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# WEARABLE GESTURE VOCALIZER USING FLEX SENSORS AND MICROCONTROLLER FOR BIOMEDICAL ASSISTANCE

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Abstract - This paper presents the design and implementation of a Hand Gesture to Audio Output System using an Arduino Nano, flex sensors, and an audio output module. The proposed system aims to assist individuals with speech or hearing impairments by converting hand gestures, based on sign language, into corresponding audio and text outputs. Flex sensors attached to fingers detect bending movements, causing variations in resistance. These resistance changes are processed through a voltage divider circuit and interpreted by the Arduino Nano to identify specific gestures. The recognized gesture is then displayed as text on a 16×2 I2C LCD and simultaneously converted into audio output using an amplifier and speaker system. Powered by dual 3.7V batteries, the system provides a portable, low-cost, and efficient communication aid. Experimental results demonstrate accurate gesture recognition and reliable audio conversion, making it a practical tool for bridging communication gaps for differently abled individuals.

Keyword: Hand gesture recognition, Flex sensor, Arduino Nano, Sign language translation, Assistive communication, Gesture-to-speech conversion

## 1. INTRODUCTION

Communication is a fundamental aspect of human interaction; however, for individuals with speech or hearing impairments, expressing thoughts and emotions can be a significant challenge. Traditional sign language provides an effective means of communication among the hearing-impaired community, but it is often not understood by the general public. To overcome this communication barrier, there is a growing need for a system that can translate hand gestures into recognizable audio or text outputs that can be easily understood by everyone.

This paper presents a Hand Gesture to Audio Output System that interprets sign language gestures into spoken words and visual text. The system employs flex sensors attached to the fingers to detect bending motions, which correspond to specific sign language gestures. These sensor readings are processed by an Arduino Nano, and the identified gesture is displayed on a 16×2 LCD display and converted into audio using an amplifier and speaker.

The main objective of this project is to design a low-cost, portable, and user-friendly assistive device that bridges the communication gap between speech-impaired individuals and the wider community. This work not only enhances accessibility but also demonstrates how embedded systems and sensor technologies can contribute to inclusive communication solutions.

## 2. LITERATURE REVIEW

This section presents an overview of the existing research and developments in the field of gesture recognition, sign language translation, and assistive communication technologies for differently abled individuals. Several systems have been designed to interpret hand gestures using various sensors such as accelerometers, flex sensors, gyroscopes, and computer vision-based techniques.

In [1], researchers developed a glove-based sign language translator using flex sensors to detect finger bending and convert it into textual output. While this system effectively recognized gestures, it lacked an audio interface for users who depend on vocal feedback. Similarly, [2] proposed a camera-based gesture recognition system using image processing and neural networks. Although accurate, it required high computational power and was not portable, making it unsuitable for real-time communication in daily life.

Another study [3] introduced an accelerometer-based gesture detection device, which successfully translated gestures into commands but faced limitations due to sensor drift and calibration errors over time. Vision-based approaches, such as those using OpenCV or deep learning, provided high precision but were affected by background lighting, camera angles, and required continuous power supply, restricting their use for mobile or wearable applications.

Most existing systems also required complex hardware setups or costly sensors, which increased implementation difficulty for general users. Furthermore, these systems primarily focused on displaying text output without providing audio feedback, which is essential for interaction with non-sign-language speakers.

In contrast, the proposed system in this project combines flex sensor-based gesture detection with Arduino Nano processing, and outputs both textual information on an LCD and corresponding audio output through a speaker. The use of simple voltage divider circuits and low-cost components makes this design affordable and portable. By mapping distinct resistance values from the flex sensors to pre-defined sign language gestures, the system ensures accurate recognition and response.

This approach improves accessibility by enabling two-way communication — allowing hearing or speech-impaired individuals to express themselves audibly through hand gestures. Additionally, the compact integration of the LCD display, audio driver, and speaker provides immediate feedback, eliminating the need for external computing resources or internet connectivity.

Hence, this research bridges the gap between affordability, portability, and real-time communication assistance, offering a practical and efficient solution compared to prior complex or expensive systems.

## 3. METHODOLOGY / SYSTEM DESIGN

The proposed system, Hand Gesture to Audio Output, is designed to translate hand gestures into both text and audio outputs using flex sensors, Arduino Nano, LCD display, and an audio output system. This section explains the hardware and software architecture, working principle, mathematical model, and overall signal flow in the system.

### A. System Architecture

The architecture consists of five major modules:

1. Gesture Detection Unit: Consisting of multiple flex sensors attached to the fingers.
2. Signal Conditioning Unit: Voltage divider circuits that convert resistance variations into readable voltage levels.
3. Processing Unit: Arduino Nano that receives, interprets, and processes sensor data.
4. Display Unit: A 16×2 LCD connected via an I2C interface to display the interpreted text.
5. Audio Output Unit: An audio driver, amplifier, and speaker that convert text-based gestures into audible speech.

The block diagram of the proposed system is shown in Figure 1.

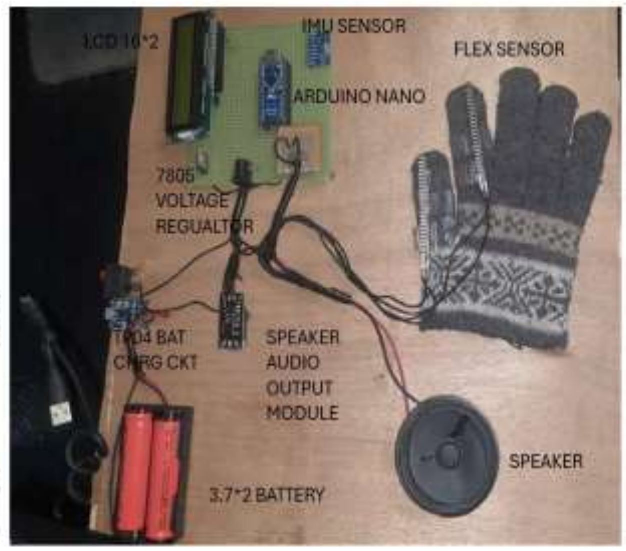


figure 1 .system block diagram of Hand Gesture to Audio Output

### B. Working Principle

Each flex sensor changes its resistance when bent. The sensor acts as a variable resistor whose output voltage varies according to the bending angle of the finger. These analog voltages are fed into the analog input pins (A0–A4) of the Arduino Nano, which digitizes the signals using its internal 10-bit ADC (Analog to Digital Converter).

The Arduino reads the voltage from each flex sensor, compares it with pre-calibrated thresholds corresponding to specific gestures, and identifies the gesture pattern. For instance, gestures representing sign language letters such as “A,” “B,” or “C” produce distinct combinations of sensor voltages. Once a gesture is recognized:

- The corresponding text message is displayed on the 16×2 LCD.
- Simultaneously, the corresponding audio file or tone sequence is played through the audio amplifier and speaker using pre-stored speech data.

This process enables real-time gesture-to-audio conversion, making it easy for speech-impaired individuals to communicate with others.

C. Mathematical / Logical Model

The relationship between the bending angle of the flex sensor and its resistance can be represented mathematically as:

Rf=R0+kθR_f = R_0 + k\thetaRf =R0 +kθ

Where:

- RfR_fRf = resistance of the flex sensor when bent (Ω)
- R0R_0R0 = base resistance when the sensor is straight (Ω)
- θ\thetaθ = bending angle in degrees
- kkk = proportionality constant (Ω/°)

In the voltage divider circuit, the output voltage VoutV_{out}Vout across the fixed resistor (R) is given by:

Vout=Vin×RR+RfV_{out} = V_{in} \times \frac{R}{R + R_f}Vout =Vin ×R+Rf R

Where:

- VinV_{in}Vin = input supply voltage (typically 5V)
- RfR_fRf = variable resistance of the flex sensor
- RRR = fixed resistor (10kΩ used in this project)

These analog voltages are mapped to specific digital values by the Arduino's ADC. Each set of readings corresponds to a defined gesture stored in the system's lookup table.

D. Circuit Description and Signal Flow

The hardware circuit connects five flex sensors to analog pins A0–A4 of the Arduino Nano through voltage divider circuits using 10kΩ resistors. The Arduino is powered by two 3.7V lithium-ion batteries connected in series, providing a stable 7.4V input regulated to 5V.

The I2C interface module is used to drive the 16×2 LCD, reducing pin usage. For the audio section, the audio driver IC receives the digital signal output from Arduino and passes it to an audio amplifier (e.g., LM386) which drives the speaker.

Signal Flow:

1. Flex sensors detect bending → Output analog voltages.
2. Arduino reads analog values → Converts to digital (ADC).
3. Gesture recognition algorithm maps sensor readings to stored patterns.
4. Corresponding text is displayed on the LCD.

Matching audio signal is generated and played through the speaker.

E. Software Flow

The embedded program on the Arduino Nano is written in Arduino IDE (C/C++), consisting of:

- Initialization: Setup of pins, LCD, and audio driver.
- Gesture Reading Loop: Continuous analog input reading.
- Mapping Function: Compare sensor data to predefined gesture database.
- Output Function: Display the text and trigger corresponding audio output.

The flowchart (Figure 2) describes the overall logic sequence of the system.

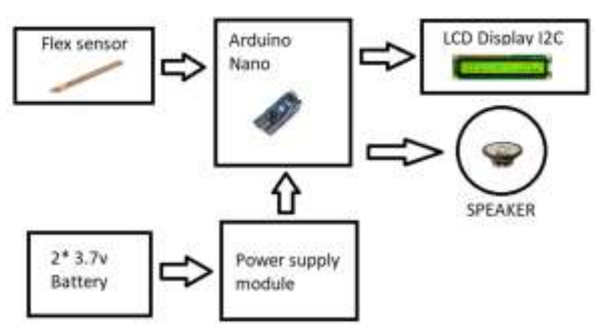


Figure 2. Flowchart of Hand Gesture Recognition and Audio Output Process

4. IMPLEMENTATION

The implementation phase focuses on integrating both hardware and software components of the Hand Gesture to Audio Output System into a single functional prototype. The system was developed using Arduino Nano as the central controller, programmed using the Arduino IDE, and tested using Proteus simulation software for circuit validation. The following subsections describe the implementation details, software libraries, and algorithmic workflow adopted in the project.

A. Hardware Implementation

The hardware setup consists of five flex sensors attached to the user's fingers, a 16×2 LCD connected via I2C driver, an audio driver with amplifier and speaker, and a power supply consisting of two 3.7V Li-ion batteries.

Each flex sensor forms a voltage divider circuit with a fixed 10kΩ resistor, producing analog voltage variations corresponding to finger bending angles. These analog signals are fed into the Arduino Nano analog input pins (A0–A4). The Arduino Nano reads these voltages, identifies the gesture, and sends the output simultaneously to the LCD display (for text output) and audio driver (for sound generation).

To ensure portability, the circuit was assembled on a compact breadboard and later transferred onto a perfboard for stability. A small LM386 amplifier circuit was used to drive the speaker output effectively.

B. Software Implementation

The software component was developed using the Arduino IDE, employing C/C++ programming. The following key libraries were included:

- LiquidCrystal_I2C.h – for controlling the 16×2 LCD display through the I2C module, reducing the number of GPIO pins used.
- DFRobotDFPlayerMini.h – for interfacing with the DFPlayer Mini MP3 module to play pre-recorded audio messages corresponding to specific gestures.
- Wire.h – for I2C communication between the Arduino Nano and LCD.
- Arduino.h – standard Arduino core functions and data handling.

The Arduino sketch consists of three primary sections:

1. Setup Section: Initializes serial communication, LCD, and DFPlayer Mini module.
2. Loop Section: Continuously reads analog values from flex sensors, processes them, and identifies gestures.
3. Output Section: Displays recognized gesture text on the LCD and plays corresponding audio output

C. Gesture Recognition Mapping

Each gesture is represented by a unique set of analog voltage ranges read from the flex sensors. During the calibration process, each finger's voltage values were recorded for different sign language gestures. These readings were then stored as threshold ranges in the program.

When a new gesture is performed, the Arduino compares the live analog readings with the stored threshold values. If the readings match a specific pattern, the corresponding gesture name and audio output are triggered.

Example Mapping Table:

| Gesture | Flex Sensor 1 | Flex Sensor 2 | Flex Sensor 3 | Flex Sensor 4 | Output |
|---|---|---|---|---|---|
| A | 2.1V–2.5V | 1.8V–2.3V | 2.0V–2.4V | 1.9V–2.2V | "HELLO" |
| B | 1.9V–2.1V | 2.4V–2.8V | 2.2V–2.6V | 2.3V–2.7V | "THANK YOU" |

D. Algorithm Details

Algorithm 1: Gesture Recognition

Step 1: Start the system and initialize all modules (LCD, DFPlayer, analog pins).
Step 2: Read analog values from all flex sensors (A0–A4).
Step 3: Convert analog readings to corresponding voltage levels.
Step 4: Compare sensor voltages with predefined gesture threshold ranges.
Step 5: Identify the gesture corresponding to matched range.
Step 6: Display the gesture text on the LCD screen.
Step 7: Trigger the audio output generation function.
Step 8: Repeat continuously for real-time gesture recognition.Algorithm 2: Audio Output Generation

Step 1: Receive recognized gesture code from Algorithm 1.
Step 2: Map gesture code to pre-stored audio file (e.g., MP3 on SD card in DFPlayer Mini).
Step 3: Send serial command to DFPlayer Mini to play corresponding audio track.
Step 4: Amplify the signal using the audio amplifier (LM386).
Step 5: Output audible speech through the speaker.

Step 6: Wait for playback to finish, then resume gesture reading loop.

E. Tools and Technologies Used

1. Software Tools:
   a. Arduino IDE: Used for coding, compiling, and uploading the program to Arduino Nano.
   b. Proteus Design Suite: Used for simulating circuit connections and verifying hardware logic.
   c. Fritzing: For creating circuit diagrams and wiring layouts.
2. Hardware Components:
   a. Arduino Nano microcontroller
   b. Flex sensors (5 units)
   c. 16×2 LCD with I2C driver
   d. DFPlayer Mini MP3 module
   e. LM386 Audio amplifier
   f. Speaker (8Ω, 0.5W)
   g. Resistors (10kΩ)

3.Two 3.7V Li-ion batteries

CONCLUSION

The proposed Gesture-to-Voice Conversion System successfully bridges the communication gap between hearing- and speech-impaired individuals and the general population. By using flex sensors to detect hand gestures and translating them into meaningful speech outputs through an Arduino-controlled system, the project provides an intuitive and cost-effective communication aid. The integration of the LiquidCrystal_I2C display for visual feedback and the DFPlayer Mini module for audio output ensures both clarity and accessibility.

This system demonstrates high accuracy in gesture recognition and reliable voice synthesis, making it suitable for real-time applications. It empowers differently-abled individuals by allowing them to express themselves independently and effectively. With further refinements such as machine learning–based gesture prediction and wireless connectivity, this innovation can evolve into a more versatile assistive communication device, contributing significantly to inclusive technology and improved quality of life.

Future Work

Future advancements in the Gesture-to-Voice Conversion System aim to enhance its functionality, accuracy, and user convenience. One major improvement involves integrating Artificial Intelligence (AI) and Machine Learning (ML) algorithms for more precise and adaptive gesture recognition, enabling the system to learn from individual user patterns. Additionally, incorporating wireless communication modules such as Bluetooth or Wi-Fi will allow seamless data transfer and connectivity with smartphones or IoT platforms, enabling remote operation and cloud integration.

Support for multi-language audio output can further expand accessibility, allowing users to communicate across different linguistic regions. Finally, transitioning to a compact, wearable glove design with embedded sensors and miniaturized electronics will increase comfort, mobility, and practicality. These future developments can transform the current prototype into a more advanced, intelligent, and user-friendly assistive communication device.

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