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LUNA: Bridging Communication with Sign Language Translation

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Abstract— This paper presents Learn, Unite, Network and Assist (LUNA) App, an assistive Internet of Things (IoT) system designed to facilitate two-way communication between individuals with hearing and speech impairments and the general public. The LUNA system integrates a smart glove embedded with flex sensors and an MPU6050 accelerometer to recognize hand gestures and translate them into real-time text displayed via a mobile application developed using Flutter. Beyond gesture recognition, LUNA includes a sign language learning module, GPS-based emergency location tracking, and video call functionality via WebRTC, enabling enhanced communication and user safety. Developed using the Scrum methodology, the system combines ESP32 microcontroller-based hardware with Firebase for real-time data handling. Experimental results demonstrate that LUNA achieves high accuracy and responsiveness, with gesture recognition response times ranging from 850 to 1200 milliseconds. This project represents a step toward inclusive communication by promoting mutual understanding and interaction between the disabled and non-disabled communities.

Keywords— Sign language, smart glove, IoT, gesture recognition, inclusive technology.

I. INTRODUCTION

Most people with disabilities such as hearing and speech impairment rely solely on sign language as their main mode of communication in public settings. These people are forced to limit their chance to show off their true skills in job interviews or workplace discussion [1]. Moreover, communicating with those who do not understand sign language can be challenging for sign language users as methods such as scribbling on their note or type on the phone might be time consuming. Thus, people with impairment and general communities need solutions to help them communicate with one another. Existing solutions only focus on how disabled parties can communicate with general parties without realising that both parties should make effort to communicate with one another.

Essentially, Learn, Unite, Network and Assist (LUNA) LUNA App aims to bridge the communication gaps between those both parties by integrating a smart glove that can translate sign language gestures into textual output through the smartphone application.

Objectives of the system include:

1. To enable two ways communication between speech and hearing impairment and public communities.
2. To translate sign language gestures into text in real-time.
3. To create a new solution by improving the existing system.

The smart glove monitors hand orientation using an MPU-6050 accelerometer and detects fingers motion using 2.2 inch flex sensors. Both hardware send data to the ESP32 microcontroller where it processes specific gestures then transmits them via WiFi into the LUNA App. We intend to go beyond the basic functionalities of existing glove-app systems.

Firstly, our LUNA app has a sign language learning module that was created to make it easier for non-disabled users to learn sign language. This module offers interactive instructions to facilitate learning to those who are interested in learning sign language. Additionally, the app's GPS integration allows users with impairments and their family members or caregivers to communicate their location in real time. This function enhances user safety by allowing caretakers to track the impaired user's exact location in case of an emergency. Those features not only help disabled people to communicate with non-disabled but also vice versa.

II. REVIEW OF PREVIOUS WORK

In this section, we analyze and differentiate those past works based on a few aspects such as accuracy, language support, advantage and disadvantage for improvement. This difference is for examining the existing gap to determine the most effective solution and provide a solid foundation for our project.

A. Smart Glove for Arabic Hijaiyah Detection for Quran Citation

Based on the review of existing systems, it is evident that while they share the common goal of improving the lives of individuals with hearing and speech impairments, they differ in scope. For instance, Smart Glove for Arabic Hijaiyah

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Detection for Quran Citation system is designed to recognize Arabic letters used in Quranic recitation, as shown in Figure 1 [2]. This system was developed in response to the challenges faced in the learning process and the lack of qualified Islamic educators proficient in teaching the Quran using sign language. By integrating technology into Quran recitation through sign language, members of the deaf Muslim community are empowered to fully engage with and embrace their faith [2].

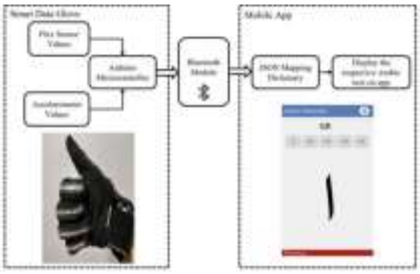

Fig. 1: Hijaiyah detection [2]

B. Sign Language Translation (SLT) Application

Ambar et.al. [1] created a wearable sensor glove to facilitate communication between a deaf person and normal community. They underline that communication between these two individuals is extremely impossible without the assistance of an interpreter. Aside from sign language, there is another technique to help deaf people: hearing aids. However, after wearing this instrument for an extended period of time, the user reported experiencing discomfort. In order to address people's everyday communication requirements, this project focuses on the fact that most people use smartphones and aims to investigate new possibilities by integrating sign language translation into smartphones, shown in Figure 2 [1].

Fig. 2: SLT "Assalamualaikum" detection [1]

C. Smart glove for ASL translation

Abougarair and Arebi [3] discussed how very few people are fluent in sign language. As a result, persons who rely primarily on sign language for communication may find it difficult to converse with others or simply express their opinions. In this rapidly evolving technological era, there are numerous different solutions available, including behind-the-ear, in-the-ear, and canal aids. Despite their usefulness, these devices make the user uncomfortable and allow them to hear background noise. This project intends to create wearable technology that allows the general public and the deaf population to interact while taking user comfort into account, as depicted in Figure 3.

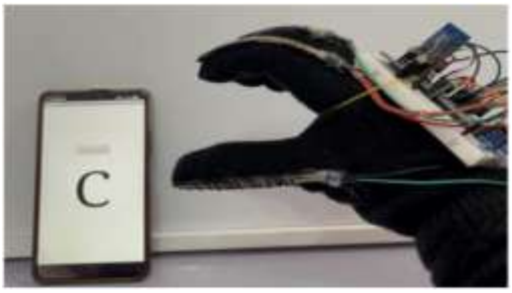

Fig. 3: ASL "C" output in display [3]

D. E-Voice Smart Glove

Amin et al asserts that communication barriers often arise when interacting with individuals with disabilities that limit their ability to engage with the general public [4]. This project addresses such challenges by proposing the development of a portable assistive device that reduces the reliance on others to learn sign language, highlighting one of the glove's principal features. Specifically, the project involves the design of an E-Voice Glove capable of translating hand gestures associated with sign language into alphanumeric text, while concurrently generating voice output through an integrated speaker, illustrated in Figure 4. The primary objective of this initiative is to establish seamless communication between individuals by developing a system that is highly accurate, cost-effective, and functionally independent.

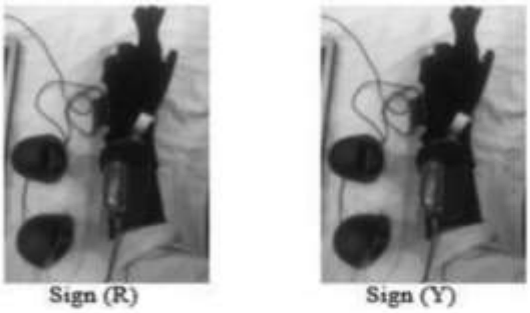

Fig. 4: Sign R and Y[4]

E. Malaysian Sign Language (MSL) Translator

Through the creation of a glove that can convert simple speech signals into images, text, and voice, this system seeks to enhance communication for the mute and deaf people in Malaysia [5]. Additionally, Mohamad & Lias optimized the flex sensor capability for the data glove application and created an app that can translate hand motions. In the absence of a workable solution, deaf and mute persons could find it difficult to interact with others, as shown in Figure 5.

Fig. 5: MSL output from smartphone [5]

Most existing systems employ similar hardware components—namely flex sensors, accelerometers, and Bluetooth module in the development of smart gloves. While the majority of these systems utilize Arduino as the primary microcontroller, this particular project opts for the ESP32. The rationale for selecting ESP32 lies in its integrated Bluetooth and Wi-Fi capabilities, eliminating the need for external Bluetooth modules as observed in previous implementations [3]. Projects that favor Arduino typically do so due to its simplicity, which makes it a suitable choice for small-scale projects and for individuals new to embedded systems. Moreover, Arduino remains a popular microcontroller due to its affordability and versatility, offering significant advantages for educators, students, and hobbyists when compared to other microcontrollers used in similar applications [4].

Furthermore, based on our review of existing systems, there are 3 systems that use MIT App Inventor [1][3][5] and 1 system uses Flutter SDK [2] to develop their application. The MIT App Inventor is block-based tools that are designed for beginners as it enables developers to learn fundamental coding without additional assistance. Mohamad and Lias explained that using MIT App converter supports debugging and real time testing of the application [5]. This app also helps developers to see how the application behaves when they connect the software to their smartphone. Elshareif et al developed their software module using Flutter SDK using the same language as the Arduino microcontroller which is C++ [2]. However, most existing solutions focus solely on gesture recognition and displaying text results within the app. While this is helpful for one-way communication, it lacks the ability to enable two-way interaction or provide support in emergency situations.

The LUNA system addresses these limitations by integrating multiple modules into a single application. It not only recognizes basic hand gestures using a smart glove embedded with flex sensors and an MPU6050 accelerometer, but also allows users to:

- Display gesture outputs on LUNA mobile application.
- Learn gesture languages from photo and video provided
- Initiate one-to-one video calls with a linked emergency contact using WebRTC
- View and share real-time location data using Firebase and OpenStreetMap,

Unlike prior systems, LUNA aims to facilitate mutual communication between two communities which are the hearing-impaired and the general public by combining assistive gesture recognition with communication and emergency support features. This project adopts an IoT-based architecture using ESP32, MQTT, and Firebase, alongside Flutter for the mobile front end. The final goal is to offer a reliable, scalable, and user-friendly communication aid that supports users in both daily interaction and emergency contexts.

III. METHODOLOGY

Generally, methodology describes how the development approach is employed, the methodologies used to collect information and create system requirements, an overview of the pre-production phase, and the prototype activities carried out prior to full-scale development.

A. *Development Methodology*

In order to ensure an efficient and organized process, we adopted Scrum as a development approach for our project. Scrum is an iterative method for frequent changes, reduced risk and fast delivery to develop a software project [6]. Most software companies use Scrum and it has a positive effect on their software project management [6]

The adopted Scrum process is illustrated in Figure 6, which outlines the flow from product backlog to sprint completion. The team functioned in focused development cycles that allowed for iterative progress and reflection. which outlines the flow from product backlog to sprint completion. The team functioned in focused development cycles that allowed for iterative progress and reflection [7].

Each sprint lasted approximately 4 weeks, depending on task complexity and integration needs. This longer sprint cycle was necessary due to the dual development of hardware and software. The process involved maintaining a product backlog of core features such as gesture recognition, video call and map location, holding a sprint planning meeting to choose sprint goals, executing tasks through development, testing and integration, and ending with a sprint review and retrospective to access results and refine the next sprint [8].

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Fig. 6 : The Scrum Development Process Flow [7]

B. System Design and Tools

The Use Case Diagram shown in Figure 7 outlines the key functionalities available to the user in the LUNA system. These include actions such as signing up, editing the user profile, using the learning module, viewing the home page, changing the language, and triggering the SOS video call feature[9]. The diagram also shows interaction with the emergency contact, who can receive location data and video calls during emergencies. This helps define the system's scope and the responsibilities of each actor.

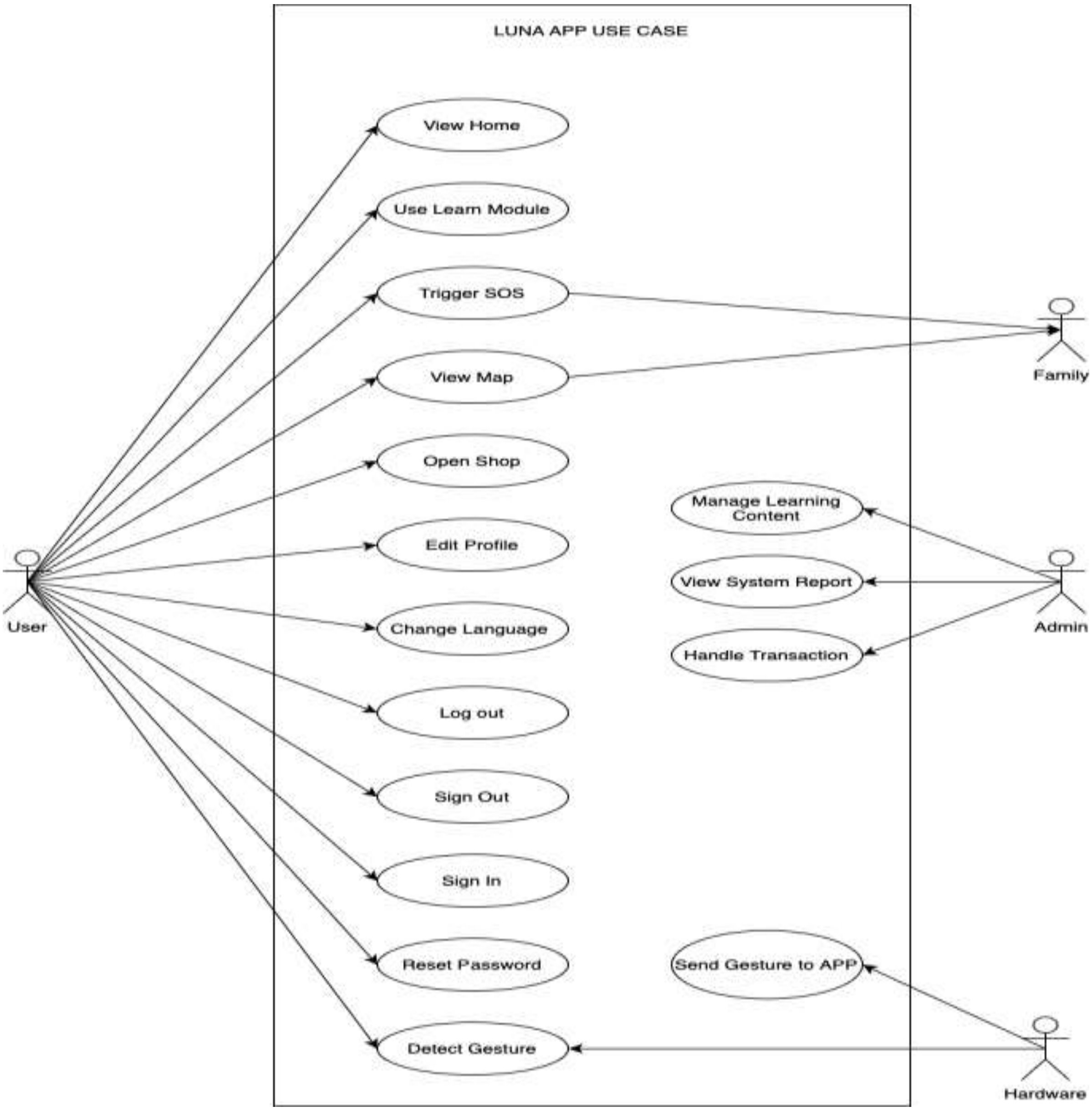

Fig. 7 Use Case Diagram

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The Sequence Diagram in Figure 8 shows the process flow involved in detecting and displaying a hand gesture. It starts with the user performing a gesture, which is detected by the smart glove. The glove sends sensor data to the ESP32, which processes and translates the gesture before transmitting the result to the mobile app. The app then displays the translated text output to the user in real time. This diagram is essential for understanding the interaction between hardware and software components in the system.

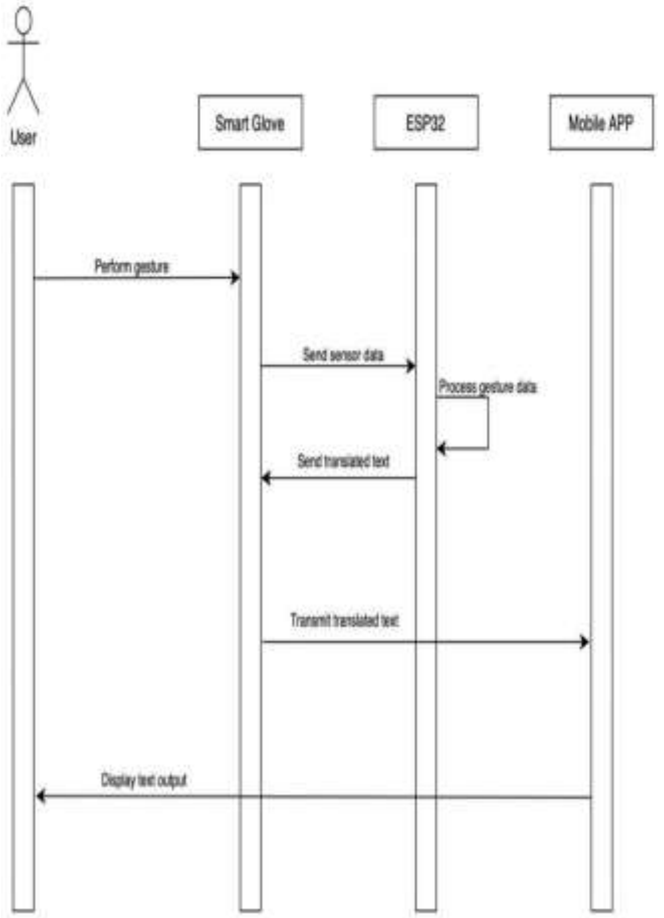

Fig. 8 Sequence Diagram

The Sequence Diagram shows the process flow involved in detecting and displaying a hand gesture. It starts with the user performing a gesture, which is detected by the smart glove. The glove sends sensor data to the ESP32, which processes and translates the gesture before transmitting the result to the mobile app. The app then displays the translated text output to the user in real time. This diagram is essential for understanding the interaction between hardware and software components in the system.

Table 1 shows all the tools that we used to develop the system for both LUNA Apps and Smart Glove:

TABLE 1
SOFTWARE AND HARDWARE TOOLS USED

Category	**Tool/Technology**
Programming Language	Dart (Flutter) , C++ (Arduino)
Frameworks	Flutter
Backend	Firebase Firestore, Realtime Database
Communication Protocol	MQTT (PubSubClient)
Location & Map Services	geolocator, flutter_map, OpenStreetMap, latlong2
Hardware	ESP32 (TTGO), 2.2 Inch Flex Sensors, MPU6050
Development Tools	Visual Studio Code, Arduino IDE

IV. RESULTS

The LUNA system successfully integrates a smart glove with a Flutter mobile application, offering the following functionalities: The LUNA system is capable of detecting basic hand gestures using a smart glove equipped with flex sensors and an MPU6050 motion sensor. gestures are displayed in real time both within the Flutter mobile application and on the TTGO display. During testing, gesture outputs were shown almost immediately, with an average response time ranging from 850 to 1200 milliseconds.

Users can also link a trusted emergency contact by entering their email address. Once linked, this contact will appear as the default option for emergency video calls and location tracking. If location sharing is enabled, the app retrieves and displays the emergency contact's last known location on an interactive map.

Additionally, the system supports direct one-to-one video calling between the user and their emergency contact. This feature is implemented using WebRTC, allowing real-time audio and video communication with proper camera and microphone permission handling across platforms [10].

A. System Testing Results

We conducted functional and performance testing on the mobile application to verify that all key features worked as intended. In addition, we performed performance testing on the glove integration to measure gesture detection threshold, average response time and pass rate, and the results are shown in Table 2.

All core features of the LUNA application successfully passed functional testing, as shown in Table 2. This is largely due to the fact that the app is relatively lightweight, with a focused set of features tailored specifically for gesture recognition, emergency communication, and basic user interaction. Unlike larger mobile applications that may involve complex navigation, multimedia processing, or high resource usage, LUNA was designed with simplicity and efficiency in mind. As a result, its features performed

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smoothly with no major issues across devices. The streamlined architecture contributes to overall system stability and responsiveness during testing. The response time thresholds differ between gestures due to the hardware limitations and sensor configurations of the current glove setup. The "Peace" gesture relies on flex sensors attached to the index and middle fingers, allowing for fast and accurate detection. As a result, a threshold of 1000 ms is sufficient, and testing showed a pass rate of 100% for this gesture under that threshold. In contrast, the "Hello" gesture is recognized using only the MPU6050 motion sensor, without any flex sensor input

TABLE II
APPLICATION FEATURE TESTING

Pages	Test Data	Test Condition	Expected Result	Actual Result
Sign up	Full Name, Email and Password	Tap "Sign Up" button	New user's account successfully registered	Pass
Sign in	Registered Email and Password	Tap "Sign In" button	Existing authorized user can navigate to Home page	Pass
Reset Password	Registered email	Tap "Send Reset Link"	Reset password link is sent to user's email	Pass
Learn	N/A	Tap all categories (Alphabets A-Z, Numbers 1-10 etc..)	Relevant videos and visuals load correctly	Pass
SOS	Camera and microphone access, emergency linked user	Tap "SOS" button	Video call is triggered to emergency contact	Pass
Map	Location access, emergency linked user	Tap "Map" button	User's and family location shown	Pass
Shop	N/A	Tap "Buy Now" button	User will navigate to whatsapp app to order the smart glove	Pass
Translation	Paired glove	Perform hello gesture	"Hello" text displayed on screen	Pass
Family Contact	Registered email of family	Add contact & toggle location sharing	Contact linked	Pass

This type of detection depends on hand movement patterns, which require slightly more time to stabilize. Therefore, a higher threshold of 1100 milliseconds is used for "Hello" to improve reliability, achieving a pass rate of approximately 90%. These variations in threshold values help balance gesture detection speed and accuracy based on the sensors involved.

TABLE III
PERFORMANCE TESTING

Gesture	T Total	Passes	Fails	Threshol	Average Respons Time	Pass Rate
Peace	10	10	0	≤ 1000	873 ms	100%
Hello	10	9	1	≤ 1100	1019 ms	90%

The Gesture Recognition test was conducted to evaluate the accuracy and response time of the glove in recognizing the predefined sign gestures. This testing is executed to ensure the smart glove consistently detects gestures and displays the correct output within an acceptable time.

Each gesture was tested 10 times under the same environment. The system was programmed to record the time when a gesture was detected and the time when the output (text) was displayed on the serial monitor. The difference between these timestamps represents the response time in milliseconds. The Arduino function millis() was used to capture timestamps, and each gesture detection was confirmed through Serial Monitor output.

The accuracy was calculated based on the number of successful detections over the total trials using the following formula:

$$Accuracy\,(\%) = (Pasess\,/\,Total\ Trials) \times 100$$

The core features of the LUNA application are shown in Figure 9. These screenshots include the Welcome Page, the Home Page, and the Side Drawer. These screens illustrate how users navigate the app, initiate gesture recognition, and access emergency features.

The Gesture Result Page displays the output of the hand gesture detected by the smart glove, as shown in Figure 10. Once the user performs a gesture, the sensor data is processed by the ESP32 and transmitted to the mobile application. The app then shows the recognized gesture inside a dedicated output box on the screen.

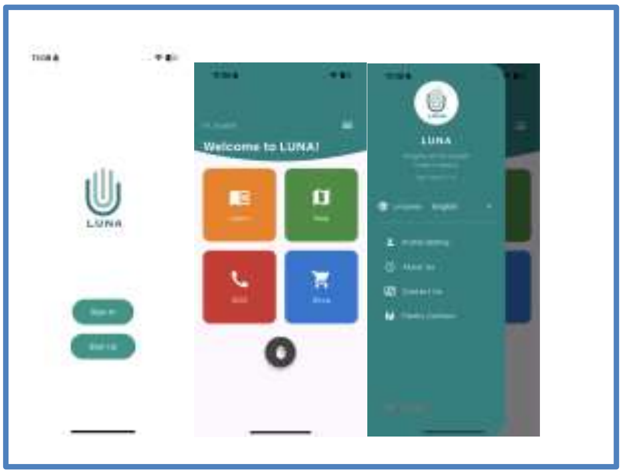

Fig. 9 LUNA App Features

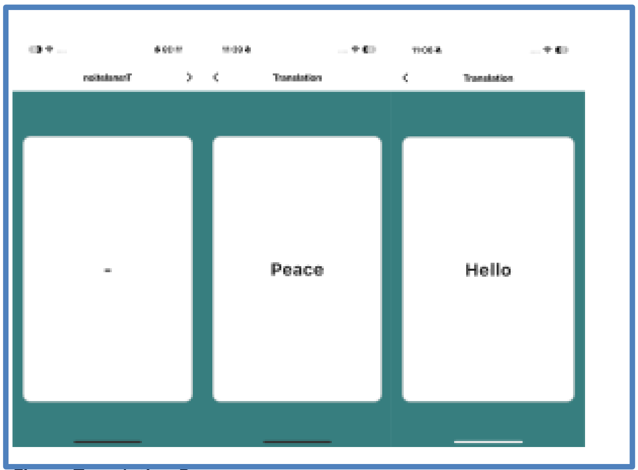

Fig. 10 Translation Page

IV. DISCUSSIONS

The primary goals of the LUNA system was to enable two ways communication between speech and hearing impairment and public communities through gesture recognition and emergency support features. Based on the final implementation and testing the system can:

- enable users to express basic phrases through hand gestures using a smart glove,
- display gesture results in a mobile app in real time,
- allow emergency communication via video calls and location sharing with a family contact.

A. Strength

The LUNA system demonstrates a number of key strengths that contribute to its overall effectiveness, usability, and social value. One of its most notable strengths is the ability to perform real-time gesture recognition using a smart glove embedded with flex sensors and an MPU6050 accelerometer. This allows users to receive immediate visual text output on the mobile application that enhances confidence and communication clarity [11]. The system also offers emergency contact integration, enabling users to link a trusted individual who can receive both SOS video calls and real-time location updates. This is a significant improvement over many existing solutions, which typically focus only on gesture output and lack direct emergency response features.

Furthermore, the LUNA application is designed to be lightweight, intuitive, and focused, with minimal clutter and a clean user interface that supports smooth performance even on low-spec devices. Unlike larger or more complex applications, LUNA provides a targeted set of features that address specific communication challenges. Lastly, one of the most impactful strengths of the system is its commitment to inclusive interaction. Unlike traditional assistive tools that focus only on the user with a disability, LUNA supports two-way communication between the hearing-impaired and the general public, promoting mutual understanding and empowering both sides of the conversation.

B. Limitation and Challenges

While the LUNA system successfully met its core objectives, several limitations were observed during development and testing. One of the limitation for our system is only two fingers are supported. The current glove prototype only detects gestures involving two fingers (index and middle). This limitation arose due to a change in communication method. Initially, the glove was designed and fully soldered for Bluetooth Low Energy (BLE) communication. However, due to BLE instability and time constraints during integration, the team switched to MQTT over Wi-Fi. As a result, only two flex sensor pins were reassigned and functional in the new configuration, while the rest remained tied to the original BLE circuit. Modifying the hardware setup further was not feasible within the available time frame.

Additionally, while the system displays the emergency contact's last known location, real-time tracking is not continuous. Location updates rely on manual toggles or re-opening the app, which may delay response during emergencies.

Furthermore, the glove's communication with the mobile app is fully dependent on a stable Wi-Fi connection. Since MQTT operates over Wi-Fi, the system cannot function in offline mode or via mobile data unless specific configurations are changed. This may limit usability in certain environments without reliable connectivity.

V. CONCLUSION AND FUTURE WORK

The LUNA system successfully achieves its goal of supporting real-time, two-way communication between individuals with hearing and speech impairments and the general public. Through integration of gesture recognition, emergency response features, and sign language learning modules, LUNA offers a comprehensive and user-friendly solution. Functional testing confirms that all major features perform reliably across devices, while performance testing validates the system's ability to detect gestures within acceptable response times. Despite current hardware limitations, such as partial flex sensor support and reliance on Wi-Fi connectivity, LUNA demonstrates significant potential as an inclusive communication tool. Future enhancements will focus on extending gesture recognition to all five fingers, enabling continuous emergency tracking, and incorporating customizable gesture libraries and AI-based recognition for more robust and adaptive user interaction.

For future work, we aim to redesign the glove to support all five flex sensors using a stable Wi-Fi-based connection. This will allow a broader range of gestures to be recognized, increasing communication flexibility. Currently, only the last known location of the emergency contact is displayed. Future versions should implement continuous background location tracking with real-time updates, improving emergency responsiveness. Moreover, we also plan to implement a user-defined gesture library that has the ability for users to add, manage, and personalize their own gesture library. This feature would allow individuals to map custom gestures to phrases or commands, making the app more adaptable to different languages, dialects, or personal communication needs.

In addition, more tests will be conducted, such as effectiveness, usability and robustness test. The detailed testing will enhance the quality of the app and gloves.

Furthermore, future upgrades can integrate artificial intelligence (AI) to automatically detect sign language gestures (via camera or glove sensors) and generate live captions during video calls. This would enhance mutual understanding during real-time communication, especially when one party does not know sign language.

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Conflict of Interest

The authors declare that there is no conflict of interest

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