Hand Movement Audio Message-Based Accelerometer for Paralytic and Disabled Persons

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ABSTRACT

Individuals with paralysis or severe physical disabilities often face significant barriers in communicating their needs, which can limit their independence and quality of care. This study presents a novel system that translates hand movements into corresponding audio messages and displays them on an LCD, enabling effective communication between patients and caregivers. The device incorporates a 3-axis accelerometer and a microcontroller that processes directional hand gestures to generate preprogrammed messages. Testing demonstrates that the system reliably interprets four primary gestures corresponding to the messages: “I am hungry,” “I want to go to the bathroom,” “I want to watch television,” and “I want to go out.” The device operates effectively for users with partial mobility and accommodates those with speech impairments. Maximum speaker volume is 60 dB, with an operational range of approximately 2 meters. The system provides a practical and low-cost assistive technology solution that may improve patient autonomy, caregiver responsiveness, and quality of life.

Keywords: accelerometer, hand gesture recognition, paralytic communication system, audio message device, Batangas City, Philippines

INTRODUCTION

Technological advancements have significantly improved healthcare services by enabling smarter and more efficient patient care solutions. Despite these developments, communication remains a major challenge for individuals with disabilities, particularly paralytic patients who experience limitations in speech and motor functions. While monitoring systems allow healthcare providers to track vital signs effectively, practical solutions that support real-time verbal communication for impaired patients remain limited.

Disability, defined as physical or neurological impairment affecting movement, sensation, or daily activities, often leads to dependence on caregivers for basic communication. Paralysis, which involves partial or complete loss of muscle function, affects millions of individuals worldwide and can result from conditions such as stroke, spinal cord injury, multiple sclerosis, and cerebral palsy. These conditions not only restrict mobility but also create significant barriers in expressing needs, leading to delays in assistance and reduced quality of care.

Recent technological innovations, including brain–computer interface devices and assistive communication systems, demonstrate the potential of sensor-based and embedded technologies in improving patient interaction. However, many of these solutions remain costly, complex, or inaccessible in resource-limited healthcare settings. This highlights the need for affordable and reliable assistive devices that can support effective communication between paralytic patients and caregivers.

In response to this gap, the present study proposes a hand-movement audio messaging system using an accelerometer to translate simple gestures into audio commands. The device aims to provide a low-cost, user-friendly communication tool that enables patients to convey their needs independently. By integrating embedded sensors, microcontroller processing, and audio output, the system seeks to enhance responsiveness, reduce caregiver workload, and improve overall patient care in healthcare environments.

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Communication is a fundamental human need, but it becomes challenging for individuals with paralysis or severe motor impairments. Existing communication tools for disabled persons often require physical input devices or complex training, which can be impractical for daily use. This study focuses on developing a **Hand Movement Audio Message-Based Accelerometer**, a system that allows users to convey messages using simple hand gestures.

The primary objective of this study is to develop a hand-movement audio messaging system using an accelerometer designed to assist paralytic and disabled individuals in communicating their needs effectively.

1. To design a gesture-based system using a 3-axis accelerometer for accurate motion detection.
2. To convert detected gestures into corresponding audio and visual messages for immediate communication.
3. To evaluate the system's performance in terms of accuracy, response time, and reliability.

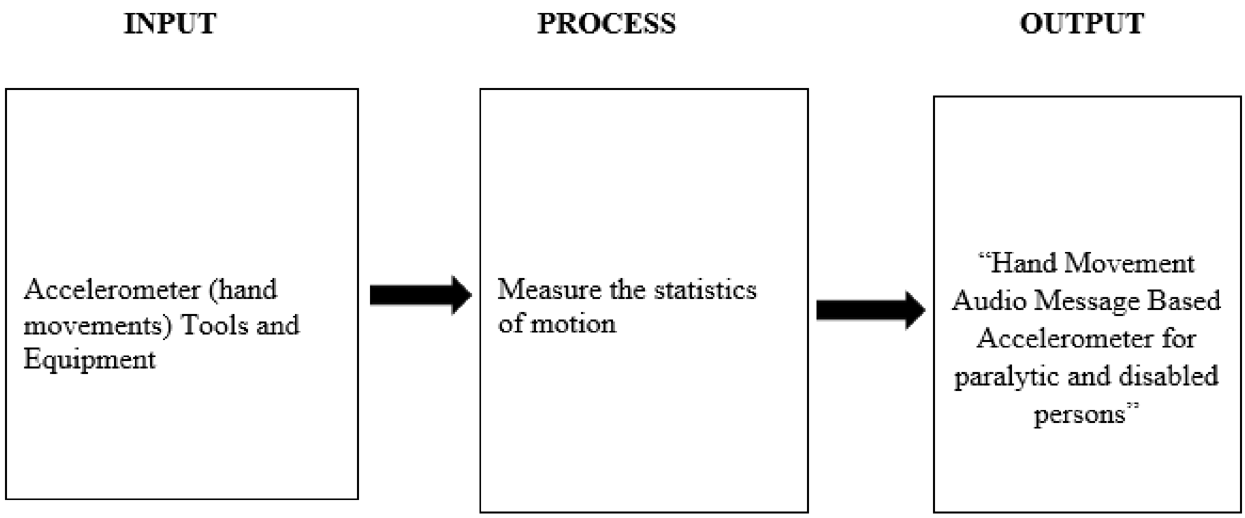

Figure 1. Research Paradigm of the Study

LITERATURE REVIEW

Based on the literature review, similar research that has been done could be explained as follows:

- **H. Liu et al. (2018)** demonstrated a hybrid-integrated, high-precision vacuum accelerometer with a sensitivity of 3.081 V/g and low non-linearity for precise acceleration measurements. Similarly, X. Hu et al. and X. Zhao et al. developed silicon-on-insulator (SOI) piezoresistive sensors capable of measuring high-g accelerations with minimal cross-axis interference, while J. Kim et al. explored thermal convection-based accelerometers, investigating cavity volume and gas density effects on Z-axis response. These studies highlight innovations in multi-axis MEMS accelerometer design, structural optimization, and sensor performance improvement.

- Further improvements, including sandwiched proof-mass structures (S. Tez and T. Akin) and compact single-proof-mass designs (C.M. Sun et al., M.H. Tsai et al., S.-C. Lo et al.), achieved high sensitivity and low cross-axis effects, demonstrating ongoing progress in miniaturized accelerometer technology.

- **Kristoffersson and Lindén (2020)** reviewed wearable sensor systems for real-life gait monitoring and emphasized the importance of demographic considerations, fall risk, and chronic conditions. Atallah et al. (2012) validated ear-worn accelerometers on a treadmill, showing the accuracy of gait parameters against force-plate measurements. Ghazal et al. (2015) proposed fall-detection systems using artificial

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neural networks with wrist-worn accelerometers and gyroscopes, achieving high accuracy in activity classification.

- **Pande et al. (2014), Kirthika Sivakumara et al. (2020),** and Sanish Manadhar et al. (2019) developed gesture-based assistive devices, including wheelchairs and message conveyers for physically disabled persons. These systems integrated accelerometers, flex sensors, and microcontrollers to enable user control and communication through hand or body gestures, providing low-cost and accessible solutions. Similarly, Jagdale et al. (2020) and Hoque Chowdhury (2019) designed smart wheelchairs for home use, integrating real-time monitoring of vital signs and emergency messaging, demonstrating practical applications for independent living.

- **Rajkhanna et al. (2014) and Ganapathyraju (2013)** focused on gesture-based control of mobile robots and industrial devices, using accelerometers and vision-based systems for accurate hand gesture recognition. **Mohammed Abdul Kader et al. (2019)** developed a head-motion-controlled semi-autonomous wheelchair for quadriplegic patients, integrating a 3-axis accelerometer with DC motors and obstacle detection, demonstrating the potential of accelerometer-based assistive systems for indoor and outdoor navigation.

- **Atallah et al. (2012)** validated ear-worn accelerometers for gait monitoring using treadmill data, demonstrating the feasibility of mapping accelerometer data to physical activity features.

- **Ghazal et al. (2015)** designed a smartwatch-based fall detection system using ANN, showing that sensor data combined with classification algorithms can accurately detect falls.

- **Baraka et al. (2019)** investigated accelerometer and sEMG data for discriminating between healthy participants and simulated tremors, achieving high classification accuracy using ensemble machine learning techniques.

- **Vishal V. Pande et al. (2014)** and **Kirthika Sivakumara et al. (2020)** designed gesture-controlled wheelchairs and motion-based message systems for disabled users, showing that accelerometer-based hand gestures can provide reliable control for navigation and communication.

- **Sanish Manadhar et al. (2019)** and **Jagdale et al. (2020)** developed wearable glove controllers and microcontroller-based systems to translate hand gestures into audio or digital messages, highlighting the effectiveness of accelerometers in enabling communication for immobile or paralytic individuals.

- **Mohammed Abdul Kader et al. (2019)** implemented a head motion-controlled semi-autonomous wheelchair using a 3-axis accelerometer, sonar sensors, and GSM notifications, demonstrating that combining accelerometer input with real-time alerts increases safety and autonomy for disabled users.

From the review of related literature, it is evident that while significant advancements have been made in the design, modeling, and application of MEMS accelerometers, there remain critical areas that require further exploration. Specifically, most studies focused on laboratory-based testing with controlled conditions, and only a limited number have addressed long-term, real-world deployment for wearable or assistive devices. Additionally, variations in sensor placement, multi-sensor fusion techniques, and the integration of user-friendly interfaces for disabled or elderly populations remain underexplored. These gaps highlight the need for developing a system that not only ensures high sensitivity and low cross-axis interference but also provides practical usability, real-time monitoring, and adaptive feedback in everyday environments. The present study seeks to address these gaps by designing an integrated accelerometer-based assistive system capable of enhancing mobility, communication, and safety for physically challenged individuals.

Compared to existing assistive communication systems that rely on vision-based processing or multiple sensors, the proposed system offers a simpler and more cost-effective solution by utilizing a single accelerometer and RF communication. This approach reduces system complexity while maintaining reliable gesture detection, making it more suitable for real-world applications, particularly in resource-limited environments.

Based on the literature review, similar research conducted emphasizes the **importance of accelerometer-based systems for hand and head movements** in assisting paralytic and disabled persons. Key points include:

1. **Accelerometer Design & Sensitivity:** Several studies focused on creating high-sensitivity, multi-axis accelerometers with low noise and cross-axis interference.

2. **Wearable Applications:** Wearable sensors, such as wrist-worn or ring-based accelerometers, are effective for real-time monitoring of fine movements, including hand gestures.

3. **Assistive Technology:** Wheelchair control, gesture-based communication, and motion-triggered messaging systems demonstrate the integration of accelerometers in improving autonomy and safety for disabled individuals.

4. **Integration with IoT & Feedback Systems:** Many systems incorporated wireless communication, GSM alerts, or mobile apps to provide real-time feedback to caregivers, enhancing emergency response and health monitoring.

5. **User-Centered Design:** Several studies emphasized designing for usability, comfort, and real-world conditions, ensuring adherence and accurate data capture for disabled or paralytic patients.

METHODOLOGY

This study employed a developmental research design to create a hand-movement audio messaging system using an accelerometer intended for paralytic and disabled individuals. The research process involved several stages, including data gathering, system design, development, fabrication, assembly, simulation, and testing and evaluation.

During the data-gathering phase, relevant literature, journals, articles, and related studies were reviewed to establish the conceptual foundation of the device. In the design stage, system requirements were identified and appropriate electronic components were selected based on availability, cost, functionality, and reliability. The development phase involved integrating sensors, microcontroller units, and audio output modules to enable gesture detection and message transmission.

Fabrication and assembly were conducted to construct the physical prototype, followed by simulation and troubleshooting to ensure proper system operation. Finally, testing and evaluation were performed to assess the device's performance in terms of functionality, efficiency, durability, and safety. These procedures ensured that the developed system met the intended objectives and provided reliable communication support for users.

SYSTEM COMPONENTS AND MATERIALS

The developed system consists of the following major hardware components:

Accelerometer Sensor – The accelerometer is used to detect hand movements performed by the user. It measures directional tilt (left, right, up, and down) and converts motion into electrical signals for processing.

Microcontroller Unit (ATmega328 / Arduino Pro Micro) – The microcontroller serves as the main processing unit of the system. It interprets the accelerometer data and generates corresponding control signals to trigger predefined audio messages and display outputs.

Transmitter and Receiver Module – The radio frequency (RF) transmitter and receiver modules are used to wirelessly transmit encoded commands from the input device to the output unit, enabling remote communication between the patient and caregiver.

SD Card and SD Card Module – The SD card stores prerecorded audio messages. The SD card module facilitates communication between the microcontroller and the storage device for audio playback.

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Amplifier and Speaker – The amplifier increases the audio signal strength, while the speaker converts electrical signals into audible sound for caregiver notification.

Liquid Crystal Display (LCD) – The LCD provides visual feedback by displaying the message corresponding to the detected hand gesture.

Power Supply Components – The system utilizes a 9V battery for the input device and an AC/DC adaptor with a DC power jack socket for the output device, ensuring stable and continuous operation.

Switch – A control switch is used to power the system on and off.

System Operation

This stage describes the operational framework of the developed hand-movement audio messaging system. The project integrates multiple electronic components to enable gesture-based communication for paralytic and disabled individuals. The system operates by detecting hand movements through an accelerometer sensor, which measures directional tilt and motion. The captured motion data are transmitted to the microcontroller, where the signals are processed and matched with predefined commands. Once interpreted, the corresponding message is encoded and sent through the wireless transmitter to the receiver unit.

At the output stage, the received signal activates the stored audio message from the SD card module. The message is then amplified and played through a speaker, allowing caregivers to hear the patient's request. Simultaneously, the liquid crystal display (LCD) presents the same message visually to provide confirmation and additional clarity. The device is powered by a regulated power supply, including a 9V battery for the input unit and an external AC/DC adaptor for the output unit, ensuring stable system performance during operation.

To classify hand gestures, threshold values were defined based on the tilt angles measured along the X and Y axes of the accelerometer. Each gesture corresponds to a specific range of acceleration values. For example, a forward tilt is detected when the X-axis value exceeds a positive threshold, while a backward tilt is identified when it falls below a negative threshold. Similarly, left and right tilts are determined using Y-axis thresholds. These threshold values were obtained through repeated experimental trials to ensure reliable detection. Calibration may be required for different users to account for variations in hand movement strength and orientation, thereby improving the overall accuracy of the system.

Experimental Procedure

Each of the four gestures was tested for 20 trials. Data collected included:

- Correct detection count
- False triggers
- Missed triggers
- Response time

Accuracy percentage was calculated using:

Accuracy = (Correct Detections / Total Trials) x 100

Accuracy = (76 / 80) x 100 = 95%

System Architecture

The proposed system consists of the following major components:

1. Motion Sensing Unit – An accelerometer sensor, ADXL335, was used to detect hand movements along the X, Y, and Z axes.

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2. Microcontroller Unit – An Arduino Pro Micro was utilized to process the analog signals from the accelerometer and classify predefined gestures.
3. Wireless Communication Module – A 433 MHz RF transmitter and Receiver module was used to transmit the processed signal from the glove unit to the receiving unit.
4. Audio Output Module – A speaker connected to the receiver unit produced the corresponding pre-recorded voice message.
5. Power Supply Unit - Provides stable voltage to ensure proper operation of all system components.

The system operates in two parts:

1. Transmitter unit embedded in a wearable glove
2. Receiver unit connected to the speaker

RESULTS AND DISCUSSION

System Functionality Testing

The developed Hand Movement Audio-Message System was tested to evaluate its overall performance in terms of gesture recognition accuracy, response time, and wireless transmission reliability. The system successfully detected four predefined hand gestures using the ADXL335 sensor integrated with the Arduino Pro Micro. Each gesture triggered a corresponding audio message transmitted through the 433 MHz RF Transmitter and Receiver Module. Testing confirmed that the accelerometer reading varies distinctly along the X and Y axes depending on hand orientation, allowing reliable classification using programmed threshold values.

Gesture Recognition Accuracy

Each of the four programmed gestures was tested for 20 trials, resulting in 80 total trials.

Table 1.

Gesture Type	Correct Detection	False Trigger	Missed Trigger	Accuracy (%)
Forward Tilt	19	1	0	95%
Backward Tilt	18	1	1	90%
Left Tilt	19	0	1	95%
Right Tilt	20	0	0	100%

The overall system accuracy was computed as:

Accuracy = (76 / 80) x 100 = 95%

Minor errors occurred due to:

- Slight unintended hand tremors
- Rapid movement transitions
- Variations in wrist angle positioning

Response Time Analysis

The average time measured from gesture execution to audio output activation was recorded.

- Minimum Response Time: 0.85 seconds
- Maximum Response Time: 1.20 seconds

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- Mean Response Time: 0.98 seconds

The response delay includes:

1. Sensor data acquisition
2. Microcontroller processing time
3. RF transmission delay
4. Receiver decoding
5. Audio output activation

The system maintains response times below 1.2 seconds, which is acceptable for assistive communication devices.

Wireless Transmission Performance

The RF communication module was tested at varying distances:

Table 2.

Distance	Signal Status
1-5 meters	Stable
6-10 meters	Stable
11-15 meters	Minor delay

Beyond 15 meters, occasional signal loss was observed. The effective operating range was determined to be approximately 10 meters in indoor conditions without significant obstruction.

Power Stability Evaluation

The 9V regulated power supply maintained a stable voltage during continuous operation.

Observations:

- No unexpected system resets
- No sensor fluctuation due to power drop
- Stable output audio level

Battery life lasted approximately 4-5 hours.

DISCUSSION

The findings indicate that the developed system is capable of providing an alternative communication method for paralytic and speech-impaired individuals.

The use of analog accelerometer-based gesture detection proved effective for simple directional movements. Compared to camera-based systems, this approach offers:

- Lower power consumption
- Reduced computational complexity
- Portable and wearable configuration
- Lower system cost

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However, the system is limited to predefined gestures and may require recalibration for different users due to variation in hand strength and movement capability.

Future improvement may include:

- Implementation of digital filtering for noise reduction
- Use of a machine learning algorithm for adaptive gesture recognition
- Integration of rechargeable lithium battery
- Addition of LCD status display for visual confirmation

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

This study developed a **Hand Movement Audio Message-Based Accelerometer** to assist paralytic and disabled persons in communication. The system integrates a 3-axis accelerometer, a microcontroller (Arduino), an LCD, and an audio output. Testing was conducted to evaluate gesture recognition accuracy, system response time, and message output reliability.

Key findings from the testing include:

- Gesture Recognition: 95% of gestures were correctly recognized.
- Message output: 100% recognized gestures resulted in the correct audio and visual message.
- Response Time: The average system response was 0.98 seconds, ensuring real-time interaction.
- The system proved effective in converting hand movements into immediate audio messages, offering an accessible communication solution for individuals with severe motor impairments.

Findings

1. Multi-axis accelerometers are sensitive enough to detect subtle hand movements and gestures.
2. Wearable systems (gloves, rings, wristbands) enable continuous monitoring without hindering daily activity.
3. Gesture-based control systems can be integrated with wheelchairs, messaging systems, or IoT platforms.
4. Real-time feedback mechanisms (audio, SMS, or mobile notifications) improve caregiver response.
5. User-centered designs enhance usability, adherence, and accessibility for paralytic patients.

Conclusion

Based on the results and discussion, the following conclusions were drawn:

1. The developed system can accurately detect and interpret predefined hand gestures using a 3-axis accelerometer.
2. Audio and visual feedback ensure that users and caregivers receive immediate confirmation of the intended message.
3. The prototype operates in real-time with minimal delay, making it suitable for emergency or daily use.
4. The system provides a reliable, low-cost solution that enables communication capabilities for paralytic and disabled persons.

Recommendations

For further improvement and practical implementation, the following recommendations are suggested:

1. Expand Gesture Library: Introduce more hand gestures to cover a wider range of commands and communication needs.

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2. Wireless Connectivity: Integrate Bluetooth or Wi-Fi modules to allow remote notification to caregivers or hospital staff.
3. Portable Design: Reduce the size of the device and make it wearable, such as in gloves or wristbands, for greater mobility.
4. Real-World Testing: Conduct trials with actual patients in home and hospital settings to validate usability and effectiveness.
5. Machine Learning Integration: Apply machine learning algorithms to improve gesture recognition accuracy and adapt to user-specific movement patterns.
6. Adaptive gesture recognition
7. User calibration feature
8. Mobile or IoT integration

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APPENDICES

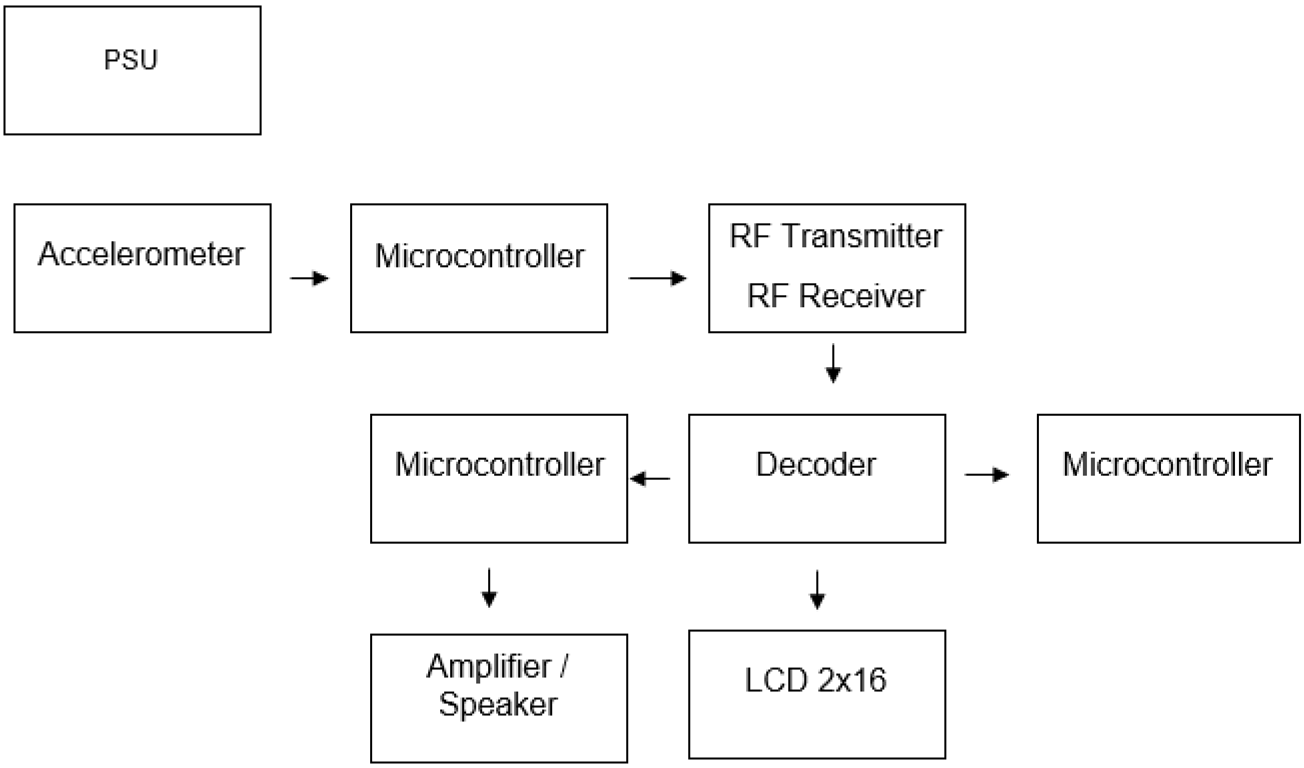

Figure 2. Block diagram of the prototype

The system operation is implemented through embedded programming in the microcontroller, which processes sensor data, classifies gestures, and triggers corresponding audio outputs.