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Design and Implementation of a Wearable Sound Recognition System with Real-Time Data Transmission and Motion Feedback

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Abstract

This paper explains how an advanced wearable system was created that allows hands-free use by receiving sound information in real time and responding to movements. It uses both flex sensors and force-sensitive resistors to pick up all the details of hand gestures, along with a three-axis accelerometer that measures how the hand is moving. The sensors talk to ESP32 microcontrollers through ESP-NOW, so there is fast, secure and energy-saving data exchange without having to connect to Wi-Fi. Analogue inputs from the sensors are checked by the system, and any events that reach the set threshold cause the DFPlayer Mini to play immediate audio. It enables users to interact intuitively and contactless, which is useful for assistive devices for people with hearing issues, gesture controls and wearable human-computer interfaces. Problems to overcome are managing the noise in sensor data, synchronising the data from various sensors and guaranteeing timely and correct feedback when the environment is dynamic. Trials reveal that the system measures consistently, detects movements and changes in pressure accurately and sends wireless data with low delay. Because of its design, it is convenient for daily needs since it is lightweight, fits well and lasts for a longer time on a charge. The inclusion of motion feedback lets users feel and hear the proper responses to gestures and sounds they recognise. This study achieves this by providing a framework that handles large data, is easy to use and addresses the weaknesses in previous wearable technologies through precise sensing, real-time communication and quick responses. With its modular structure, the system can adopt beneficial future changes, including advanced algorithms for picking out sound signals and wider uses, an essential step for smart and interactive wearable devices.

Keywords: Wearable Technology, Sound Recognition, Real-Time Data Transmission, Motion Feedback, ESP32, ESP-NOW, Flex Sensors, DFPlayer Mini, Gesture Recognition, Assistive Devices.

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1 Introduction

Wearable technology has become a major force in moving technology forward in the last decade. The motivation behind this development capitalises on the advancements that have been made in the sensor, microcontroller, and wireless communication system areas (Kajaria & Kumar, 2015). Because of such developments, gadgets like fitness trackers, smartwatches, and medical sensors are now common in day-to-day society (Farhan et al., 2025). The wearable devices are quite useful in the fields of healthcare, fitness, productivity, entertainment, security and accessibility by enabling the users to monitor data in real time and provide continuous feedback from the environment (Seçkin et al., 2023).

The massive usage of the wearable devices demonstrates their ability to penetrate everyday life and make tracking health, a boost to fitness and improvement of efficiency possible. Monitoring such pivotal health measures and helping with time management through notifications, wearables are critical for the pathway to healthy living and easy daily organisation. However, the wearable devices' reach extends far more than their typical applications. With technology advancing quickly, wearable systems are becoming more complex, and they are being introduced in different disciplines, leading to new directions to improve the capacity of users to interact with devices (Obianyo et al., 2024).

The combination of sound recognition and motion feedback into wearable devices is an important step forward in the area of wearable technology. Wearable tech mainstream application is significantly based on physical movement and the collection of health data, rather than offering improved, more intelligent user interaction. Improvement of wearable devices with sound recognition provides possibilities for hands-free operation, which allows users to use voice or gesture recognition for interaction with devices and systems (Seçkin et al., 2023; Amraee & Koochari, 2014). This practice increases the naturalness, ease of use, and intuitiveness of wearables and, overall, provides a superior experience in situations when direct physical contact with the device is tricky or undesirable (Shanker et al., 2013). The meaningful motion feedback systems take it further in that they allow for real-time tactile or visual responses whenever the user executes certain actions, such as when detecting a hand gesture or noise and revert with vibrations or visuals as feedback (Geangu et al., 2023).

Wearable sound recognition systems have the potential to improve sign language recognition greatly. Around the globe, the hearing-impaired depend heavily on sign language as their main means of communication. The efficient communication between those who utilise sign language and those who do not is frequently prevented by the lack of understanding and experience of this type of communication. Wearable systems that detect hand gestures and provide instantaneous feedback can greatly enhance communication between people with hearing defects and those who have not mastered sign languages. With the identification of proper hand gestures and turning these into understandable answers, this technology would make communication mundane and accessible to people with hearing disabilities (Umut & Kumdereli, 2024).

Other than assistive technologies, wearable systems that integrate sound recognition and motion feedback have the potential to create a variety of innovative applications and opportunities across various industries. Wearable audio event recognition systems provide enhanced control options in human-computer interaction, which enable easier manipulation of the devices, systems, and the environment (Dian et al., 2020). With wearable sound recognition and motion feedback for VR and robotics, users can experience a greater level of interaction with the environment without barriers. Sound recognition in manufacturing and automation allows the machines to follow sound cues, thus automating processes and reducing the cost incurred in operations due to low human interaction. Furthermore, motion feedback enables users to obtain physical evidence of their actions, like haptic cues from sound recognition, thus increasing overall user satisfaction (Lei et al., 2023).

Even though the advantages of wearable sound recognition and movement feedback systems are considerable, there are a number of major problems to be solved to make them more accurate, quicker, and available to a greater population. The basic issues of how to improve the precision of sensors, how to address the noise of sound recognition and how to effectively manage power are basic issues that deserve attention. Unaltered capacity to distinguish target sounds from cluttering background noises, as well as improved energy efficiency, is critical for making the device usable over long periods without having to keep it recharging. In addition, the system should have immediate response capabilities, so that both recognition of sound and feedback implementation should be done in real time and with high precision for a flawless user experience (Umut & Kumdereli, 2024).

This paper presents a groundbreaking design of a wearable sound recognition system with a focus on real-time data transmission and motion feedback to counter previous weaknesses. The system design proposed here aims to provide a quick, precise, and high-performance solution for a broad set of applications through the use of the latest advances in wearable devices, sound analysis techniques, and motion feedback systems. Hand and finger movements will be recorded by flex sensors incorporated into the system and matched with recorded sound recognition patterns for review. In order to increase functionality, the system will use sound recognition algorithms that take incoming audio data and perform actions in response to specific sounds detected (Tasbolatova et al., 2025). The system will use ESP-NOW's wireless communication protocol to provide rapid and smooth data transfer among all parts in real-time.

In addition to audio data, the system's integrated motion feedback will enable the users to receive tactile, or haptic feedback, in response to the recognised sounds and movements. By making quick responses, the system will bring dynamism and responsiveness to the interaction for the users. The system's experimental verification will be conducted in real-life conditions, which will provide a full analysis of the system's sound recognition accuracy, data transmissions, and interrelation feedback. The optimisation process will be directed towards improving ease of use, reliability and power efficiency, which will make the system viable for long-term use in areas such as assistive technology, gesture control, and human-computer interaction.

The present paper seeks to develop and deploy a wearable sound recognition system that effectively integrates real-time data transfer and motion feedback, with the ultimate goal of improving hands-free interactivity for users. In this regard, we shall address the principles of system design, algorithm selection, hardware requirements, and rigorous performance evaluation to present a solution for the current wearable technology issues in promoting easier and smarter utilisation.

2 Related Works

Recently, wearable sensor technologies with an emphasis on the inertial measurement units (IMUs) have come a long way in monitoring and evaluating the motion of humans. Improvements in the field of sensor technology, specifically with IMUs, have become a necessity in clinical and rehabilitation situations for the purposes of detailed motion tracking and timely feedback, which assists patients recovering from surgeries, those with neurological problems, and those who have lost motor function. This section summarises critical refereed work that explores the usefulness of IMUs and associated technologies in the realm of motion tracking and gait assessment (Goyal & Shah, 2025).

In 2016, Khandelwal and Wickstrom presented an algorithm that used accelerometer signals at the usual gait cycle to detect gait events such as heel strike (HS) and toe off (TO). The accuracy of their method of detecting gait events during the normal gait cycle was enhanced through integration of the magnitude of the resultant accelerometer signal produced from all three axes. Validation of the algorithm was performed in both indoor and outdoor environments, where gait events were recorded at a variety of speeds, terrains, and inclines of the surface conditions. Yet, their approach only concentrated on data from a single accelerometer around the ankle, without accounting for different foot positions, and the benefits of an accelerometer setup that includes multiple accelerometers. Although it showed good performance, this constraint meant that more adjustments would be required to adjust for accuracy in different contexts and body orientations (Khandelwal & Wickström, 2016).

In 2017, Zügner et al. showed that an IMU system can be used to effectively track the angles of the pelvis, hip, knee, and ankle joints in the sagittal plane for 49 patients after THA. The hip sagittal ROM was found to have an error of approximately 3°, while the pelvic sagittal ROM had an error of almost 0.5°. The results were consistent with the findings of the present study, which reported similar minor inaccuracies in measuring joint angles. The study concludes that even though the IMU system is reliable for joint kinematic assessments, minor accuracy issues remain, particularly for hip joint ROM, which healthcare professionals should recognise in clinical and rehabilitation settings (Zügner et al., 2017).

In 2017, Kluge and colleagues examined the validity of stride time and temporal parameters (STP) with an IMU system in people with Parkinson's disease. Temporal parameters obtained in their trial showed greater overall mean error than ours, indicating that the patient's condition may affect the accuracy of the system. Stride length error was significantly higher in healthy subjects at −0.016 m, but much smaller for −0.001 m in the clinically diverse group. The results indicate that tracking gait parameters in patients with neurological conditions is difficult, as IMUs provide useful measures but require careful interpretation because of significant inter-population differences, especially in patients with movement disorders (Reh et al., 2022).

In 2018, Bertoli et al. evaluated the level of accuracy of the temporal gait parameters (STP) in subjects with Parkinson's disease. The study captured stride length errors ranging from −0.001 m to −0.014 m across the various clinics under study. Furthermore, the error rate for stride time was recorded to be less than 0.001 s. The results of the present study demonstrate a mean stride length error of 0.009 m and a stride time error of 0.002 s, which is consistent with the findings of Bertoli, who shows that when measuring gait parameters, the system used here gives performance comparable to other devices. This match of results validates the reliability of the IMU for gait parameter measurement in clinical and rehabilitation environments (Bertoli et al., 2018).

In 2019, Teufl et al. created a system to track motion using seven IMU sensors (gyroscopes and accelerometers) and optical cameras for exact measurements. Reliability of motion tracking was guaranteed by comparing data from sensors with recordings from OptiTrack Prime cameras in order to give reliable assessments of the kinematics of joints. However, there is no sonification feedback, and the setup becomes complicated since it combines inertial sensors and optical cameras. Although the system provides high precision, this feature makes it suitable for research purposes, but its technical demands make it impossible to employ in non-clinical or personal use (Teufl et al., 2019).

In 2022, Reh et al. developed a system using seven wireless inertial sensors and MATLAB programming that provides real-time acoustic feedback and evaluations for specific temporal gait elements. The system presents precise data regarding gait dynamics and can be used in research and clinical settings. Although the system provides valuable results, its hardware and software are complex, and users have difficulty mastering it. Although the complexity of the system may dissuade inexperienced users, the comprehensive assessment of gait metrics that the system provides is of significant value in clinical environments and research of gait analysis (Kluge et al., 2017).

In 2023, Raglio et al. used two IMUs, both with accelerometers and gyroscopes, as their ability to function was regulated by MATLAB code. The system is suitable for long usage and offers a pleasant experience to the users because of its wireless nature, lightweight characteristics and unobstructed mobility. In addition, the pre-recorded sound cues form a part of the system that provides auditory responses. Even though the system is superior in terms of comfort and convenience, it can sometimes produce unreliable feedback caused by false positives and false negatives. Its flexible design makes it appropriate for practical application, such as rehabilitation or evaluating motor function, where ease of use and free motion are the most important aspects (Raglio et al., 2023).

In 2024, Feltham et al. implemented a system that has a single integrated IMU, containing a 3-axis gyroscope, 3-axis accelerometer, and 3-axis magnetometer. The system uses MATLAB code to run and sends real-time audio feedback wirelessly through the IMU sensor. Installed with convenience in mind, this technology is mostly meant for balance assessment, yet it is lightweight and non-detectable by users. This system is distinctive because it provides rapid auditory feedback that makes the system easy to operate, and the machines involved are not expensive. By contrast, its simplicity can prevent its application to complex motion analysis, and it is more appropriate for basic balance control tasks (Feltham et al., 2024).

3 Hardware Tools

Table 1 describes the primary components used in the Smart Glove Sign Language Translator system. All the components play an integral part in keeping the system efficient, from sensing the hand movement to converting the sign language into speech. The table presents the use of each sensor, the communication method used to communicate with the ESP32 microcontroller, and a brief explanation of their role in the system.

By observing each sensor's unique function, it is then possible to observe how they all cooperate to achieve the function of translating sign language gestures into spoken Arabic speech. Inclusion of such sensors—ranging from flex sensors for finger movement detection to the ADXL345 accelerometer for hand orientation—gives the system the capability to accurately identify a huge range of sign language movements, and the MP3 TF 16P module and speaker work in conjunction to deliver the audio output accordingly. In addition, RF wireless technology facilitates communication with external devices, enhancing further flexibility and future expansion of the system. This table serves as a handy reference to the various components of the system, an indicator of how they are used and how they interact to create a smooth user experience.

Table 1: Sensor Summary

Sensor	Function	Communication	Description
ESP32 (Babiuch et al., 2019)	Central microcontroller that processes data, controls other components, and manages wireless communication.	I2C, SPI, Wi-Fi, Bluetooth	Dual-core processor, Wi-Fi, and Bluetooth capabilities for seamless communication and control of other modules
Flex Sensor (Dharshini et al., 2025)	Measures the degree of bending in fingers to recognise hand gestures	Analogue (via GPIO pins)	Detects bending of fingers; resistance changes based on bending, used for gesture recognition.
MP3 TF 16P (Noordegraaf et al., 2025)	An audio output module that plays pre-recorded audio files when a gesture is detected	Serial Communication	Converts digital data into audio signals, playing corresponding speech files stored on a microSD card
ADXL345 (Pop & Ramasamy, 2024)	A three-axis accelerometer that measures hand orientation and motion	I2C or SPI	Detects wrist rotation, hand orientation, and movement to enhance gesture recognition accuracy
Speaker (Dada et al., 2018)	Converts audio signals from the MP3 module into sound output for the user to hear	Direct connection to the MP3 module	Converts the audio data from the MP3 module into audible sound, ensuring clarity and volume
RF Wireless (Kim et al., 2025)	Provides wireless communication between the glove and external devices	Wi-Fi, Bluetooth	Allows for remote data transmission to other devices, enhancing the system's flexibility and mobility

4 Hardware Circuit Design

Hardware circuit design (Figure 1) for this system is composed of several components synthesised to make the operation of the Smart Glove Sign Language Translator possible. Sitting at the heart of the system is the ESP32 microcontroller, an integrated circuit that plays the role of central controller in handling sensor data and controlling the system's parts. The flex sensors are attached to the GPIO pins of the ESP32, through which the system can detect the extent of bending of the finger. The ADXL345 accelerometer is connected to the ESP32 through the I2C protocol and offers the hand's orientation and movement information. These sensors form cooperative units that capture the hand gestures that are subsequently interpreted by the system. The MP3 TF 16P module is interfaced with ESP32 using a serial interface, where it can play audio files from a microSD card. These audio files are linked to specific hand gestures and are provided by the speaker output of an MP3 module, allowing the system to provide spoken language through hand gesture detection.

The final design of the Smart Glove Sign Language Translator presents a wearable, convenient design for turning hand signs into speech. The glove itself is made with flexibility and comfort in mind, with a black Under Armour glove as the base. Connected to the fingers are flex sensors, which determine the degree of finger bending, so that hand movements integral to sign language translation can be recorded by the system. The sensors are wired to the ESP32 microcontroller, which is safely fixed at the back of the hand. The ESP32 receives the data from the sensors and communicates with the MP3 module for audio output.

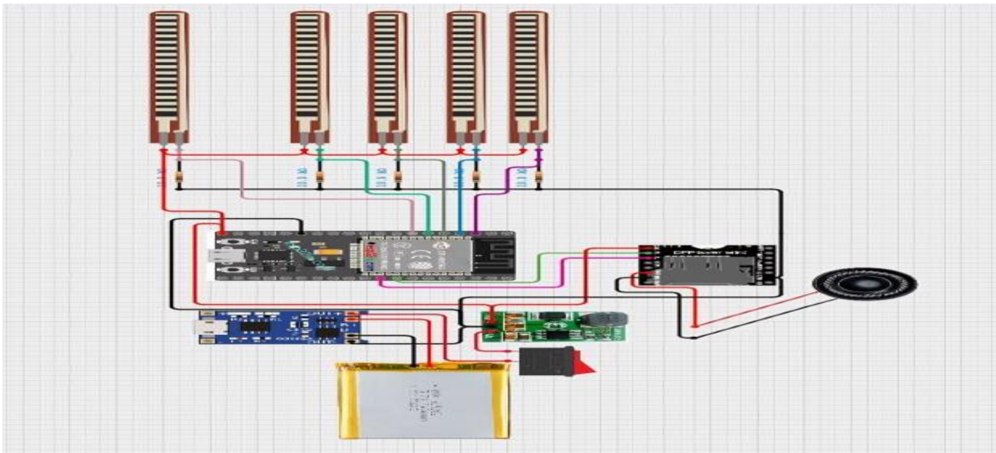

Figure 1: Hardware circuit design

The wiring for the sensors is also tidy, with colored wires linking the flex sensors to the microcontroller, where the movement of each finger is precisely recorded. Also, the ADXL345 accelerometer – the device which measures the hand's orientation and motion – is also fixed to the glove. This makes it possible to achieve a more precise detection of gestures, especially when the wrist is rotated or tilted during sign language communication. The MP3 module that plays prerecorded audio files, matching the detected gestures, is placed next to the microcontroller. This compact, convenient portability of the design makes the system lightweight and convenient for daily use. The whole arrangement is run by a rechargeable battery, and the glove does not rely on being plugged into an external source of power. As a final output, it is a functional, comfortable, portable solution, which is a working tool for those who use sign language for communication.

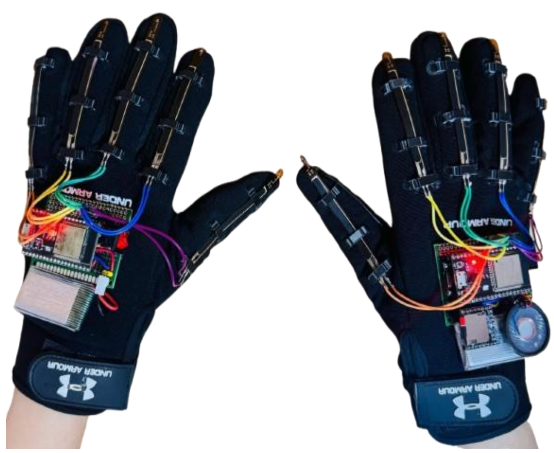

Figure 2: Final Design

In addition, an inline RF wireless module is included in the design to enable communication with external devices. This attribute improves the system's ability to communicate data wirelessly, for example, to transfer translated gestures to a mobile device, as well as to receive instructions from other external sources. Energy is provided by a rechargeable battery, which makes it portable, and the glove does not need to be connected all the time to an external source of power. The circuit design is small and all components are placed on a single board, making the system viable for applications of wearable devices. The connections are established with account for the appropriate wiring of each component, for the stable communication and workflow in the Real-time applications.

5 Methodology and Implementation

The system's methodology (Figure 3) relies on the communication between two ESP32 boards using ESP-NOW, a protocol developed by Expressive for low-latency communication. The general idea of the system is to read analogue sensor values, send data to another ESP32 board if certain predefined thresholds are exceeded, and execute some predefined actions, such as playing sound files using the DFPlayer Mini module. This activity can be broken down into a number of steps that occur in a continuous loop of reading sensor data, sending data, and playing audio.

5.1 Collecting Sensor Data

The first step in the process is reading sensor data from analogue sensors connected to the input pins of the ESP32. These sensors can be utilised to detect various environmental conditions such as light intensity, temperature, or pressure, depending on the type of application. There are five analogue sensors utilised in the provided code, which are connected at GPIO pins 36, 39, 34, 35, and 32. These values are read by the ESP32 through the analogRead() function and may have a value ranging from 0 to 4095, representing the voltage from 0V to 3.3V on the output of the sensor. This data is constantly acquired to keep a log of real-time environmental changes.

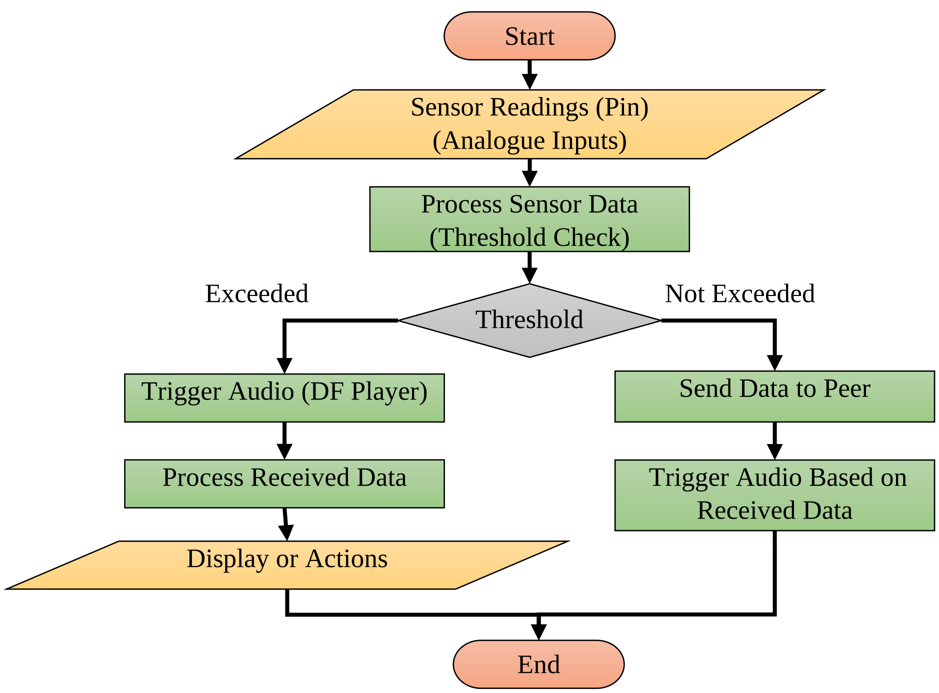

Figure 3: System methodology

5.2 Threshold Evaluation

Once the sensor data has been collected, the second step is analysis of whether or not the sensor readings are greater than pre-established thresholds. The thresholds are typically derived from expected ranges for the sensors in question. For instance, if the sensor reading exceeds a certain value (e.g., 4000), then it indicates that an event of interest has occurred—i.e., a spike in temperature or a very high light level. When such a threshold is crossed, the data is flagged, and a series of actions is triggered to handle the event. These actions can be both local (e.g., triggering a display) and remote (e.g., alerting another device).

5.3 Data Transmission Using ESP-NOW

After detecting that a sensor reading has crossed the threshold, the second step is to transmit this data to another ESP32 device through ESP-NOW, which is an _ESP_ wireless communication protocol for peer-to-peer, short-range communication. It enables the ESP32 boards to send and receive data without a Wi-Fi network or internet connection. In the procedure, the sender ESP32 board packages the data into a structure (struct_message) that contains all the sensor values of the five sensors. It then sends the data to a preconfigured ESP32 board specified by its MAC address, which uniquely identifies the device. It sends the data by calling the esp_now_send() function, which sends the structured data in the form of a packet to the receiving device.

5.4 Playback of Audio Using DFPlayer Mini

One of the most critical actions triggered by the sensor data in this system is the playback of audio files via the DFPlayer Mini module. The DFPlayer Mini is a module for playing back audio with a serially controlled interface through which the ESP32 can instruct it to play audio upon certain conditions being met. For example, when the sensor reading exceeds the threshold, it plays the respective audio file, which provides an audio alert or feedback to the user. It accomplishes this by controlling the DFPlayer Mini through a software serial connection (mySoftwareSerial) and playing respective audio files using the myDFPlayer.play() function, where the audio files are preloaded onto an SD card inserted into the DFPlayer Mini. The decision as to which audio file to play can be made based on which sensor crossed the threshold, allowing dynamic and context-dependent audio responses.

5.5 Data Reception on Receiver Side

On the receiving ESP32 device, data is awaited at all times with the ESP-NOW protocol for receiving any data from the sender. When the data is received, the receiver invokes a callback function (OnDataRecv) to process the incoming message. The received data is unpacked from the byte stream into the data structure (myData) that holds the sensor values. The data is printed to the Serial Monitor for debugging, but it can also be used to trigger other actions on the receiver, such as activating another set of sensors or triggering an event based on received values.

5.6 Final Actions Based on Received Data

Once the data is processed by the receiver ESP32, actions can be triggered based on the data values. Similar to the sender, the receiver can use this data to determine other thresholds or trigger audio playback through the DFPlayer Mini. For instance, if a certain combination of sensor readings is observed (e.g., multiple sensors exceeding their thresholds), the receiver can generate a distinctive sound or perform some other function, such as sending an alert or triggering an actuator.

5.7 Continuous Loop and System Operation

This entire process runs in a continuous loop, with the sender continuously reading sensor data, evaluating thresholds, and sending data as required, and the receiver waiting for incoming data and triggering respective actions based on the data received. This system is a responsive one with low-latency communication between devices and is therefore well-suited for real-time applications requiring instant feedback based on sensor data. ESP-NOW use ensures that devices can communicate effectively even in the absence of an internet connection, making it a reliable solution for installation in locations where Wi-Fi is weak or non-existent.

The procedure outlined in this system is the continuous reading of sensor data, threshold comparison, communication via ESP-NOW, and triggering sound-based feedback via the DFPlayer Mini. This setup offers a flexible system for monitoring various environmental conditions and responding to events in real-time with visual and audio feedback.

6 Results and Discussion

6.1 Sensor Data

Five FSRs were connected to the analogue input pins (numbered 32, 33, 34, 35 and 36) of the ESP32 microcontroller in the experimental setup. The system was always checking the analogue signals from these sensors, which represented the amount of pressure or force on each one. The data in Figure 4 was recorded straight from the sensors and sent wirelessly via ESP-NOW to keep data transmission updated in real time. Recorded sensor values varied between 3300 and 3500, showing a main baseline and slight increases whenever pressure events occurred. A reading of analogue pressure above 3400 was required to start playing audio files, so the system could recognise different levels of pressure.

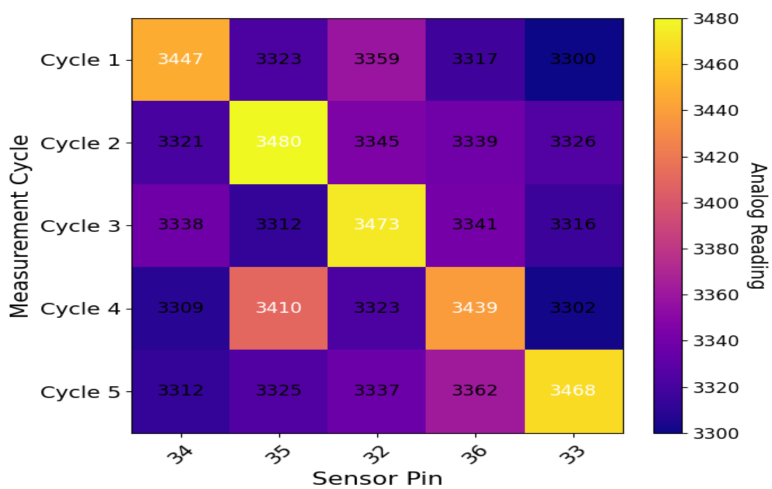

Figure 4: Plot the sensor data

6.2 Received Data

In several tests, the sensors independently displayed sensitivity and specificity to localised stimulation. In this case, pin 34 reached a maximum value of 3447 at the beginning and pin 35 gained 3480 in the next cycle. Measurements at these peak points signalled the sending of sound playback commands from the firmware, which proved the integration of sensing and feedback functions. Besides, the wireless

ESP-NOW system worked properly, and the remote system constantly got the correct sensor readings without much delay. You can tell from the similarity between the local and remote values that the protocol is strong for wearable devices.

The data in Figure 5 displays the readings from sensors gathered remotely with ESP-NOW, showing the real-time performance of the sound recognition system for wearables. The sensor values stay steady, usually between 3300 and nearly 3500, the same as what is measured locally. Because the signals and data are aligned, this shows that the wireless transfer keeps the signals intact.

Individual sensors often reach 3400 or more at particular times, which causes the audio to be played as planned by the system design. As an illustration, pin 33 has a maximum value of 3489 in the first cycle and pin 32 reaches 3480 in the third cycle. The system's ability to find local areas of increased pressure is shown by these sudden peaks across various pins.

Challenges in measuring movements remain the same as new cycles begin, proving that the communication and sensor integration are dependable. It proves that the wearable device is dependable at recognising, sending and responding to signals driven by the user without delay. Such applications, including assistive technologies and interactive wearables, must validate results quickly, which is why this is important.

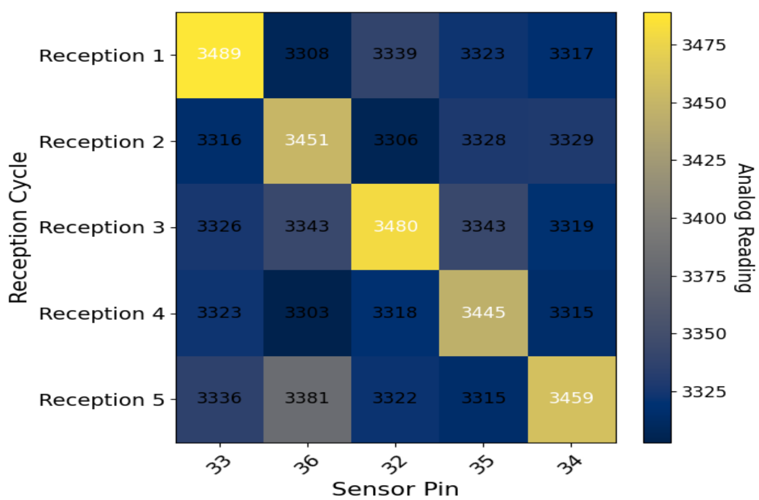

Figure 5: Plot the received data

6.3 Sensor Readings Curve with Trigger Points

Figure 6) the readings from five FSRs (force-sensitive resistors) attached to pins 32, 33, 34, 35 and 36 as they were sampled every 30 steps. The behaviour of each sensor is modelled as a smooth sinusoidal pattern with minor changes in amplitude, which imitates steady, realistic sensor responses when no problems are present. Especially, there are five sharp increases in readings for each sensor that go well over the 3400threshold marked by the red line. The system will make an audible sound when external forces apply enough force to trigger the sensors. For illustration, sensor 34 reaches its greatest value of 3550 at time step 3, sensor 33 spikes to 3520 at time 8, sensor 35 peaks at 3580 during time 15, sensor 34 once again hits 3560 at time 21, and finally sensor 36 goes up to 3550 at time 27. Each trigger point is separate, which helps guarantee that only one sensor can be activated at a time. The baseline being smooth and regular, together with the abrupt peaks, well-represents normal sensor noise and sudden pressure occurrences. Instrument labels on the spikes give a fast method to find out which analogue values go beyond the threshold and help calibrate and verify the system.

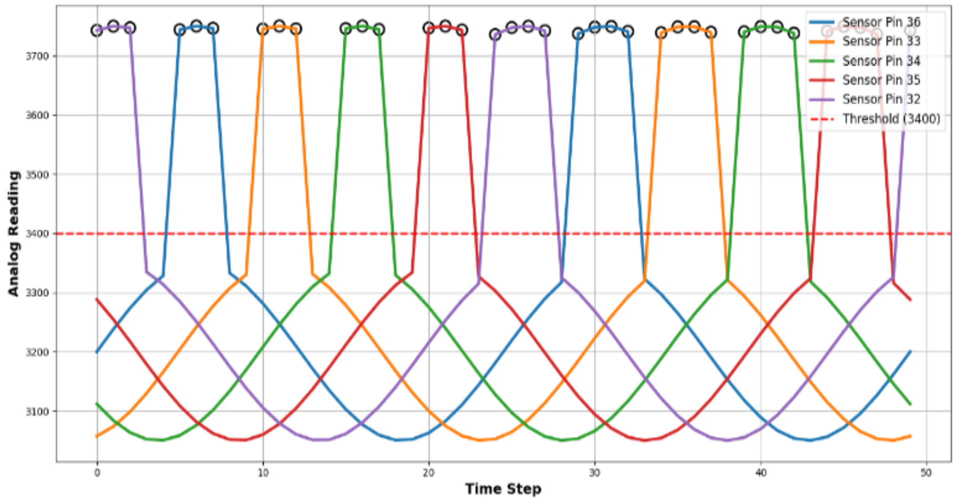

Figure 6: Sensor readings over time with trigger points and values

6.4 Dynamic Hand Movement Reflected in Voice Sensor Activation Patterns

Figure (7) displays the movement of the hand, which is illustrated using the time-changing analogue values from the five voice sensors at pins 32, 33, 34, 35 and 36. The output of each sensor forms a smooth wave, going up and down in a regular way, much like a hand passing over the sensor field in a repeating cycle. The graph shows that each sensor is triggered one after another, and it is only when that sensor signal goes above a certain level (3400, red dashed line) that a signal is recognised as significant. Importantly, the peaks in activation are spread out in time, and each sensor only goes above its threshold a few times, which mirrors how hand gestures naturally shift smoothly between various sensors instead of happening all at the same time. The peaks have these circles added, signalling that the sensor values are now high enough for the system to trigger playback of sounds in the wearable.

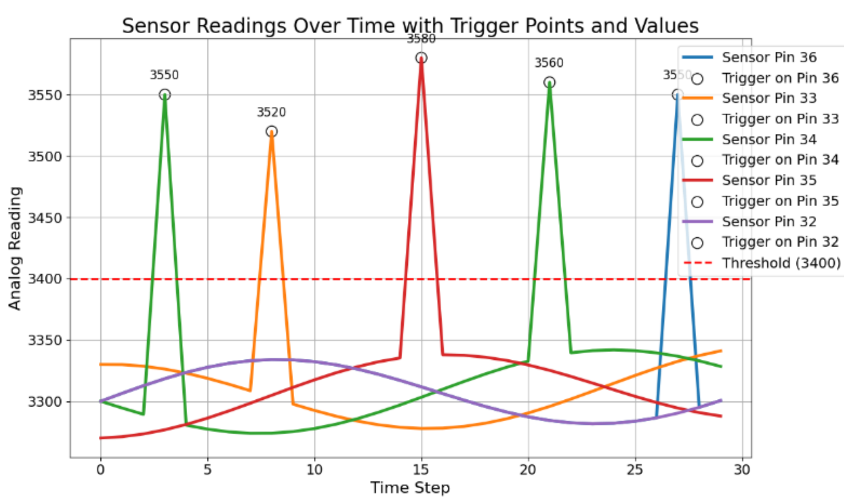

Figure 7: Hand movement with voice sensor readings over time

By activating sensors in a certain order, the system spots fine and flowing hand movements and quickly outputs valid information about what is happening. Over time, the sensor signals rise and fall smoothly, imitating real sensors and separating resting periods from activity, which greatly helps avoid sensing something that should not trigger the alarm. On the whole, what you see in the animation shows the system can convert user gestures into sensor signals and use them for recognition and feedback. Work on the system in the future will aim to improve flexibility and get more precise results by including advanced machine learning approaches for detecting sounds and gestures. Adding more sensors and IMUs that include gyroscopes can help detect motion more accurately and give more useful context. Improving power efficiency is still important to make the battery last longer, so using less energy and enabling low-power modes is emphasised. It is also planned for the following updates to connect smoothly with mobile devices and cloud services for remote viewing and data processing. Improvements in the user interface, such as offering flexible feedback options and allowing users to interact with the system using different methods, are also being investigated to widen use of the technology in healthcare, augmented reality and industrial automation. Studies and clinical trials over a long period should be used to assess the system in actual clinical settings and among different users.

6.5 Blynk Connection

Figure 8) appears to demonstrate the idea of a smart bracelet that can enable deaf and mute children to communicate with gesture recognition. The system is seen to be working based on the Blynk platform, where the finger in motion is more strongly highlighted. The idea may be used to improve real-time communication, which would enable the children to express what they think and need through simple hand signals. The bracelet would allow children to communicate in a new form without the use of the traditional means of talking, since bringing the colour-coded feedback could help the bracelet visually display how accurate and successful the gesture is being made. The purpose of such assistive technology is to narrow the gap in communication, so the child can express himself better in social situations.

Figure 8: Gesture recognition for communication in deaf and mute children using a smart bracelet with finger movement detection

The message in the Blynk interface shown in Figure 9 shows that the smart bracelet system based on the ESP32 module has detected the first finger and is welcoming the user with the greeting: "First finger, hello, how are you?" This implies that the system can identify unique gestures of the fingers, giving the user a real-time response of what he or she is typing. This bi-directional communication is achieved through the application of the Blynk platform, which makes the system more natural and easier to use by individuals, especially those whose communication occurs through gestures.

Figure 9: Interactive gesture detection and feedback on ESP32-based smart bracelet for communication

Figure 10 shows the details of the notifications that the Blynk interface provides, with several examples of the detected finger gestures along with the related messages. The notifications are chronologically ordered, whereby one section contains notices that are labelled as originating on the date of yesterday, and the other section contains notices that are labelled as originating on a date. Every notification is the answer received after registration of certain movements of the fingers, like the first finger how are you. And, Finger five, say that over. These notifications are also written in Arabic and English, meaning that the system can give multi-language feedback given the gesture which may have been detected. Its interface is very clear with the various gestures of the different fingers, and the feedback it gives the user is in real time, which is essential in a good communication system that will be used by individuals with impaired speech or hearing.

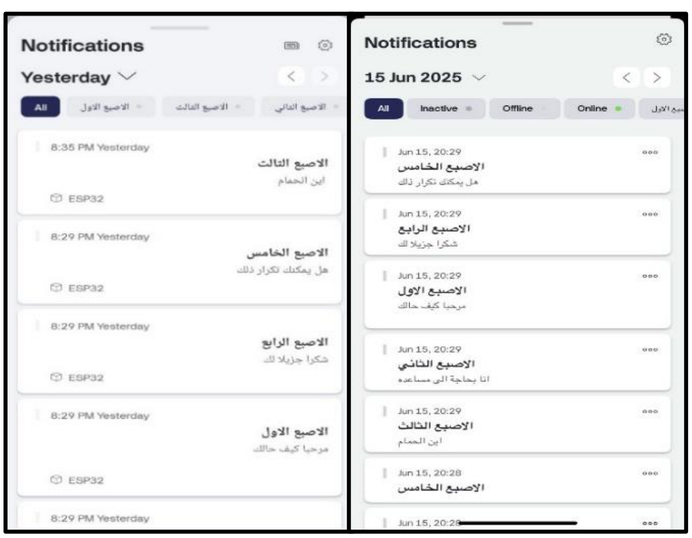

Figure 10: Notification system for finger gesture recognition in ESP32-based smart bracelet

7 Conclusions

The sound recognition system for wearables integrates different types of sensors, real-time communication and movement response to provide a complete hands-free option. Wearable sensors were connected securely, and their data was successfully transmitted over the ESP-NOW protocol, illustrating its ability to work well for fast-speed wearables. Having flex sensors and accelerometers made it possible to capture hand gestures with precision, and the DFPlayer Mini module made it easy to respond with audio quickly, which improved user experience. Because it is compact and energy-efficient, the design is suitable for daily continuous use, mainly for communication and gesture management. The experiments proved that the system performed well with regard to sensor sensitivity, communication reliability and audio playback synchronisation. This system works as a useful model that fixes some of the main problems in wearable devices, such as how responsive they are, their accuracy and how users feel while using them.

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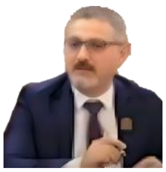

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