An Intelligent Android System for Automatic Sign Language Recognition and Learning

Soha A. Shaban * and Dalia L. Elsheweikh

Department of Computer Science, Faculty of Specific Education, Mansoura University, Mansoura, Egypt
Email: prof_soha@mans.edu.eg (S.A.S.); dalia_lotfy@mans.edu.eg (D.L.E.)
*Corresponding author

***Abstract*—This paper presents an intelligent Android system developed for automatic recognition of both Arabic and American sign languages, as well as for the teaching and learning of these sign languages. It contains two subsystems. The first subsystem, the Sensory Smart Glove System (SSG-Sys), is based on Internet of Things (IoT) and is designed for automatic sign language recognition. It comprises a smart glove equipped with five flex sensors, which measure the bending of fingers according to the gestures being performed, and an MPU-6050 accelerometer sensor to track the hand's position across three axes (X, Y, Z). The sensed data are processed by an Arduino Nano microcontroller, and the text of the recognized gesture is transferred via HC-05 Bluetooth module to an Android phone. This phone displays the text and converts it into audible voice using an Android application. The SSG-Sys results demonstrated high recognition accuracy rates for Arabic Sign Language (ArSL) (98.42%) and American Sign Language (ASL) (98.22%). The second subsystem is the Mobile Augmented Sign Language Learning System (MASLL-Sys). It is a mobile educational app that leverages marker-based augmented reality technology, to enhance and make the sign language learning process more realistic and effective. It consists of five main modules: registration, learning, augmented learning, tests, and student module. Overall, the performance of the proposed intelligent system was evaluated by a group of experts, who revealed that it is a promising tool for sign language recognition and learning.**

***Keywords*—Sign Language (SL), American Sign Language (ASL), Arabic Sign Language (ArSL), intelligent glove, Augmented Reality (AR)**

I. Introduction

According to statistics from the World Federation of the Deaf and the World Health Organization (WHO), there are more than 70 million deaf-mute people in the world. The total number of deaf people is 360 million, including 32 million deaf children. It is expected that by the end of 2050, about 900 million people will suffer from hearing loss [1–4]. All of these people face a great challenge in communicating and interacting with their normal peers, especially in their educational, social, and professional environment [5]. Moreover, the majority of them are unable to write or read in standard languages and face difficulties in learning them [2, 6]. They are deprived of their rights to equal professional and educational opportunities [7]. As a result, the percentage of deaf and mute people who are educated and employed is lower [8]. Due to these and similar issues, they are excluded from society, which fails to benefit from their contributions [9].

Hence, Sign Language (SL) plays an effective role as an alternative for these individuals to express their opinions and to bridge the communication gap between them and others. SL is the mother language of the mute and deaf people [2, 10]. In SL, hand movements, finger gestures, and facial expressions are primarily used to convey a message instead of sound [2, 3, 11]. SL varies from one country to another and even from one region to another. It is not a universal language, examples are British Sign Language (BSL), American Sign Language (ASL), Arabic Sign Language (ArSL), and so on [12–14]. Although SL is the most widely used method for teaching deaf individuals, there are few SL teaching institutions available in our society [8]. Consequently, there are limited opportunities for training and certifying SL teachers/interpreters, which negatively impacts the ability of deaf students to learn the SL [15]. Moreover, SL lessons are expensive and time-consuming, and are often conducted in formal one-to-many sessions with a teacher who instructs learners on how to perform signs [16].

In essence, the learner needs a self-guided learning tool to guide him on how to perform the correct gestures, monitor their performance, and identify any errors during execution. Thus, more attention is required by researchers in the field of information systems to automate SL recognition and learning more effectively and efficiently. Hence the importance of IoT emerges as an excellent technology in today's world [17, 18] that has brought about a radical and rapid transformation in the world of automation and has enabled effective "Human-Things Interaction" [19].

IoT is about giving students and teachers new windows to the world, and new opportunities for limitless learning [20]. IoT plays a crucial role in the development of many applications, such as wearable devices, including Intelligent Glove (IG), which is a significant solution that facilitates communication between deaf-mute and non-deaf-mute [1]. Using sensory gloves in teaching not only

Manuscript received March 25, 2024; revised May 6, 2024; accepted May 29, 2024; published August 7, 2024.

doi: 10.12720/jait.15.8.923-940

reduces teacher stress, but also enhances students' sense of immersion in the classroom [21]. The SL glove seems to be very useful in helping sign language education [10].

Augmented Reality (AR) is among the latest technologies garnering increasing attention in various sectors, particularly in the field of education. In the educational field, AR is being leveraged to develop engaging interactive systems that significantly enhance students' enthusiasm, interest, and motivation for learning [22]. AR can be categorized into different types, including marker-based, markerless, etc. In marker-based AR, markers are used such as 2D images containing Quick Response (QR) codes or barcodes, which are detected by a reader device, usually a smartphone camera, to obtain specific results [23]. Most educational applications fall into the category of marker-based AR due to its ease of implementation, robust tracking capabilities, and low computational cost compared to markerless AR [24]. Given these benefits, AR can greatly enhance teaching methods and learning outcomes by providing an interactive learning environment that encourages students to actively participate in their education.

Accordingly, this paper uses IoT and AR technologies to build an intelligent Android system for automatic SL recognition and facilitate SL teaching and learning in a compelling and motivating way. For automatic SL recognition, the Sensory Smart Glove System (SSG-Sys) is designed to recognize ArSL and ASL gestures, including alphabets, numbers, and some common words, using a smart glove and an Android app. For SL learning, the Mobile Augmented Sign Language Learning System (MASLL-Sys) provides an augmented learning environment using marker-based AR technology and an Android app to learn ArSL and ASL.

II. Related Work

Nowadays, IoT techniques and wearable sensors have become burgeoning research topics, which provide a more natural, fast, and intelligent way of human-machine interaction. The emergence of such smart technologies that require almost no human intervention, as well as the continuous increase in the number of deaf-mute people, especially in the Arab region, has led to an increase in the importance of recognizing sign language [25, 26]. In general, there are two basic approaches to SL recognition: the vision-based approach and the sensor-based approach (data glove). The glove-based approach achieves higher accuracy, faster processing, and greater mobility than the vision-based approach, which faces the challenge of complex data algorithms and other challenges that include lighting conditions, backgrounds, and field-of-view restrictions [1, 13, 27]. Therefore, in the current paper, the glove-based approach was selected. A wide range of technologies are used globally to enhance teaching and learning processes. Among these technologies, augmented reality is gaining significant momentum due to its substantial positive impact on students' learning outcomes. AR transforms educational environments into spaces that are not only more attractive and interactive, but also authentic and enjoyable [28, 29]. Furthermore, AR facilitates learning and practice within a simulated environment where users can repeat tasks, make corrections, and failure without risks. In addition, it integrates physical and digital information in real-time, using various technological formats, including smartphones [30]. The use of AR through smartphones enables SL learning anytime and anywhere, tailored to the user's preferences [31]. Table I reviews studies that have used IoT and AR for SL recognition and learning, with a particular focus on ASL and ArSL.

TABLE I. A Review of Studies That Have Used IoT and AR for SL Recognition and Learning, Focusing on ASL and ArSL

References	Methods Used	Key Findings	Improvements
Bhore *et al.* [32]	A glove was designed specifically for deaf-mute students to recognize ASL alphabets and translate them into spoken English. It included four Spectra Symbol Flex Sensors and an MPU-6050. The data from these sensors were read, averaged, and packaged using a Raspberry-pi microcontroller.	When the experiment was conducted 10 times, the average success rate was 91.54%.	The system can be enhanced to recognize ASL words and sentences using both hands, not just one-handed alphabets. Additionally, the Bee Module can be added to transmit data wirelessly and the IC converter can be used to convert text to voice to speak alphabets and words.
Kumuda *et al.* [33]	A model of smart glove equipped with flex sensors was proposed to convert ASL into text and voice. This system used the LabVIEW program's signal processing kit and a data acquisition device, specifically the NI USB 6008 DAQ card. It was applied to letters and a set of letters up to 6 letters.	It aided teachers who train hearing- and speech-impaired students in schools. It also helped patients who suffered from loss of speech and partial paralysis but were able to move their fingers.	This model will be enhanced by replacing flex sensors with velostat and conductive wires, which could reduce costs and simplify the construction process. Also, incorporating a wireless mechanism will eliminate the problems associated with multiple wires protruding from the smart gloves, thus improving usability and mobility.
Dweik *et al.* [34]	A smart glove and mobile app called "SGTArSL" were developed to translate ArSL alphabets. It allowed ordinary people to communicate with mute individuals.	The system's success rate was about 88.21%.	The SGTArSL can be enhanced using more accurate sensors and translating ArSL words and sentences into text and voice. This can be implemented by wearing smart gloves on both hands, with or without using mobile app.
Qaroush *et al.* [35]	An ArSL recognition system was developed, which combined data from a 3-axis accelerometer and gyroscope Inertial Measurement Units (IMUs) sensors. The collected data from sensors were transmitted to a mobile device via Bluetooth for analysis and gesture recognition.	The system was trained and subsequently tested using the Arabic alphabets, and the recognition accuracy was 98.6% for user-dependent data and 96% for user-independent data for SVM.	This system requires expanding the dataset by adding the most common words or gestures used by Arab individuals. It should then be tested using sequence-based classification methods such as Hidden Markov Model and Recurrent Neural Networks.

Rum *et al*. [36]	A system named "LEARN SIGN" was developed to facilitate SL learning through a mobile app, using AR and speech detection. The system was built using C#, Unity, and Blender. Users have the ability to scan any words in a document, or record their voices as input into the system, which will translate these inputs into SL.	The LEARN SIGN system was simple and easy to use by the users.	The system can be improved by adding real-time SL detection and increasing the detection accuracy.
Abuhuraira and Duraisamy [37]	A mobile app-based AR was developed to enhance educational engagement for people with disabilities. It enabled the user to scan text and convert it to SL using Optical Character Recognition (OCR). Android Studio was used for AR app development.	The system demonstrated the ability to recognize handwriting not only computer printouts with up to 99% accuracy.	This app will be improved by increasing the megapixel for the programming in dictating the words clearly, increasing the distance of scanning and obtaining the real information accurately, creating links to YouTube to access videos, adding voice recognition, and recording video during using the app.
Ekhsan *et al.* [38]	An "ADDIE" model was developed to assist users in learning SL. It used the 3D model, target image, mobile app, and audio. The 3D model was created using Blender, while the target images were designed using Photoshop. These target images were stored in Vuforia, and the 3D models were imported into Unity3d software.	The result of the usability test confirmed that this model effectively enabled ordinary people to learn the basics of SL.	This model requires further development in 3D modelling for hand signs and alphabets which need smooth, high-quality, and detailed 3D images.
Soogund *et al.* [39]	A "SignAR" system was presented to assist deaf children learn English and SL and hearing people learn SL. Once the phone's camera scans a word, the corresponding sign animation is augmented on the user's screen by the Vuforia platform.	After developing the entire system, it was used by three users with hearing loss. The response was amazing and very motivating.	The system feedback provided the developer with valuable insights, creating opportunities for future enhancements such as adding a button to translate the entire sentence.

Through a review of the literature, it was found that some studies focused on developing systems based on sensory smart gloves for automatic SL recognition to facilitate communication between the deaf-mute people and the non-deaf-mute people. While others focused on using AR for SL learning to enhance the educational participation of people with disabilities. However, what distinguishes this paper is its use of IoT and AR technologies together to enhance SL recognition and learning. An IoT-based smart glove and an Android application are designed to recognize gestures in both ArSL and ASL, and display the corresponding numbers, alphabets, or words in written and spoken form in real-time. Additionally, a mobile-based educational app is developed to teach some of the most common SL vocabulary in 7 topics: alphabets, numbers, people, animals, food, health, and time. Furthermore, the marker-based AR technology is used to present digital information associated with an educational card scanned by the user's smartphone camera. This card displays a number, alphabet, etc., and the digital information provided includes the corresponding sign image with a textual description of how to perform it, a YouTube icon for related videos, etc. This approach creates an attractive learning environment for students to learn SL. Finally, various models of multiple-choice tests are provided to monitor students' performance levels and evaluate their learning outcomes.

III. The Proposed System

This paper introduces an intelligent Android system designed primarily for automatic recognition of sign language. Additionally, the system serves as an auxiliary tool for learning sign language, thereby enhancing communication efficiency between deaf-mutes and non-deaf-mutes. The proposed system contains two subsystems: SSG-Sys and MASLL-Sys. Each will be discussed in detail in Sections III.A and III.B below.

A. The Proposed SSG-Sys

This subsystem is an IoT-based smart data glove to recognize ArSL and ASL gestures and translate them into numbers, alphabets, or words in written and spoken form in real-time. Below is a detailed analysis of this subsystem.

1) SSG-Sys components

The proposed SSG-Sys consists of two components namely: hardware and software. The following section provides a brief description of these components.

- **Hardware components**

Fig. 1 shows the hardware components of SSG-Sys. Below is a description of these components.

a) Arduino nano microcontroller

The Arduino Nano (Fig. 1(a)) is a complete, small, and breadboard-friendly board based on the ATmega328P. It features fourteen digital I/O pins, six analog input pins, and CLK speed of 16 MHz [40, 41]. In this paper, it represents the brain of the SSG-Sys which processes sensors data and gives the outputs in text form.

b) Flex sensor

Flex sensor (Fig. 1(b)) is essentially a variable resistor whose terminal resistance increases when the sensor is bent [42]. In this paper, five 2.2-inch flex sensors were installed on the fingers of the glove. When a gesture is performed, the fingers are bent and then a specific value for each sensor is sent to the Arduino Nano.

c) HC-05 bluetooth module

The HC-05 Bluetooth module (Fig. 1(c)) aids the user to see the data in the mobile app converted on the Arduino board. It is very easy to pair it with microcontrollers because it works using the Serial Port Protocol (SPP) [43, 44].

d) Resistor (10k Ohm)

The 10k ohm resistor (Fig. 1(d)) is a circuit component that restricts the flow of electrical current. It is an important component commonly used in electronic projects and circuits [45].

e) Accelerometer

The MPU-6050 accelerometer sensor (Fig. 1(e)) is used to track the direction and movement of the hand. Each MPU-6050 has a three-axis accelerometer, which is responsible for measuring the linear acceleration along the X, Y, and Z axes. It is positioned on the wrist to sense the bending motion [46, 47].

f) Breadboard

The breadboard (Fig. 1(f)) is a plastic board containing numerous tiny holes used to construct and test circuits. Using it, various devices can be provided with power [48, 49].

g) Jumper wires

A jump wire (Fig. 1(g)) is a single electrical wire or a group of them in a cable and is used to make connections between elements on the breadboard and Arduino's header pins [50, 51].

h) USB cable

A USB cable (Fig. 1(h)) is essential for the operation of the smart glove, as it connects to a laptop to power the Arduino Nano.

i) The glove

The glove (Fig. 1(i)) used in this paper is a right-hand glove, black in color, made of cotton material, and flexible so that the user can move his fingers naturally when performing gestures.

j) Android mobile

Android mobile (Fig. 1(j)) is a mobile phone that runs on the Android operating system, with more advanced computing capability and communication power than a regular phone [52].

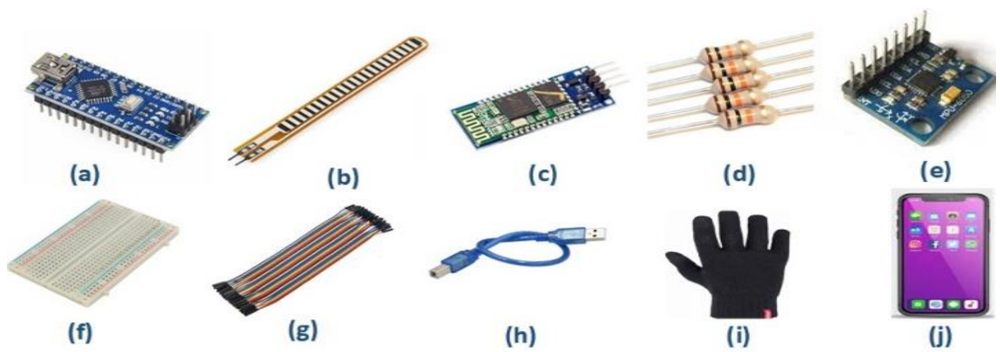


Fig. 1. Hardware components of SSG-Sys, (a) Arduino nano, (b) Flex sensor, (c) HC-05 bluetooth module, (d) Resistor, (e) Accelerometer, (f) Breadboard, (g) Jumper wires, (h) USB cable, (i) The glove, (j) Android mobile.

- **Software components**

The following section provides a detailed description of the proposed SSG-Sys software components.

a) Fritzing software

It is an open-source software that enables users to design electronic circuits. It supports them in transitioning from prototype experimentation to constructing more sustainable circuits [53]. The version used in this paper is "0.9.8". Fig. 2 shows the circuit diagram of the proposed SSG-Sys using Fritzing software.

b) Proteus software

Proteus is a program for simulating various projects before implementing them in hardware. It features built-in sensors, other electronic components and other non-inclusive components that are included by downloading specific libraries and including them in the Proteus's library section [54]. This paper utilizes version "8.10" of the Proteus software. Fig. 3 shows the simulation of the proposed SSG-Sys using Proteus software.

c) Arduino IDE

It is the program used to open, write, edit, and upload the source code into the Arduino board. It was built from JAVA, but the program uses its own programming language similar to C and C++ called sketch [55]. This paper uses version "2.1.0" of the Arduino IDE. Fig. 4 shows the sample code for the proposed SSG-Sys in the Arduino IDE.

d) MIT app inventor 2

It is an open-source web app that enables users to create applications capable of running on Android smartphones. First, users must add interface elements to their apps such as images, buttons, etc. (as shown in Fig. 5(a)). Second, they need to add logic and procedures using plain language instruction blocks that snap together like building blocks of a puzzle (as shown in Fig. 5(b)) [56].

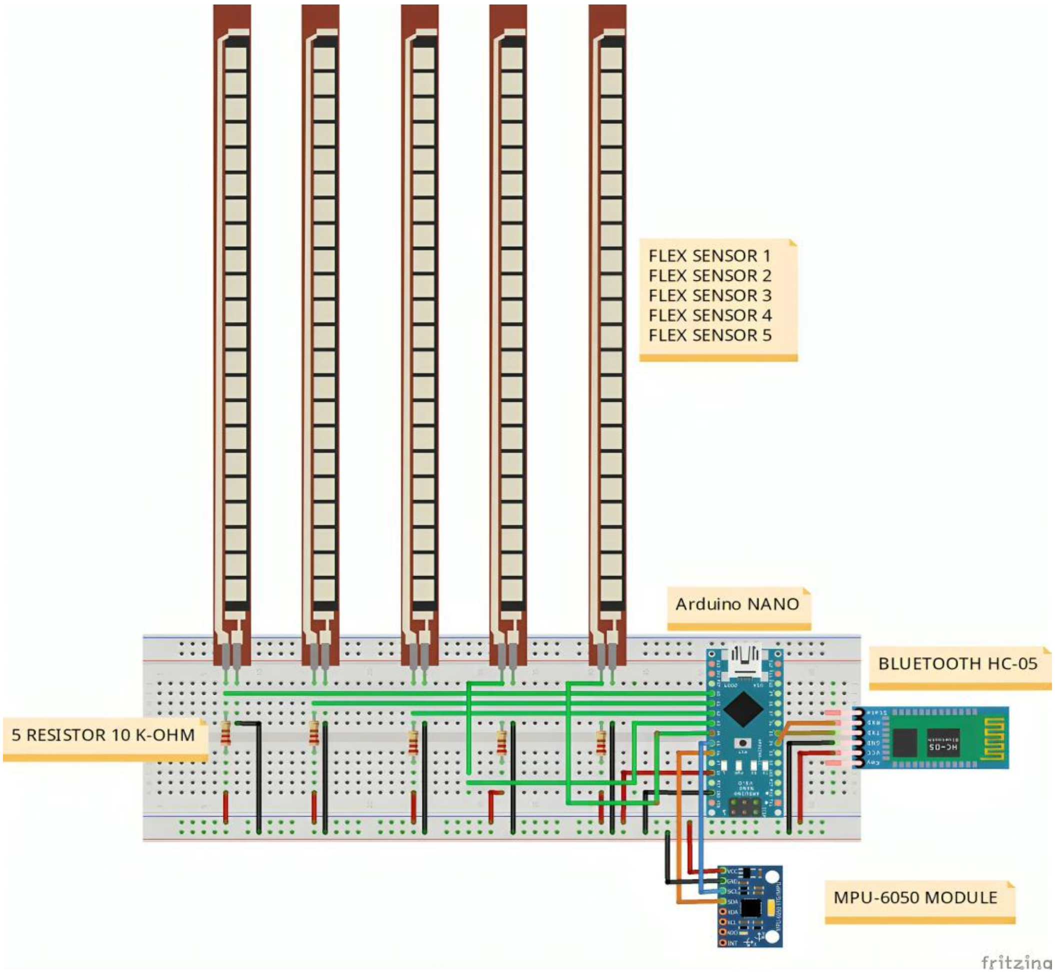


Fig. 2. The circuit diagram of the proposed SSG-Sys using fritzing software.

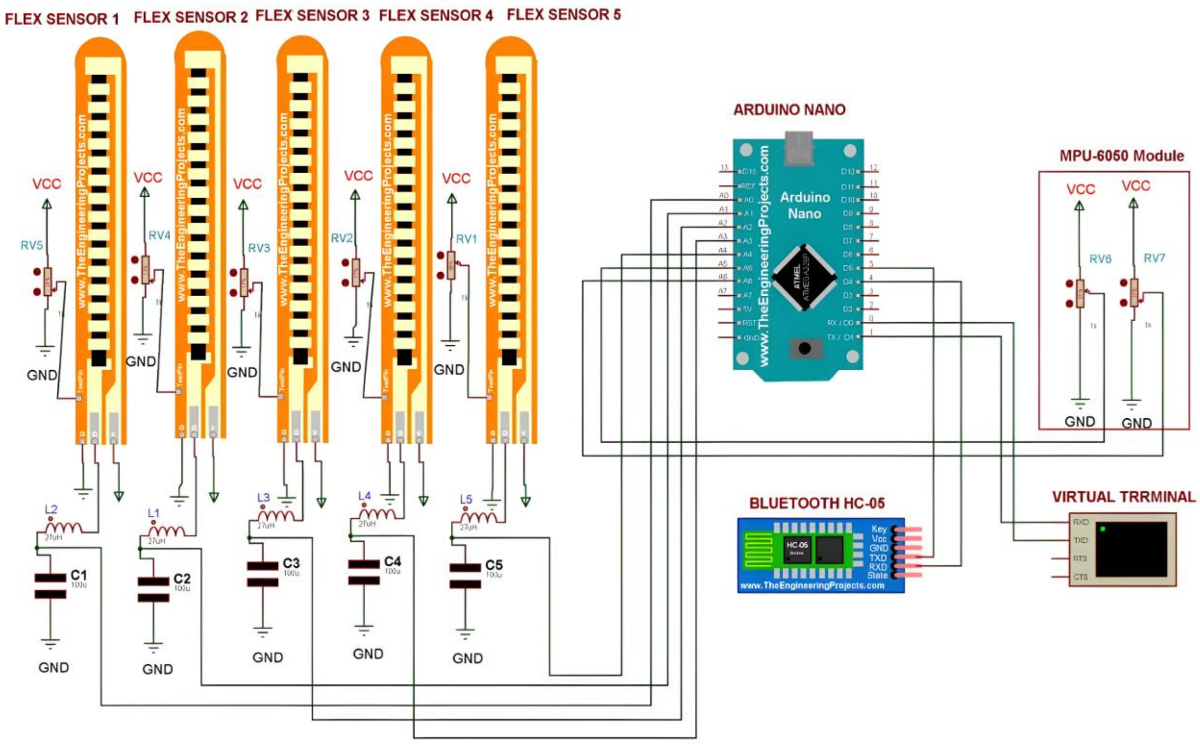


Fig. 3. Simulation of the proposed SSG-Sys using proteus software.

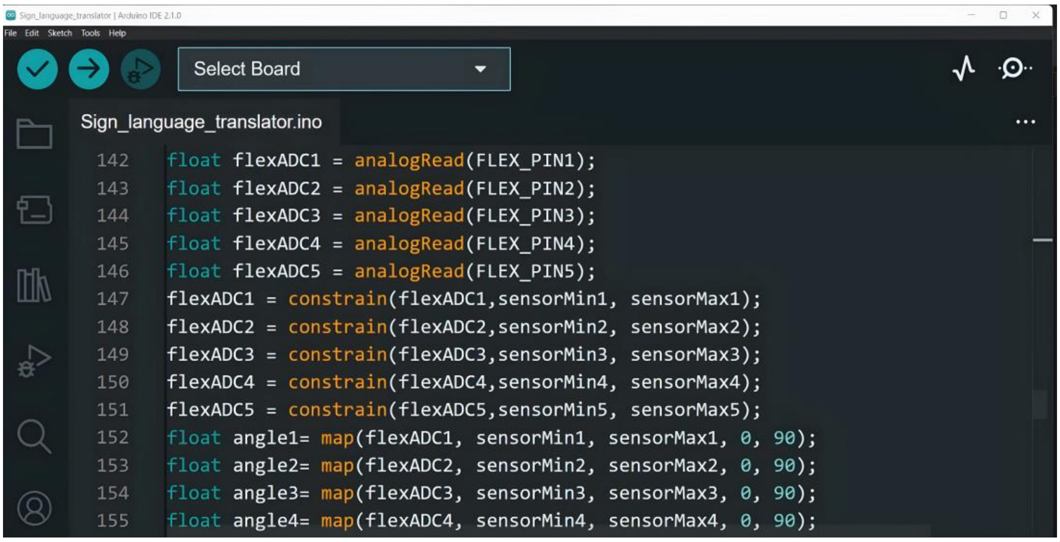
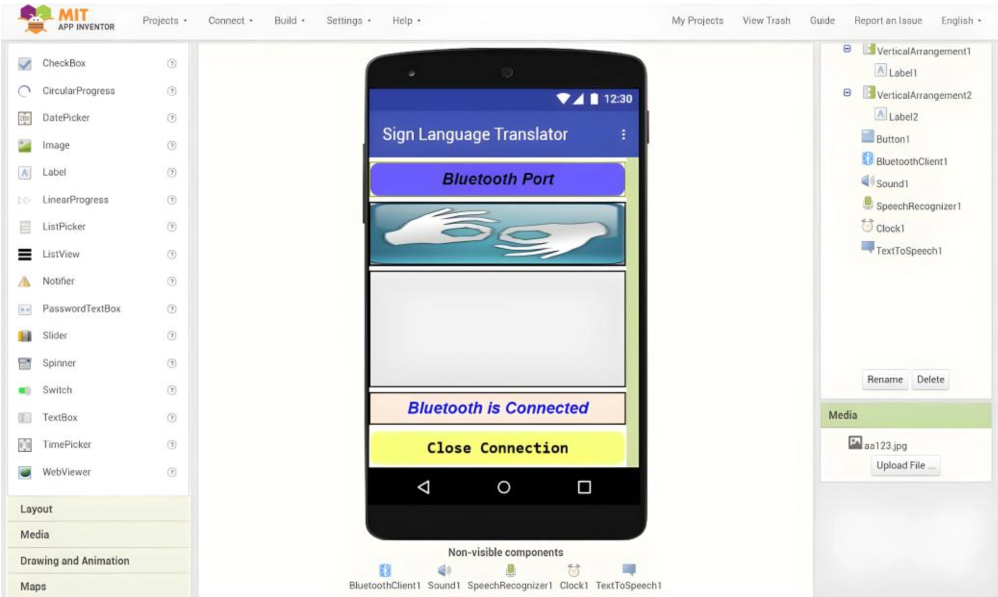
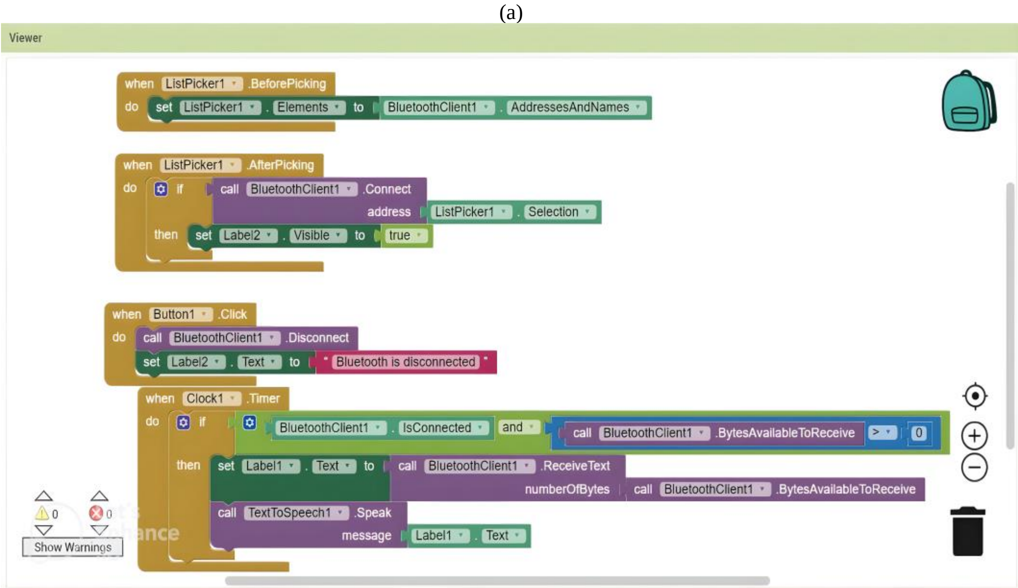


Fig. 4. Sample code for the proposed SSG-Sys in the Arduino IDE.



(a)



(b)

Fig. 5. Processes for developing the proposed Android app for the SSG-Sys, (a) design process, (b) blocks process.

2) SSG-Sys prototype

In this paper, a right-hand-wearable smart glove is designed to translate ArSL and ASL gestures. Fig. 6 shows the design of the SSG-Sys prototype, which includes several steps:

- Installing five flex sensors on the fingers of the glove to measure the degree of bending of the fingers.
- Connecting each flex sensor with a 10 KΩ resistor to restrict the electrical current.
- Installing the MPU-6050 accelerometer sensor on the breadboard on the back side of the right palm to measure the orientation and rotational movement in the 3 axes (X, Y, Z).
- Installing the Arduino Nano microcontroller on the breadboard.
- Installing the HC-05 Bluetooth module on the breadboard in preparation for connecting to the proposed Android application.
- Connecting all sensors and modules to the Arduino Nano using jumper wires.
- Powering the Arduino Nano using a USB cable connected to a laptop.

Fig. 6. Prototype of the proposed SSG-Sys.

3) SSG-Sys architecture

The architecture of the proposed SSG-Sys is shown in Fig. 7. In general, the SSG-Sys consists of two stages, training and testing. Fig. 8 displays the flowchart for the training and testing stages of the proposed SSG-Sys. A detailed analysis of these two stages will be presented in the following sections.

- **Training stage**

At this stage, features of gestures for alphabets, numbers, and some common isolated words are being identified and recorded. These features will be utilized for matching purposes during gesture recognition in the testing stage. These features are obtained based on a set of repeated measurements (approximately four times), and then the average is calculated. Overall, this stage consists of two modules: sensing and processing. The following section provides a detailed explanation of these modules.

Sensing Module: In this module, the five flex sensors are connected to the analog pins (A0–A4) of the Arduino nano. Then, the **analogRead( )** function [57] is used to read the values of the flex sensors from the selected analog pins. Additionally, the **constrain( )** function [58] is used to restrict the output values to be within the range (0–1023). Accordingly, each flex sensor gives a value from 0 to 1023. Also, the MPU-6050 accelerometer sensor is connected to the Arduino's analog pins (A5–A6). The data for each axis (X, Y, Z) is stored in two bytes or registers of the MPU-6050. The **wire. requestFrom( )** command is used to request the bytes and then the **wire. read( )** command is used to read these bytes [59, 60]. As a result, there is a value for each axis (X, Y, Z). Therefore, we will obtain eight values for each gesture as shown in Fig. 9, which shows the five values for the flex sensors and the three values for the accelerometer sensor for the "student" gesture.

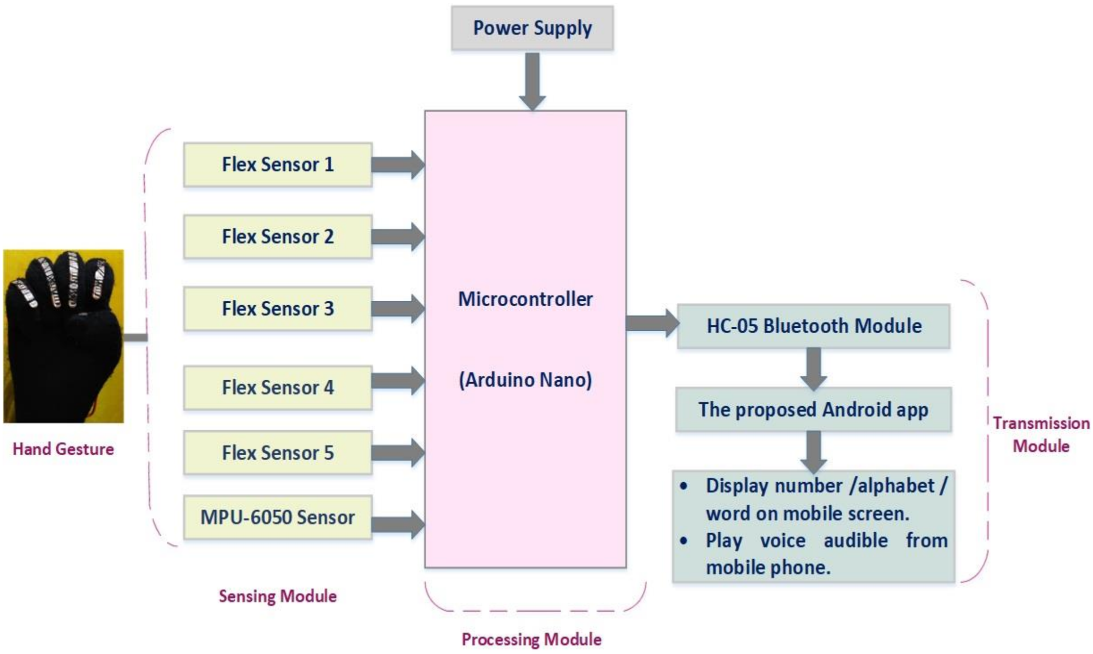


Fig. 7. The architecture of the proposed SSG-Sys.

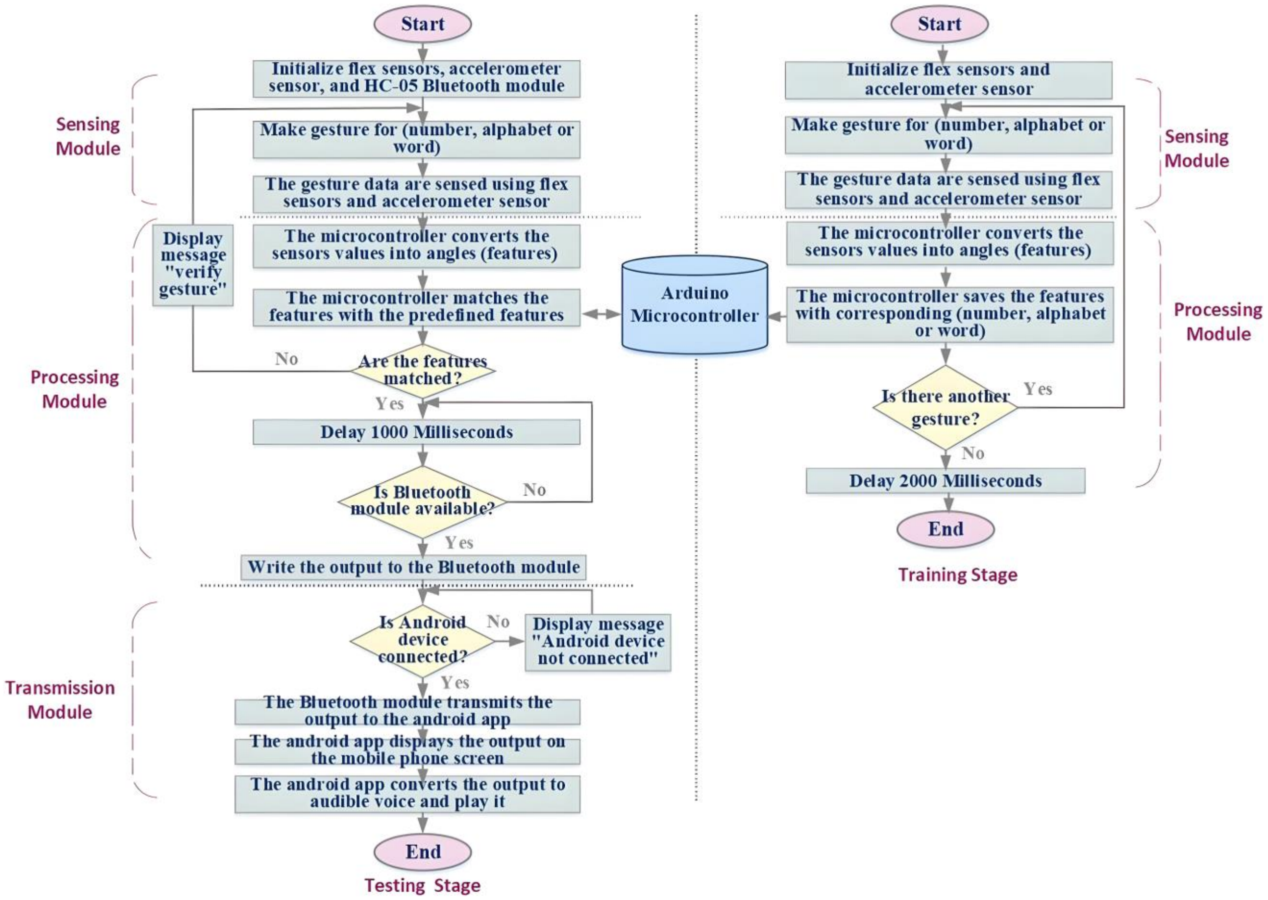


Fig. 8. Flowchart for the training and testing stages of the proposed SSG-Sys.

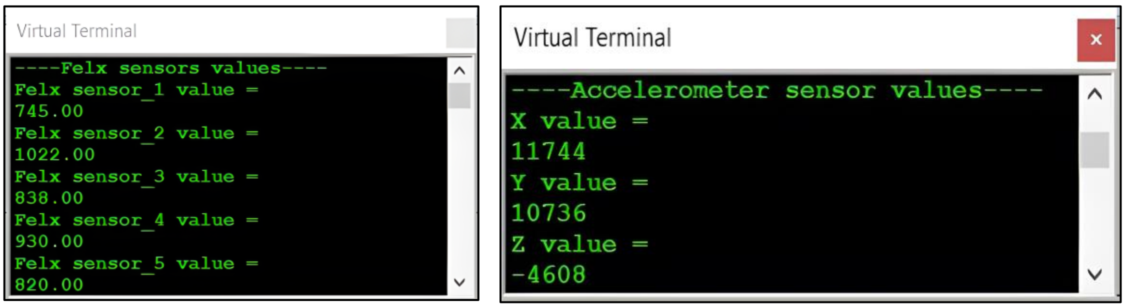


Fig. 9. Sensed data values for the "student" gesture.

Processing Module: The microcontroller receives the values of the flex sensors, and each value is mapped by an angle from 0° to 90° using the **map( )** function [58] as follows:

map (value, fromLow, fromHigh, toLow, toHigh**)**

where:

value: the NUMBER to map.

fromLow: The lower limit of the value's current range.

fromHigh: The upper limit of the value's current range.

toLow: The lower limit of the value's target range.

toHigh: The upper limit of the value's target range.

The microcontroller also receives the values of the MPU-6050 accelerometer sensor. Each value is transformed to obtain the angle [61]. All angles are within the range of 0–360° for accurate recognition. Fig. 10 shows values of the angles for both the flex and accelerometer sensors for the "student" gesture.

Thus, there are eight angles (features) for each gesture. Then, these features are processed by the microcontroller using the If...Then…Else statement and the logical operator "AND" to associate them with the text of the corresponding number, alphabet, or word. Tables II–VII show features of gestures for some alphabets, numbers, and common words in ASL and ArSL.

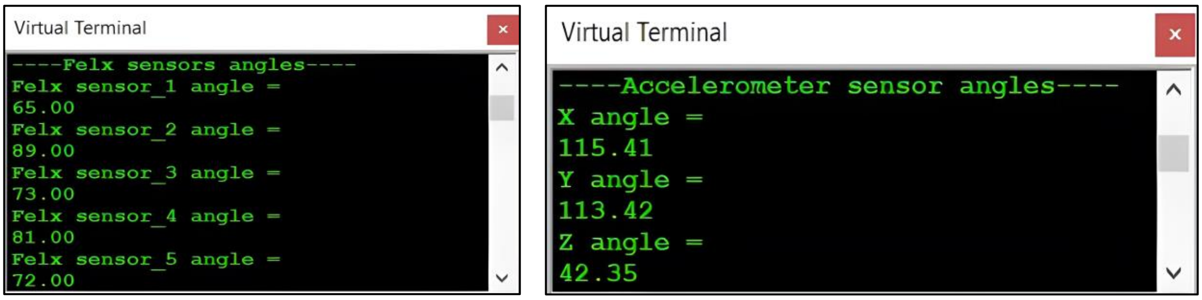


Fig. 10. Values of the angles for the flex and accelerometer sensors for the "student" gesture.

TABLE II. FEATURES OF SOME ASL ALPHABETS

Alphabets	Thumb	Index	Middle	Ring	Little	X-axis	Y-axis	Z-axis
A	68.00	74.00	76.00	82.00	73.00	93.26	233.33	94.37
B	72.00	66.00	67.00	77.00	63.00	96.06	130.27	82.85
C	69.00	71.00	82.00	81.00	68.00	91.77	96.41	74.61
…	…	…	…	…	…	…	…	…
Y	65.00	73.00	74.00	72.00	62.00	92.32	255.49	98.89
Z	73.00	67.00	74.00	74.00	72.00	59.05	12.28	82.56

TABLE III. FEATURES OF SOME ASL NUMBERS

Numbers	Thumb	Index	Middle	Ring	Little	X-axis	Y-axis	Z-axis
1	66.00	65.00	83.00	82.00	73.00	87.57	78.80	77.91
2	69.00	65.00	84.00	81.00	73.00	93.90	126.23	84.68
3	65.00	65.00	71.00	81.00	72.00	88.45	39.60	88.72
…	…	…	…	…	…	…	…	…
9	67.00	70.00	69.00	68.00	62.00	97.58	127.78	80.26
10	64.00	75.00	76.00	77.00	73.00	76.64	50.88	73.71

TABLE IV. FEATURES OF SOME ASL COMMON WORDS

Words	Thumb	Index	Middle	Ring	Little	X-axis	Y-axis	Z-axis
CALL ME	65.00	74.00	76.00	74.00	62.00	45.45	13.97	76.24
GOOD	64.00	73.00	75.00	74.00	72.00	19.23	8.76	66.16
…	…	…	…	…	…	…	…	…
YES	72.00	75.00	78.00	77.00	74.00	78.69	85.21	22.75
YOU	73.00	66.00	74.00	73.00	70.00	29.42	11.88	69.54
STUDENT	65.00	89.00	73.00	81.00	72.00	115.41	113.42	42.35

TABLE V. FEATURES OF SOME ARSL ALPHABETS

Alphabets	Thumb	Index	Middle	Ring	Little	X-axis	Y-axis	Z-axis
أ	67.00	72.00	87.00	82.00	74.00	31.93	359.88	90.19
ب	70.00	63.00	82.00	78.00	71.00	81.20	20.18	86.74
ت	68.00	63.00	83.00	77.00	71.00	87.38	284.65	99.94
…	…	…	…	…	…	…	…	…
و	66.00	70.00	83.00	79.00	71.00	91.86	96.46	73.99
ى	62.00	65.00	79.00	75.00	58.00	101.80	229.92	103.94

TABLE VI. FEATURES OF SOME ARSL NUMBERS

Numbers	Thumb	Index	Middle	Ring	Little	X-axis	Y-axis	Z-axis
١	74.00	66.00	87.00	82.00	73.00	84.04	13.78	88.53
٢	72.00	65.00	68.00	82.00	73.00	81.17	306.66	101.80
٣	71.00	64.00	70.00	79.00	75.00	75.82	20.81	84.51
…	…	…	…	…	…	…	…	…
٩	68.00	65.00	75.00	81.00	72.00	80.98	287.99	116.05
١٠	75.00	64.00	88.00	81.00	74.00	22.55	11.09	64.74

TABLE VII. FEATURES OF SOME ARSL COMMON WORDS

Words	Thumb	Index	Middle	Ring	Little	X-axis	Y-axis	Z-axis
لوسمحت	74.00	86.00	84.00	79.00	72.00	79.39	297.52	09.77
شكرا	73.00	66.00	75.00	80.00	63.00	134.38	167.68	77.94
…	…	…	…	…	…	…	…	…
توقف	65.00	63.00	67.00	66.00	63.00	111.95	168.02	85.11
أنا بخير	70.00	69.00	73.00	80.00	65.00	91.82	217.57	91.40
يؤلم كثيرا	73.00	70.00	88.00	74.00	74.00	115.80	149.32	74.00

- **Testing stage**

This stage aims to recognize a query gesture by matching its features with the features previously stored in the training stage. It should be noted that the user must return his hand to the neutral position to start a new gesture to avoid unintended gestures. The detailed analysis of the modules of this stage is as follows:

Sensing Module: The query gesture data are sensed using the flex sensors and the MPU-6050 sensor.

Processing Module: The sensed data from the previous module are converted into features. If these features match any of the previously stored features of different gestures, the number, alphabet, or word corresponding to the matched features will be the recognition output of the query gesture. Otherwise, a “verify gesture” message will appear on the mobile phone screen.

Transmission Module: The HC-05 Bluetooth module is paired and connected to an Android phone. After that, the text of the recognized number, alphabet, or word is sent via the Bluetooth module, to the proposed Android app created using MIT App Inventor 2 called (Sign Language Translator.apk). In the MIT App Inventor 2 program, the “Bluetooth Client” tool is used to achieve the desired connection to a smartphone which supports linking with the HC-05 Bluetooth module [62]. Finally, the “TextToSpeech” component is used to make the smartphone speak the text audibly [63].

B. The Proposed MASLL-Sys

MASLL-Sys plays an important role in creating an engaging augmented learning environment for deaf and non-deaf students to learn sign languages (ArSL and ASL). MASLL-Sys is developed using Android studio environment. In Android studio, XML is used to create the UI layout, and JAVA is used to code the application. While the SQLite database is used to create the internal database. Fig. 11 describes the architecture of MASLL-Sys, which includes five main modules. A detailed description of these modules is provided in the following sections.

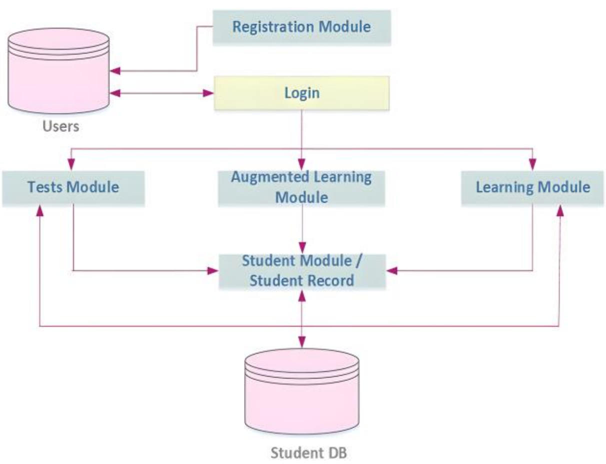


Fig. 11. The proposed MASLL-Sys architecture.

Registration Module: This module allows targeted users to log in to the MASLL-Sys.

Learning Module: This module aims to learn some of the most common SL vocabulary. There are 7 topics to learn: alphabets, numbers, people, animals, food, health, and time. The student can choose the topic he wants to learn, then the vocabulary text is displayed with the corresponding sign image, in addition to a detailed description of how it is represented (Fig. 12).

Fig. 12. Interface for learning the sign of the zero number.

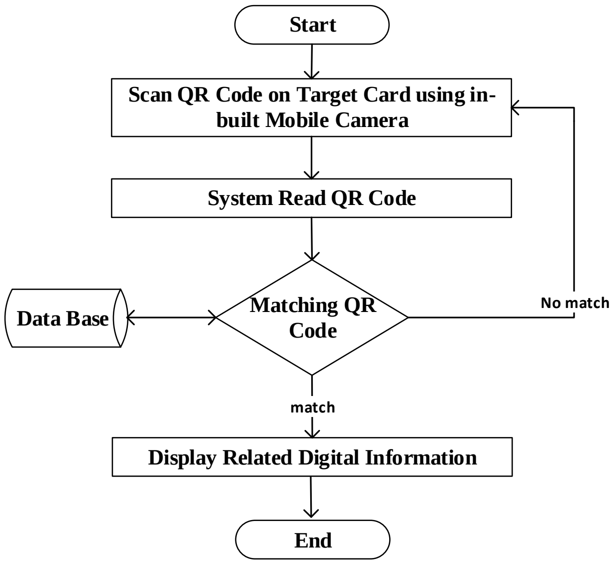


Fig. 13. The workflow of the proposed augmented learning module in the MASLL-Sys.

Augmented Learning Module: This module relies on marker-based AR technology which uses markers that can be captured by a camera and then distinguished to display associated information. Here, sample of educational cards were prepared using QR codes, which were produced using the free website (https://www.qr-codegenerator.com/). When a student directs the phone's camera to scan the QR code on the card, the system reads it and matches it with the QR stored in the database created by DB Browser for SQLite. Finally, related digital information (the corresponding sign image with a textual description explaining how it is represented, in addition to videos, etc.) will be displayed in real-time on the mobile phone screen. Fig. 13 shows the workflow of the proposed augmented learning module, and Fig. 14 shows screenshots as an example of an augmented learning in the MASLL-Sys.

Tests Module*:* The tests module aims to evaluate the knowledge acquired by students in the learning modules. This module is divided into two main categories:

Special Tests Category: This category provides different models of multiple choice tests related to each individual topic. Students have the opportunity to choose one of the topics and the number of questions required. In light of this, the system randomly creates a test on this topic. After answering each question, feedback is provided. Finally, after answering all the questions, a report is displayed that includes the number of correct and incorrect answers, and the percentage that represents the level of performance achieved by the student. Here, the system imposes a basic restriction, which is to automatically return to the same topic to study it again if the performance rate is less than 80%. Otherwise, the student can choose another topic and take his own tests. Fig. 15 shows the interface of one of the test questions.

General Tests Category: This category provides different models of general tests after studying all educational topics (all SL vocabulary). After answering all questions, the system makes a detailed report on the test results and performance level as described in the special tests category.

Student Module: The student module/ student record processes and saves the statistics about students' learning, and it is linked to the student database in which all of the student's personal and educational data is stored. Through it, the system identifies the student's teaching status, the extent to which he achieves the goals, and his level of performance. It should be noted that the registration, learning, augmented learning, and tests modules are all linked to the student module/student record as shown in Fig. 11. Fig. 16 shows the interface of the student module.

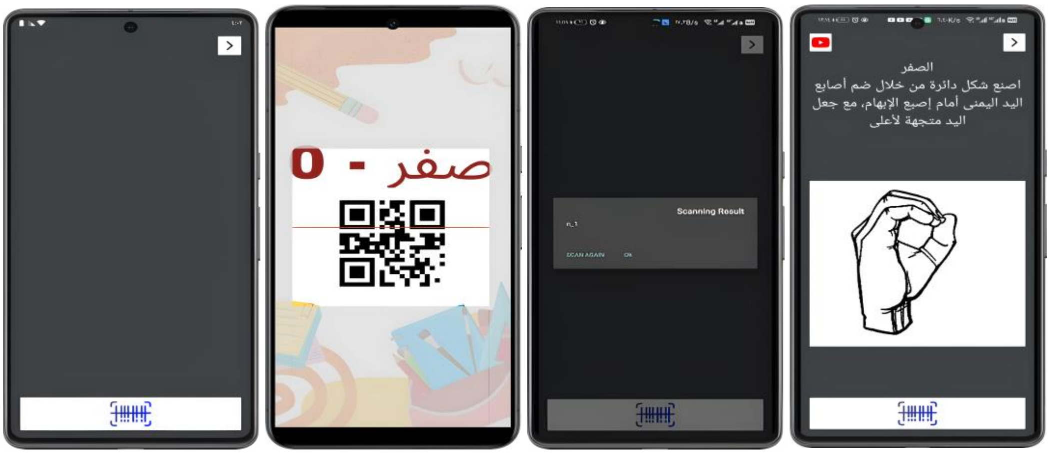


Fig. 14. Screenshots as an example of an augmented learning in the MASLL-Sys.

Fig. 15. The interface of one of the test questions.

Fig. 16. The interface of the student module.

IV. Evaluation and Experimental Results

This part deals with the methodology for evaluating the proposed system and the experimental results of the current paper, which is divided into two main sections:

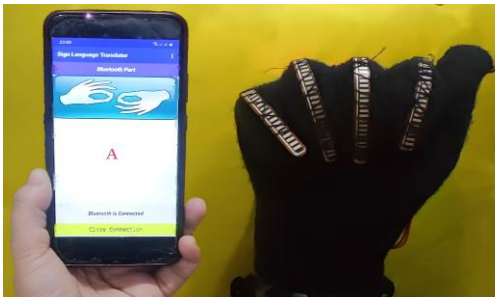
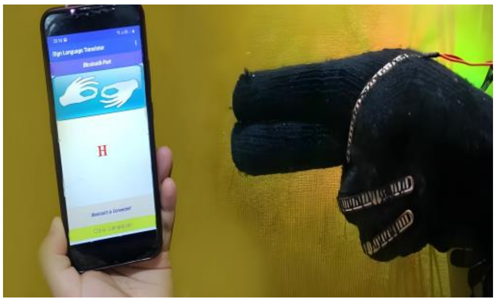
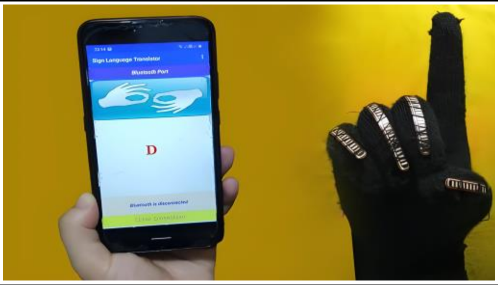
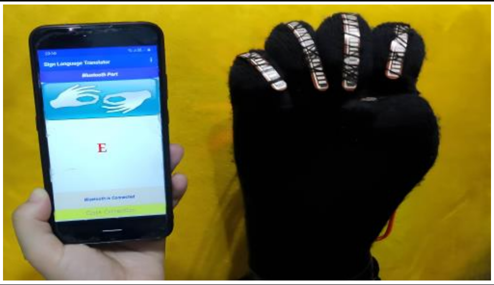
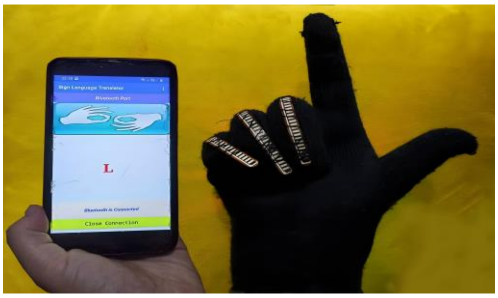
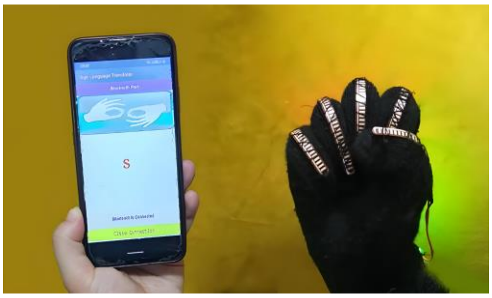
A. *SSG-Sys Evaluation*

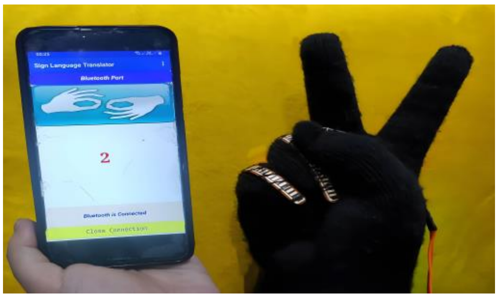
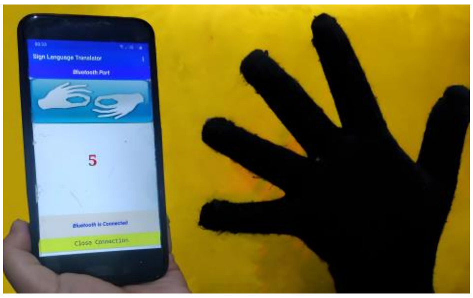
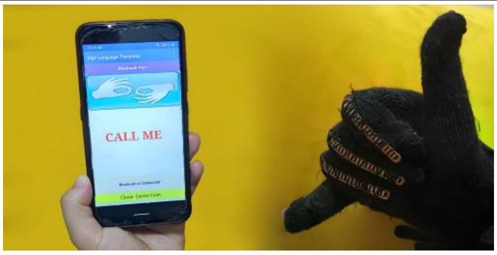
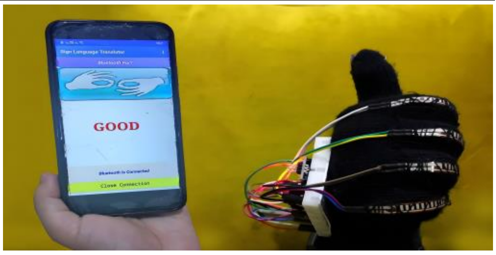
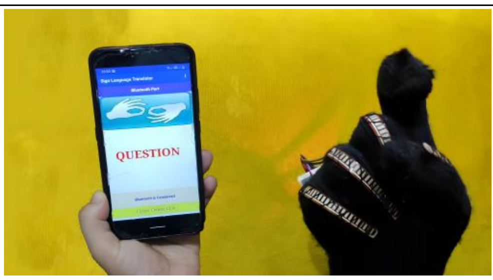
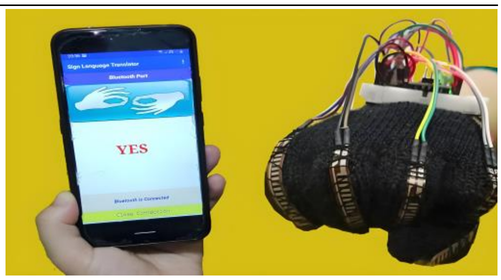
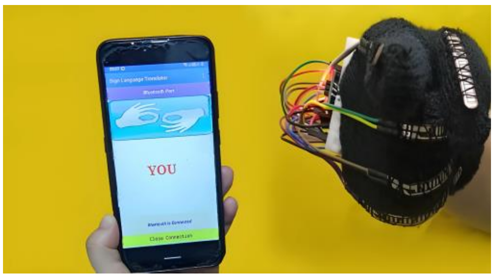
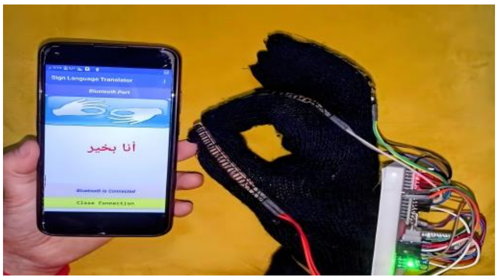
The proposed Sensory Smart Glove System was initially tested to ensure that all of its hardware and software components work as expected. It was noted that it was free of any errors, and all its components interacted properly and agreed with the expected results, which indicates the success of the system from a technical perspective. Table VIII shows samples of using SSG-Sys for gesture recognition. To further verify the system's performance, it was evaluated and tested for all alphabets and numbers, in addition to some isolated common words, in American Sign Language and Arabic Sign Language through an extensive series of experiments. Also, the recognition accuracy was calculated according to Eq. (1). In this regard, each gesture was tested 10 consecutive times, and then the average recognition accuracy was calculated. Table IX shows the obtained recognition accuracy results for the proposed SSG-Sys.

$$Accuracy = \frac{number\ of\ true\ gesture\ recognition}{total\ number\ of\ trials} \times 100 \quad (1)$$

Based on the results presented in Table IX, it is clear that SSG-Sys achieved an average recognition accuracy of (98.57%) for ArSL alphabets, (98.07%) for ASL alphabets, (99%) for ArSL and ASL numbers, (97.77) for ArSL words, and (97.69) for ASL words. It is noted that the accuracy of recognizing alphabets and numbers was higher than the accuracy of recognizing words. This is due to the fact that words involve movement that needs to be detected by more sensors, and this will be taken into account in the future. In general, the system achieved very high recognition accuracy, reaching an average of (98.42%) for ArSL and (98.22%) for ASL. However, there is still scope for improvement. There were some limitations during the implementation, which included: wear of the resistor over time due to repeated use of the glove; this issue was resolved by replacing the worn-out resistor. Another limitation was soldering the flex sensor with female /male cables due to the weakness of the sensor terminals; this problem was addressed by ensuring accurate soldering points on the terminals and proper use of the soldering caustic device. Lastly, there was some interference in the readings from neighboring fingers when one finger was bent; this issue was considered in the code to ensure accurate interpretation of the gestures.

TABLE VIII. Samples of Using SSG-Sys for Gesture Recognition

Outputs	Performing and Recognizing Gestures	Outputs	Performing and Recognizing Gestures
A		**H**	
D		**E**	
L		**S**	

2		**5**	
9		**٤**	
٧		**٨**	
CALL ME		**GOOD**	
QUESTION		**YES**	
YOU		**أنا بخير**	

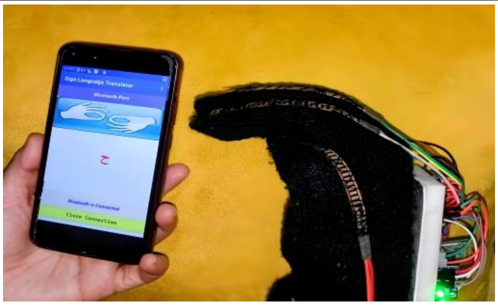
توقف		لو سمحت	
يؤلم كثيرا		ت	
ح		م	

TABLE IX. THE RECOGNITION ACCURACY RESULTS FOR THE PROPOSED SSG-SYS

ASL Alphabets/ Numbers/Words	Number of trials	Number of true gesture recognition	Accuracy (%)	ArSL Alphabets/ Numbers/Words	Number of trials	Number of true gesture recognition	Accuracy (%)
A	10	10	100	أ	10	10	100
B	10	10	100	ب	10	10	100
C	10	9	90	ت	10	10	100
D	10	10	100	ث	10	10	100
E	10	9	90	ج	10	10	100
F	10	10	100	ح	10	10	100
G	10	9	90	خ	10	10	100
H	10	10	100	د	10	10	100
I	10	10	100	ذ	10	10	100
J	10	9	90	ر	10	10	100
K	10	10	100	ز	10	9	90
L	10	10	100	س	10	10	100
M	10	10	100	ش	10	10	100
N	10	10	100	ص	10	10	100
O	10	10	100	ض	10	9	90
P	10	10	100	ط	10	10	100
Q	10	10	100	ظ	10	10	100
R	10	10	100	ع	10	10	100
S	10	10	100	غ	10	9	90
T	10	10	100	ف	10	10	100
U	10	9	90	ق	10	10	100
V	10	10	100	ك	10	10	100
W	10	10	100	ل	10	10	100
X	10	10	100	م	10	10	100
Y	10	10	100	ن	10	10	100
Z	10	10	100	هـ	10	9	90
Average			**98.07**	و	10	10	100
				ى	10	10	100
				Average			**98.57**

1	10	10	100	١	10	10	100
2	10	10	100	٢	10	10	100
3	10	10	100	٣	10	10	100
4	10	10	100	٤	10	10	100
5	10	10	100	٥	10	10	100
6	10	9	90	٦	10	10	100
7	10	10	100	٧	10	9	90
8	10	10	100	٨	10	10	100
9	10	10	100	٩	10	10	100
10	10	10	100	١٠	10	10	100
	Average		**99**		**Average**		**99**
BATHROOM	10	9	90	لو سمحت	10	10	100
BYE	10	10	100	شكرا	10	10	100
CALL ME	10	9	90	اتمنى لك حياه سعيدة	10	10	100
DISLIKE	10	10	100	توقف	10	10	100
GOOD	10	10	100	أنا بخير	10	10	100
HELLO	10	10	100	ألم	10	9	90
LOVE	10	10	100	يؤلم كثيرا	10	10	100
NO	10	10	100	يؤلم قليلا	10	9	90
OK	10	10	100	بطة	10	10	100
QUESTION	10	9	90				
YES	10	10	100				
YOU	10	10	100		**Average**		**97.77**
STUDENT	10	10	100				
	Average		**97.69**				

B. Evaluating the Overall Performance of the Proposed System

To evaluate the overall performance of the proposed system, a questionnaire was developed and presented in its initial form to a group of arbitrators (7) in the field of educational technology and SL teaching, to verify its validity and reliability. The proposed modification was applied to some statements and others were deleted to obtain the final form of the questionnaire. In this way, the questionnaire was subjected to arbitrator validation. Also, its reliability was measured using Cronbach's alpha coefficient (α = 0.971). After that, it was submitted to the arbitrators to survey their views. Their responses were recorded on a five-point Likert scale (Strongly Agree = 5, Agree = 4, Undecided = 3, Disagree = 2, Strongly Disagree = 1). The statements of the questionnaire prepared to evaluate the proposed system are as follows:

- The glove is lightweight, portable, and easy to use.
- The overall appearance of the glove is elegant, very comfortable, and extremely flexible.
- The SSG-Sys's response time for gesture recognition in ASL and ArSL is quick and even.
- The SSG-Sys can provide accurate and reliable recognition results for ArSL and ASL gestures.
- The MASLL-Sys provides real-time interaction with the real environment and enhances students' deep learning.
- The SSG-Sys is suitable for effective gesture recognition in both ASL and ArSL including numbers, alphabets, and words.
- The SSG-Sys responded to the user's ArSL and ASL gestures efficiently and converted them into sound.
- The MASLL-Sys can act as a supportive tool for deaf-mute students and their normal peers in the process of learning ArSL and ASL efficiently and realistically.
- The MASLL-Sys motivates students to become more involved in learning ArSL and ASL by presenting relevant digital information in the form of images, textual descriptions, videos, etc.
- The MASLL-Sys is capable of effectively monitoring and evaluating students' performance levels in learning ArSL and ASL.
- The proposed system is useful and applicable in various educational institutions, especially schools for the deaf and mute and training centers.
- It can be recommended to use the proposed system instead of traditional SL teaching techniques.

Fig. 17 shows the results of the arbitrators' responses to the questionnaire evaluating the proposed system.

According to the results displayed in Fig. 17, the percentages of the arbitrators' responses to the questionnaire statements ranged between 94.28% and 100%, while the overall percentage of the questionnaire was 97.85%. This confirms that the proposed system is effective and well-suited for application, particularly within educational institutions.

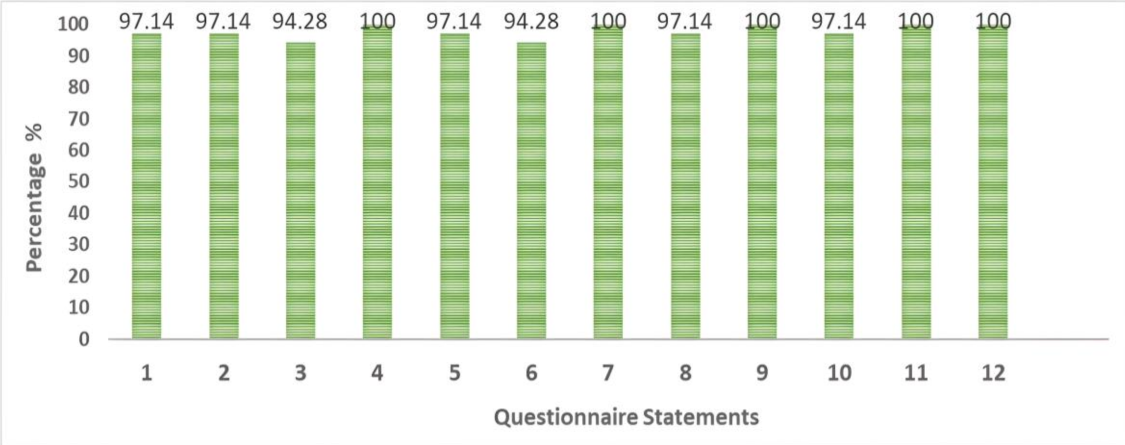


Fig. 17. The results of the arbitrators' responses to the questionnaire evaluating the proposed system.

V. CONCLUSION

Recognizing and learning sign language is a major challenge facing deaf and mute students, their normal peers, and their teachers. Also, another challenge is communication between them. This paper addresses these challenges by proposing an intelligent Android system for sign language recognition and learning and as an assistance tool for teachers in deaf schools. The SSG-Sys, which consists of a sensory smart glove and an Android app is designed to recognize ArSL and ASL gestures (alphabets, numbers, and some common words) used in daily communication in the school environment. The recognized gesture is displayed in text and audio form on the proposed Android app. The SSG-Sys results indicated a high recognition accuracy of (98.42%) for ArSL and (98.22%) for ASL, with an average accuracy of (98.32%) for the both sign languages. In addition, a mobile educational app based on maker-based AR technology, called MASLL-Sys is developed, to support the SL learning process and make it more realistic. Overall, the proposed system was evaluated by experts, who confirmed that it is accurate and reliable in SL recognition and can be used as a tutor for those who want to learn SL as well as a translator for the deaf people so that they can communicate efficiently with others. The proposed system is very useful in the light of the Egyptian state's current efforts to integrate deaf and mute children with ordinary children in schools. This is for the sake of a better social and educational life, and to consider their rights as an authentic partner in society. In future work, the system could be expanded to encompass a broader range of gestures by using a combination of two gloves instead of one. Moreover, it can recognize continuous words, not just isolated ones. This system can also be developed into a web service for use in conferences and meetings attended by the deaf people. It is also possible to embed 3D models and animation in the MASLL-Sys for deep learning of ArSL and ASL.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Soha A. Shaban and Dalia L. Elsheweikh conceived and designed the idea of the research, collected data, analyzed the data, conducted experiments, wrote the manuscript, revised the manuscript, and implemented the proposed system. All authors have contributed to validating the results obtained and approved the final version of this paper.

REFERENCES

[1] A. Barbour *et al.*, "Intelligent gloves: An IT intervention for deaf-mute people," *Journal of Intelligent Systems*, vol. 32, no. 1, pp. 1–13, 2023.

[2] P. S. Divya *et al.*, "Smart glove translates sign language in real time," *Eur. Chem. Bull*, vol. 12, pp. 2258–2265, 2023.

[3] A. Ji *et al.*, "Dataglove for sign language recognition of people with hearing and speech impairment via wearable inertial sensors," *Sensors*, vol. 23, no. 15, pp. 1–20, 2023.

[4] I. Devika, P. Chowdaiah, L. Sagarika, S. Shetty, and A. Manjula, "Hand gesture recognition and conversion system for dumb people," *International Journal of Innovative Research in Science, Engineering and Technology*, vol. 13, no. 5, pp. 7178–7186, 2024.

[5] Mudra, "An innovative device helping deaf-mute people to 'talk'," *Innovation in Disability Sector*, vol. 1, no. 1, pp. 22–23, 2017.

[6] R. Alzohairi *et al.*, "Image based Arabic sign language recognition system," *International Journal of Advanced Computer Science and Applications*, vol. 9, no. 3, pp. 185–194, 2018.

[7] Z. R. Saeed, Z. B. Zainol, B. B. Zaidan, and A. H. Alamoodi, "A systematic review on systems-based sensory gloves for sign language pattern recognition: An update from 2017 to 2022," *IEEE Access*, vol. 10, pp. 1–21, 2022.

[8] S. Monga and Kavita, "Adopting an innovative technique for deaf and dumb students for higher studies," *An International Peer-Reviewed Open Access Journal of Interdisciplinary Studies*, vol. 2, no. 1, pp. 301–306, 2019.

[9] M. I. Saleem, A. Siddiqui, S. Noor, M. L. Nieto, and P. Otero, "A novel machine learning based two-way communication system for deaf and mute," *Applied Sciences*, vol.13, no. 1, pp. 1–19, 2022.

[10] M. A. Ahmed, B. B. Zaidan, A. A. Zaidan, M. M. Salih, and M. M. B. Lakulu, "A review on systems-based sensory gloves for sign language recognition state of the art between 2007 and 2017," *Sensors*, vol. 18, no. 7, pp. 2–44, 2018.

[11] G. R. Meghana, H. S. Harshitha, L. Shyla, and K. Madan, "Glove based sign language interpreter for deaf and aphonic peoples," *International Research Journal of Engineering and Technology*, vol. 7, no. 6, pp. 383–385, 2020.

[12] D. K. Sonawala *et al.*, "Smart gloves for mute people using American sign language," *International Journal of Research in Engineering, Science and Management*, vol. 3, no. 5, pp. 943–945, 2020.

[13] S. Gurrala, N. Mounika, G. Ramya, S. Lakshmi, and V. Ramana, "IOT based smart assistance gloves for paralyzed people," *International Journal for Modern Trends in Science and Technology*, vol. 9, no. 8, pp. 31–34, 2023.

[14] H. Kaur, A. Saxena, A. Tandon, K. Mehrotra, and K. Kashyap, "A review paper on evolution of smart Glove," *International Journal of Scientific Research and Management Studies (IJSRMS)*, vol. 3, no. 3, pp. 124–128, 2016.

[15] H. M. Mohammdi and D. M. Elbourhamy, "An intelligent system to help deaf students learn Arabic sign language," *Interactive Learning Environments*, vol. 31, no. 5, pp. 3195–3210, 2021.

[16] T. Ritchings, A. Khadragi, and M. Saeb, "An intelligent computer-based system for sign language tutoring," *Assistive Technology*, vol. 24, no. 4, pp. 299–308, 2012.

[17] Y. Shivani, A. Goud, S. Phanindra, and V. Pandia, "IOT based bot using smart gloves," *International Research Journal of Modernization in Engineering Technology and Science*, vol. 4, no. 3, pp. 1142–1146, 2022.

[18] M. Khan, S. Krishna, T. Manikanta, S. Sharfuddin, and T. Nagarjuna, "An IoT based device for communication among deaf, dumb and blind people," *International Journal of Creative Research Thoughts*, vol. 8, no. 5, pp. 71–76, 2020.

[19] U. Ravindran, T. Alam, R. Vashishtha, A. Rai, and S. Sharma, "An IOT based smart glove," *Journal of Emerging Technologies and Innovative Research (JETIR)*, vol. 6, no. 5, pp. 486–493, 2019.

[20] K. V. Phaneendhra, "Transforming India's education system through Internet of Things (IoT)," *New Education Policy 2020 – Concepts, Approaches and Challenges*, pp. 74–83, 2020.

[21] X. Guo *et al.*, "A novel method for data glove-based dynamic gesture recognition," in *Proc. 2017 International Conference on Virtual Reality and Visualization*, Zhengzhou, China, 2017, pp. 43–48.

[22] B. Indriyono, N. Pamungkas, I. Zahari, Y. Lestari, and I. Dimentieva, "Application of mobile-based augmented reality technology concepts in interactive learning systems for liquefaction phenomena for the deaf," *Scientific Journal for Information and Communication Technology*, vol. 8, no. 2, pp. 116–124, July 2023.

[23] E. Baker, "Conceptual model of mobile augmented reality for engaging hearing-impaired museum visitors," Doctor thesis, UUM College of Arts and Sciences, Universiti Utara Malaysia, pp. 13–16, 2019.

[24] J. Alfaro and P. Puyvelde, "Mobile augmented reality apps in education: Exploring the user experience through large-scale public reviews," *Augmented Reality, Virtual Reality, and Computer Graphics*, pp. 428–450, 2021.

[25] S. M. Elatawy, D. M. Hawa, A. A. Ewees, and A. M. Saad, "Recognition system for alphabet Arabic sign language using neutrosophic and fuzzy c-means," *Education and Information Technologies*, vol. 25, pp. 5601–5616, 2020.

[26] S. Adhikari *et al.*, "Novel machine learning-based hand gesture recognition using HCI on IoT assisted cloud platform," *Computer Systems Science & Engineering*, vol. 46, no. 2, pp. 2123–2140, 2023.

[27] B. Shubankar, M. Chowdhary, and M. Priyaadharshini, "IoT device for disabled people," *Procedia Computer Science*, vol. 165, pp. 189–195, 2019.

[28] C. A. Garzon, J. B. Acosta, Kinshuk, J. Duarte, and J. Betancourt, "Augmented reality in education: An overview of twenty-five years of research," *Contemporary Educational Technology*, vol. 13, no. 3, 302, pp. 2–4, 2021.

[29] C. Wei, Y. Kuah, C. Ng, and W. Lau, "Augmented Reality (AR) as an enhancement teaching tool: Are educators ready for it?" *Contemporary Educational Technology*, vol. 13, no. 3, 303, pp. 2–14, 2021.

[30] M. Ghobadi, S. Shirowzhan, M. Ghiai, F. Ebrahimzadeh, and F. Tahmasebinia, "Augmented reality applications in education and examining key factors affecting the users' behaviors," *Education Science*, vol. 13, no. 10, pp. 1–16, 2023.

[31] R. Ardiani and M. Fachrie, "Augmented reality application of sign language learning for deaf people based on android," *Informatics and Science*, vol. 13, no. 3, pp. 960–966, 2023.

[32] P. S. Bhore, N. D. Londhe, S. Narsale, P. S. Patel, and D. Thanambir, "Smart gloves for deaf and dumb students," *International Journal of Progressive Research in Science and Engineering*, vol. 1, no. 8, pp. 30–40, 2020.

[33] S. Kumuda and P. K. Mane, "Smart assistant for deaf and dumb using flexible resistive sensor: Implemented on LabVIEW platform," in *Proc. International Conference on Inventive Computation Technologies*, Coimbatore, India, 2020, pp. 994–1000.

[34] A. Dweik, H. Qasrawi, and D. Shawar, "Smart glove for translating Arabic sign language 'SGTArSL'," in *Proc. 2021 31st International Conference on Computer Theory and Applications (ICCTA)*, 2021, pp. 49–53.

[35] A. Qaroush, S. Yassin, A. Al-Nubani, and A. Alqam, "Smart, comfortable wearable system for recognizing Arabic sign language in real-time using IMUs and features-based fusion," *Expert Systems with Applications*, vol. 184, 115448, 2021.

[36] S. Rum and B. Boilis, "Sign language communication through augmented reality and speech recognition (learnsign)," *International Journal of Engineering Trends and Technology*, vol. 69, no. 4, pp. 125–130, April 2021.

[37] J. Abuhuraira and S. Duraisamy, "Android based application for sign language translation using augmented reality," *International Journal of Information System and Engineering*, vol. 8, no. 1, pp. 74–84, April 2020.

[38] H. Ekhsan, M. Khairi, and J. Hamid, "Enhancing sign language learning with augmented reality," *Journal of Computing Research and Innovation*, vol. 7, no. 1, pp. 147–154, 2022.

[39] N. Soogund and M. Joseph, "SignAR: A sign language translator application with augmented reality," *Journal of Applied Technology and Innovation*, vol. 3, no. 1, pp. 33–37, 2019.

[40] A. Shelke, P. Kalasappanavar, and R. Kotgire, "Home automation application with voice commands using Arduino," *International Research Journal of Engineering and Technology*, vol. 9, no. 5, pp. 3076–3083, 2022.

[41] M. Murad, O. Bayat, and H. M. Marhoon, "Design and implementation of a smart home system with two levels of security based on IoT technology," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 21, no. 1, pp. 546–557, 2021.

[42] S. R. Shareef, M. M. Hussain, A. Gupta, and H. A. Aslam, "Hand gesture recognition system for deaf and dumb," *International Journal of Multidisciplinary and Current Educational Research*, vol. 2, no. 4, pp. 82–88, 2020.

[43] N. S. Rafa *et al.*, "IoT-based remote health monitoring system employing smart sensors for asthma patients during COVID-19 pandemic," *Wireless Communications and Mobile Computing*, vol. 2022, pp. 1–14, 2022.

[44] R. Jyothi, B. L. Lakshmishri, R. R. Pooja, P. M. Vaanyashree, and K. Yashaswini, "Gesture vocalize using smart glove for deaf and mute people using internet of things," *International Journal of Innovative Research in Science, Engineering and Technology (IJIRSET)*, vol. 9, no. 6, pp. 5113–5119, 2020.

[45] L. Padmalatha, M. Sailesh, K. Niranjan, M. Vamsi, and P. Vikas, "Detect and display the subterranean failing of cables using IoT," *International Journal of Creative Research Thoughts (IJCRT)*, vol. 11, no. 3, pp. i15–i23, 2023.

[46] S. C. Bodda, P. Gupta, G. Joshi, and A. Chaturvedi, "A new architecture for hand-worn sign language to speech translator," arXiv preprint, arXiv:2009.03988v1, pp. 1–9, 2020.

[47] A. C. Chougule, S. S. Sannakki, and V. S Rajpurohit, "Smart glove for hearing-impaired," *International Journal of Innovative Technology and Exploring Engineering*, vol. 8, no. 6S4, pp. 1188–1192, 2019.

[48] S. A. Shaban, "A smart system for the university chemical laboratory using IoT," *Journal of Advances in Information Technology*, vol. 15, no. 1, pp. 104–117, 2024.

[49] A. K. Majhi, S. Dash, and C. K. Barik, "Arduino based smart home automation," *ACCENTS Transactions on Information Security*, vol. 6, no. 22, pp. 7–12, 2021.

[50] S. Disale, D. Wagh, D. Suryawanshi, K. Dighe, and D. Shetiya, "IOT-based home automation through web server," *International Advanced Research Journal in Science, Engineering and Technology*, vol. 9, no. 11, pp. 106–109, 2022.

[51] V. D. Pandey, A. K. Chaurasiya, and S. M. Vaidya, "IOT based smart security and home automation system," *International Journal of Research Publication and Reviews*, vol. 2, no. 4, pp. 1082–1084, 2021.

[52] A. Daund, G. Merkar, M. Deshmukh, P. Janbandhu, and R. S. Badodekar, "Smart home automation using android application and Arduino microcontroller," *IJARIIE*, vol. 3, no. 3, pp. 2137–2142, 2017.
[53] A. Fahmi, M. Sarkar, A. K. Mishra, and M. B. Gulshan, "Advanced internet of things irrigation mechanism," *International Journal of Engineering Research and Technology (IJERT)*, vol. 9, no.7, pp. 682–686, 2020.
[54] A. Gupta and R. Verma, "Arduino based home automation through Internet of Things (IoT)," Bachelor's thesis, Jaypee University of Information Technology Waknaghat, Himachal, Pradesh, pp. 22–28, 2019.
[55] H. Amiliansyah, M. Galina, and J. W. Simatupang, "Access control and security system via bluetooth application on android smartphone," *Eltikom Journal*, vol. 6, no.1, pp. 100–108, 2022.
[56] A. Khilari, M. Marathe, A. Parab, and M. Rajput, "Android based aid for the deaf," *International Journal of Technical Research and Applications*, vol. 40, pp. 21–25, 2016.
[57] K. R. Chandra, V. Suhruth, K. Patnaik, M. Sandeep, and A. Prasad, "Smart glove for sign language translation using Arduino," Bachelor's thesis, ANIL Neerukonda Institute of Technology and Sciences, Andhra University, Visakhapatnam, pp. 40–45, 2021.
[58] B. Evans, *Beginning Arduino Programming*, 1st ed. Apress, 2011, pp. 90–94.
[59] M. Shlibek and M. Mhereeg, "Comparison between Arduino based wireless and wire methods for the provision of power theft detection," *European Journal of Engineering Science and Technology*, vol. 2, no. 4, pp. 45–59, 2019.
[60] B. A. Munana, "A self-stabilizing platform," Bachelor's thesis, Metropolia University of Applied Sciences, 2022, pp. 20–25.
[61] A. Vijayvergia, "Exploration of robotics need in the medical field and robotic arm operation via glove control," Master's thesis, Bucknell University, pp. 22–149, 2023.
[62] L. Brahmandam, "The development a of low-cost robotic squirrel for the study of small animal behavior," Master's thesis, Faculty of the Graduate College, Oklahoma State University, pp. 40–47, 2019.
[63] H. J. Kim and J. Modell, "Mobile app design tool for smartphones: A tutorial," *International Journal of Soft Computing and Engineering (IJSCE)*, vol. 2, no. 3, pp. 237–243, 2012.