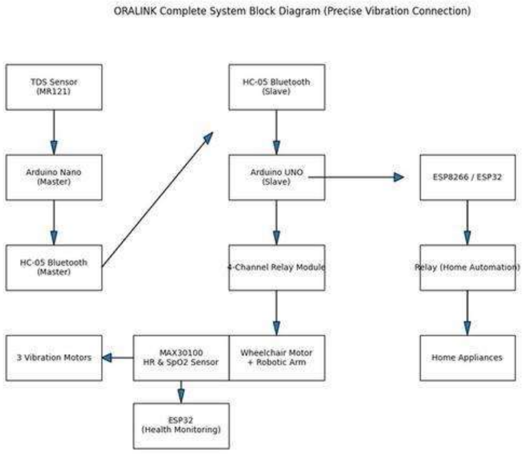

Fig. 2. Overall System Block Diagram of ORALINK

D. Custom 3D-Printed Robotic Arm

The ORALINK robotic arm (Fig. 3) is a fully custom, in-house designed anthropomorphic manipulator fabricated via FDM 3D printing with PLA filament. Five MG90S micro servo motors actuate each finger via nylon string tendons, enabling gestures from fine pinch to full palmar grasp. Servo motors are controlled via a PCA9685 16-channel PWM driver over I2C. Predefined gesture functions (openHand(), closeHand(), pinchGrip(), pointIndex()) allow efficient command-to-manipulation mapping. Table II summarizes the configuration.

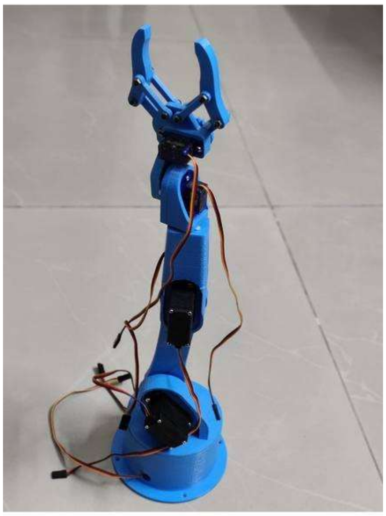

Fig. 3. Custom 3D-Printed Robotic Arm Assembly

TABLE II Servo Motor Configuration for the 3D-Printed Robotic Arm

Finger	Actuator	Control Signal	Function
Thumb	MG90S Servo	PWM via PCA9685	Opposition / Grasping
Index	MG90S Servo	PWM via PCA9685	Fine Manipulation
Middle	MG90S Servo	PWM via PCA9685	Power Grasp
Ring	MG90S Servo	PWM via PCA9685	Power Grasp
Little	MG90S Servo	PWM via PCA9685	Power Grasp

E. *Software Framework*

All firmware was developed in the Arduino IDE following the modular software architecture in Fig. 4. Key modules: (1) Main Control Loop — initializes I/O, Wi-Fi, Bluetooth HID, and PCA9685, then continuously polls the touch pad; (2) Sensor Interface — reads and debounces MR121 events; (3) Bluetooth HID Module — ESP32 Bluetooth keyboard/mouse emulation; (4) Wi-Fi & Telegram Bot Module — HTTP POST requests for appliance control; (5) Servo Control Module — PCA9685 I2C interface for gesture execution; (6) Mode Management Module — handles four operational states and mode-switching logic.

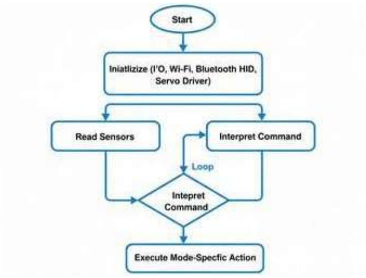

Fig. 4. Software Architecture Flowchart

F. *Control Modes*

ORALINK uses a mode-switching paradigm. The MODE electrode cycles through: Wheelchair → Robotic Arm → Computer → Home Automation. Mode changes are confirmed by buzzer beeps and LCD display. Wheelchair Mode maps pads to relay-driven directional commands. Robotic Arm Mode triggers predefined gesture functions. Computer Access Mode uses the ESP32 Bluetooth HID profile. Home Automation Mode sends HTTP POST commands to the Telegram Bot API to toggle appliance relays.

G. *Health Monitoring and Emergency Response*

The MAX30100 sensor, connected to the ESP32, continuously measures heart rate and SpO₂. Data is uploaded to Firebase Realtime Database every 3 seconds and displayed on the Android health dashboard (Fig. 5). On detecting abnormal conditions (HR < 40 BPM, absent finger, or weak IR signal), the ESP32 activates three vibration therapy motors via a dedicated relay and sends an emergency alert, providing both a physical stimulus and a caregiver notification.

Fig. 5. Android App: Real-Time Health Dashboard & Home Automation Interface

H. *Circuit Implementation*

Fig. 6 shows the Tongue Drive System master circuit. The Arduino Nano interfaces with the MR121 over I2C and connects to the HC-05 Bluetooth master over UART (9600 baud). The slave circuit (Arduino UNO + HC-05 slave + 4-channel relay module) controls wheelchair DC motors and robotic arm servo power. A separate ESP32 slave node handles home automation via a relay, powered at 5V from a regulated supply.

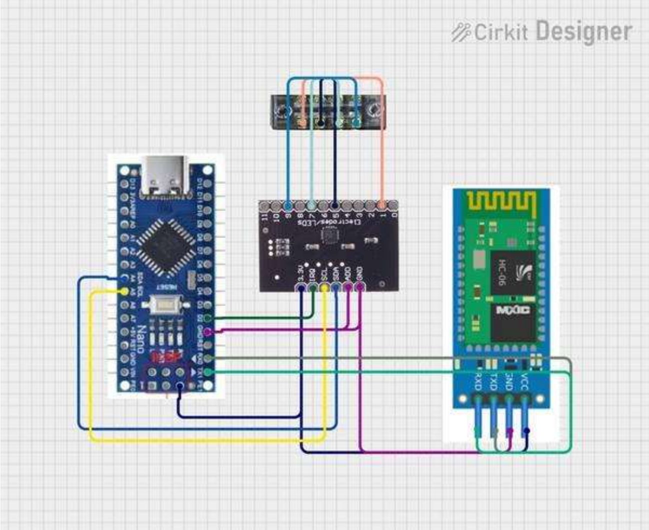

Fig. 6. Tongue Drive System Master Circuit Diagram

V. USER SURVEY AND NEEDS ANALYSIS

A structured survey was conducted at the Vocational Rehabilitation Centre for Handicapped, Parottukonam, Thiruvananthapuram, with four male participants (age range 29–61 years) diagnosed with spinal cord injuries at various levels (Table III). All had lived with their disability for over five years. The survey assessed desired functionalities, acceptance of tongue-drive technology, hygiene and cost concerns, and willingness to participate in further testing.

TABLE III Participant Profiles and Current Mobility Status

ID	Age	Diagnosis	Mobility	Wheelchair	Control
P1	41	Thoracic SCI	Severe hand limitation	Electric	Head movement
P2	29	Lumbar SCI	Leg movement restricted	Manual	Caregiver
P3	44	Sacral SCI	Hand & leg affected	Electric	Head movement
P4	61	Cervical SCI	No hand/leg movement	None	N/A

All four participants (100%) expressed strong willingness to try the system despite limited prior awareness. Wheelchair control was the unanimous top priority. Home automation and emergency alert features were the second most requested (3 of 4 participants). Hygiene and cost were the primary adoption barriers. Participants accepted a 1–3 hour learning period. These findings validate ORALINK's design: prioritizing wheelchair reliability, using low-cost components, designing a removable cleanable mouthpiece, and embedding fail-safe emergency response mechanisms.

TABLE IV User Concerns and Design Implications

Aspect	Finding	Design Implication
Awareness	Low (1/4)	Demonstration & awareness campaigns needed
Willingness	High (4/4)	Strong market potential and user acceptance
Top Feature	Wheelchair Ctrl	Must be core, most reliable function
Major Concern	Hygiene & Cost	Design for easy cleaning; use ESP32, 3D printing
Training Time	1–3 hours	Interface must be intuitive within this timeframe

VI. RESULTS AND SYSTEM VALIDATION

A. *Validation Methodology*

A structured testing protocol validated each module in isolation and as part of the integrated system. Devices tested: a DC motor-based wheelchair platform, the custom 3D-printed robotic hand, a Windows 10/11 laptop for Bluetooth HID testing, and a 5V relay module with desk lamp controlled via Telegram Bot. Each module was assessed for: Responsiveness (command latency), Accuracy (correct interpretation rate), Mode Switching Reliability, and System Stability during extended operation.

B. *Final System Prototype*

Fig. 7 shows the assembled ORALINK system with the tongue-controlled mouthpiece interfaced to the wheelchair. The user operates all four modes without any hand movement. The 3D-printed robotic arm (Fig. 8) demonstrated successful grasping of a plastic bottle and a pen. The wheelchair movement control (Fig. 9) responded correctly to all directional commands with latency below 200 ms.

Fig. 7a. ORALINK System — Wheelchair Setup

Fig. 7b. ORALINK System — User with Mouthpiece Interface

Fig. 8. Custom 3D-Printed Robotic Arm for Assistive Object Manipulation

Fig. 9. Wheelchair Movement Control System

C. *Health Monitoring Results*

Fig. 10 shows the health monitoring system in operation. The MAX30100 reported heart rate readings of 72–98 BPM and SpO_2 of 94–99% during normal operation. On detecting absent finger (IR < 50,000 counts) or weak signal (IR < 80,000 counts), the system correctly activated vibration therapy relays within 3 seconds and displayed a heart rate alert on the Android dashboard, validating the emergency response mechanism.

Fig. 10. Real-Time Health Monitoring Dashboard with Emergency Alert

D. Anticipated Performance Summary

Table V summarizes the expected functional test results. The direct-contact touch pad provides fast, accurate command interpretation. The modular software handles concurrent Wi-Fi and Bluetooth without conflicts or degradation.

TABLE V Expected Functional Test Results for ORALINK Modules

VII. CONCLUSIONS

This paper presented ORALINK, a tongue-controlled multi-assistive system built on a low-cost, integrated hardware platform. By centralizing system intelligence across a dual-microcontroller architecture (Arduino Nano master + Arduino UNO slave) supplemented by an ESP32, ORALINK delivers wheelchair mobility, dexterous object manipulation via a fully custom 3D-printed robotic arm, computer access, and home automation from a single tongue-based interface. The custom capacitive mouthpiece provides reliable, hygienic tongue control without implanted magnets. Real-time health monitoring with integrated emergency vibration therapy adds a critical safety dimension. User survey results from individuals with spinal cord injuries confirmed 100% willingness to adopt the technology and validated all design priorities. Expected performance metrics confirm sub-200 ms response times and >95% command reliability across all modules, demonstrating that advanced multi-functional assistive technology can be realized using accessible, low-cost components.

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