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Sign Language Translator for Person with Hearing Disability Applying Artificial Intelligence

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Abstract
Aim: A communication barrier exists between most of the Philippine population and the deaf and mute community who use Filipino Sign Language (FSL), which can be attributed to the lack of knowledge of sign language. To address this gap, the proponent proposed a real-time bidirectional Filipino Sign Language Translator anchored on artificial intelligence technology to facilitate effective communication between signers and non-signers.
Methodology: The AI-powered FSL translator included two modes: 1) recognition and translation from FSL gestures to text and audio output using machine learning and Google text-to-speech technology and 2) recognition and translation from the speech-to-text output using the already available Google speech-to-text technology.
Results: Results of the hardware testing, software testing, and full system testing showed that the developed FSL translator device was able to perform its recognition and translation functions successfully and accurately, tallying a 100 percent success rate in the full system testing.
Conclusion: The system that can detect hand gestures based on FSL through a camera and translate the detected FSL hand gestures into Filipino text through a display module was designed and developed. The device's identification and translation capabilities passed individual testing with outstanding results. The camera and microphone were tested as part of the hardware. The results of the hardware tests showed that both the FSL gestures and the verbal input could be successfully detected and recognized. The software testing, on the other hand, entailed converting FSL gestures to text output via the display module, FSL gestures to audio output, and vocal input to text output is also shown using the LCD. The system that translates the detected FSL hand gestures audio through an audio output device was developed and tested. The system developed in this study's FSL translator was able to detect FSL hand gestures through the camera, translate the detected FSL hand gestures into Filipino text displayed through a display module, read out the text output into speech using an audio output device, detect Filipino speech input through the microphone, and successfully translate the text output into spoken Filipino. The system was tested acceptable taking a result of 4.60 mean or "Very Successful" with the aid of ISO 25010:2011 standard.

Keywords: *Image Processing, Signer, Non-Signer, Sign Language, Speech-to-Text*

INTRODUCTION

Communication is important in people's day-to-day life as it facilitates the exchange of information among individuals, thus helping in the development of interpersonal relationships with others (The Scientific World, 2020). However, there are certain instances when some are hindered from effectively communicating due to their inability to either hear, or talk, resulting in misunderstandings in communication. According to the statistics presented in Senate Bill No. 2117, in the Philippines alone, 1.23% of the population as of 2009 were recorded to be deaf, mute, or hearing-impaired, which means that at least 517,536 individuals were limited in terms of gathering and exchanging information with others (Senate, Philippines, 2014). In these cases where spoken communication is not viable, sign language serves as a solution or an alternative to oral communication. Sign language is known to be a type of communication used mostly by the deaf and mute community, which utilizes visual gestures and signs to communicate with other people (Encyclopedia Britannica, 2023). It proves to be an effective way to communicate not

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only for the deaf, mute, or hearing-impaired, but also for those who have autism, cerebral palsy, Down syndrome, and other similar cases (Berke, 2021). The Philippines has its own official national sign language (Senate, Philippines, 2018). – the Filipino Sign Language or FSL – unique for the various regions of the country but still maintains a strong influence of American Sign Language (ASL) ingrained in it (Mendoza, 2019). For the purpose of this research, the FSL was used in the recognition and translation process.

However, a problem arises in the use of sign language: the inability or the difficulty encountered by other people in the use and understanding of sign language to facilitate effective communication between persons with disability and most of society. The introduction of a sign language translator based on AI offered some way for persons with disability or signers to communicate efficiently and effectively with other people who do not know and understand FSL or the non-signers. Artificial intelligence or AI is one of the technologies that is widespread and dramatically developing today. It works by ingesting large amounts of labeled training data in the system, analyzing the data for correlations and patterns, and using these patterns to make predictions about future states (Berry, 2019). With the power of this technology, society can manufacture AI-powered vehicles, conduct medical diagnoses, assist people, develop automated data synthesis, enhance decision-making, and provide voice input for human interaction, ultimately creating opportunities to advance people's way of life. All these point to the fact that artificial intelligence will indeed have a big impact in the future (Anderson & Rainie, 2019).

The proposed FSL translator relied on AI technology to recognize and translate FSL gestures into text and speech in real-time. Among the many types of AI –from Type 1: Reactive Machines, Type 2: Limited Memory, Type 3: Theory of Mind, and Type 4: Self-awareness – the researcher decided to use Type 1: Reactive Machines, which have no memory and are task-specific, as these are the most applicable type of AI in the project.

The deaf and mute community is seemingly left behind amidst a rapidly advancing technological world. There exists a special language for the deaf and mute community to facilitate their communication with other people. This is done through their use of sign language. However, the majority of the Philippine population does not understand sign language, specifically FSL, and modern technology is not yet fully maximized to aid this problem. This poses another hindrance to the communication of the deaf and mute community or signers with most of the population that are non-signers. To address this issue, several developments and inventions utilizing the latest computer technologies have been created to bridge the gap between signers and non-signers. Montefalcon, et. al., (2021) constructed an automated FSL recognition model using Convolutional Neural Network (CNN) ResNet architecture, utilizing computer vision and deep learning to gather images and be able to recognize FSL numbers and alphabets accurately. Rivera (2019), in his master's thesis, focused on the recognition of facial expressions in FSL conveying various aspects of communication such as type of sentences, degrees of adjectives, and emotions. Meanwhile, Sia, et. al. (2019) explored the recognition of arm and hand movement in FSL using machine learning. Lim, et. al. (2019) integrated a prototype data glove, which involves sensors to recognize hand pose and attitude, and computer vision, which uses a camera to determine hand position and gestures, to translate FSL for medical purposes. Probably the invention which gathered much attention from the public was the trainable gloves invention by a group of students from Camarines Sur Polytechnic Colleges, which can interpret FSL and convert it into speech using AI and microcontrollers (Cruz, 2021).

The group identified that there exists a gap in at least the local literature in terms of text-to-speech features of the sign language translator as well as the ability of the proposed system to translate speech into text. The two-way communication between the signers and non-signers was facilitated by the proposed AI-powered FSL translator which aimed to 1) recognize and translate FSL into text and speech, and 2) recognize and translate speech into text.

Objectives

This study aimed to create a bidirectional communication device that can interpret both FSL gestures and speech and can translate this information to text/audio and text, respectively, with the use of artificial intelligence.

Specifically, this study aimed to:

a. design a system that can detect hand gestures based on FSL through a camera and translate the detected FSL hand gestures into Filipino text through a display module;
b. develop a system by translating the detected FSL hand gestures audio through an audio output device; and
c. evaluate the acceptability of the system using ISO 25010:2011 standard.

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METHODS

Research Design

To fulfill the study's objectives, descriptive and developmental research methods were used. The situation, population, and phenomena under study were all described using a descriptive research design. Since the researcher used a survey to acquire data, this is employed (Formplus, 2021). Additionally, a system that met the requirements and objectives was designed, developed, and evaluated using developmental research. This is utilized to develop a fresh, well-tested system (Richey, 1994).

Data and Process Modeling

The System Development Life Cycle (SDLC) was used to create the system according to Figure 2. This model offers a detailed procedure that will act as a roadmap for the creation of the system. The methodology attempts to produce top-notch software that will satisfy customers. This was utilized to develop a thorough plan for the system's maintenance (Guru, 2019).

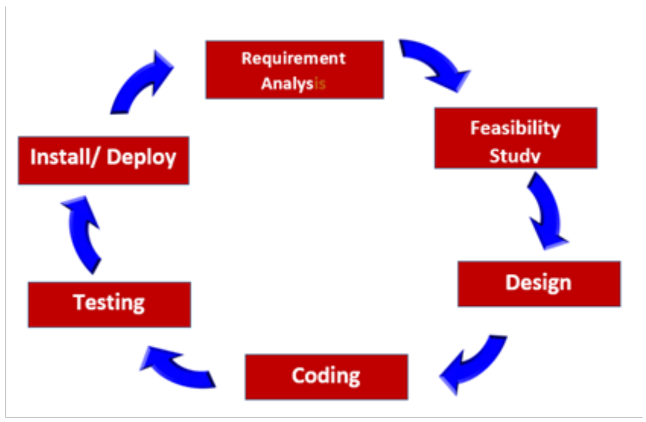

Figure 1: Systems Development Life Cycle

Regarding the system's development, the SDLC was utilized to look at the feasibility study, design, coding, testing, installation, and deployment.

Maintenance

Only the provision of the user's manual explaining how the system will function even after deployment was covered under maintenance.

Materials

To successfully produce the desired results, requirements for the hardware and software utilized in prototyping were taken into account.

Software

The developed software was subjected to an evaluation procedure using the ISO/IEC 25010:2011 standard. Testing was possible by applying the properties of the standards to the system. Not all qualities were taken into consideration when determining how acceptable the system was. These qualities include dependability, utility, and efficiency. In order to achieve the goals, suitable sub-characteristics of the standards were also chosen.

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Table 1. Software Requirements

Software	Version
C++	V20

Table 1 shows the software used in the development of the system. C++ was used as software in developing the translation together with the use of machine language.

Hardware

The following hardware listed in the table was needed for the study and development of the system.

Table 2. Hardware Requirements

Quantity	Unit	Description
1	unit	tablet

Table 2 lists the hardware specification for the system as a whole. The hardware component that was used is a tablet, which allowed the system to operate in accordance with the requirements.

Statistical Tool

A percentage was employed as the statistical tool for data interpretation in the hardware evaluation. The following is the formula to determine the percentage:

P = n / N x 100

Where: P = percent symbol
n = number of responses

The arithmetic mean was the statistical tool that was utilized in the interpretation of data during the software evaluation, which was based on ISO 25010:2011. The sum of all the items in a list of numbers divided by the total number of items in the list represents the arithmetic mean of the list of numbers. The number of respondents who evaluated the system is indicated by the number of items. The arithmetic mean was determined for each characteristic together with the sub-characteristic data obtained from the questionnaire. The following is the formula:

Formula:

$$A = \frac{1}{n} * \sum_{i=1}^{n} x_i$$

Where:
A = average (or arithmetic mean)
n = the number of terms (e.g., the number of items or numbers being averaged)
x1 = the value of each individual item in the list of numbers being averaged.

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To determine whether the system was acceptable, the arithmetic mean was utilized. The term "average" is frequently used to describe the arithmetic mean in scientific investigations, according to the English Oxford Living Dictionaries of 2019. The composite mean of each characteristic in ISO/IEC 25010:2011 was likewise calculated using this method. The characteristic or component of the entire system's composite mean is its average or mean. The general weighted mean will be determined after calculating the average of the sections.

Participants of the Study

To examine the acceptability of the system, the researcher utilized purposive sampling. The respondents consisted of 5 teachers with at least 3 years of experience in handling deaf pupils, 3 deaf students with at least 1 year of enrollment in the school, and 3 IT professionals with at least 5 years of experience.

RESULTS AND DISCUSSIONS

This chapter presents the investigation's conclusions, including the supporting elements of the system. The system evaluation procedure, including the statistical analysis to establish the acceptability of the system, is also illustrated in this chapter. The system's web-based interface is showing the following data:

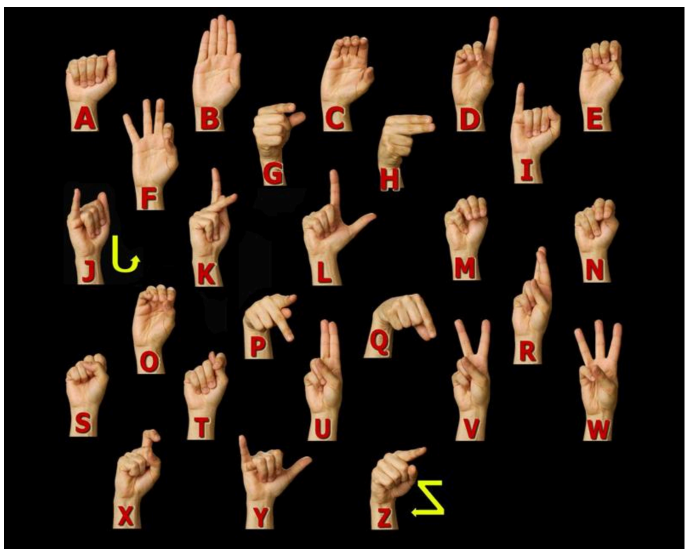

Figure 2. In this figure, I used FSL as my reference. I linked the different Filipino words to a single sign only.

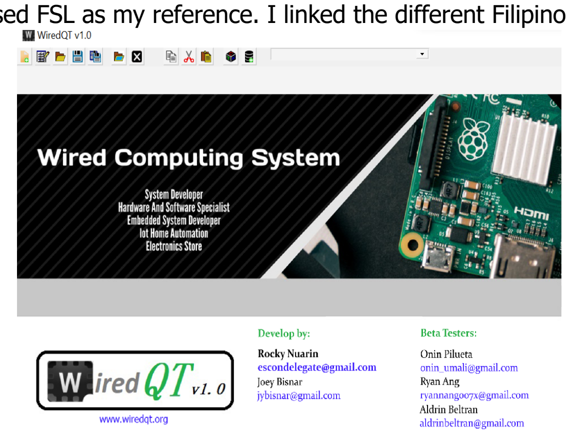

Figure 3. The system is operated through this interface.

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Figure 3. In this figure, the researcher applies the hand sign from the reference beside. And it shows how the system runs. When the hand sign is detected by the camera, the devices will produce sounds that correspond to the equivalent of the sign.

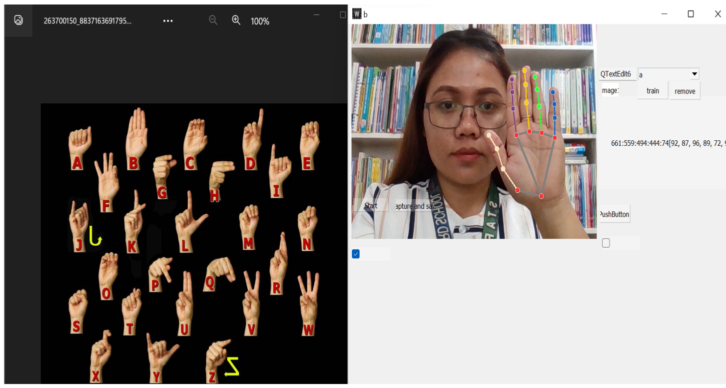

Figure 4. The system is operated through this interface.

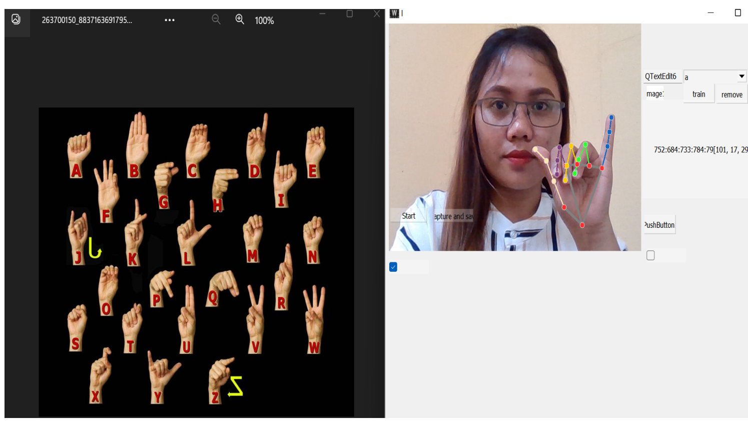

Figure 5. Transferring human voice to text.

Figure 5. This figure will show you the devices used in transferring audio (human voice) into text. The text will be displayed in the LCD screen. It is also the device used by the non-signer to bridge the gap between the signer and the non-signer.

Figure 6. Prototype part 1.

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Figure 7. Prototype part 2.

FSL Gesture Recognition Detection

The camera performed as expected during the test. It correctly recognized the hand signals. To correctly understand the hand gesture, the signer's hand must be at least one meter away from the camera. Other than that, nothing went wrong when the camera was being tested.

Table 3: FSL Gesture Detection

FSL Hand Gesture	Detection	Status
Ano?	Detected	Successful
Saan?	Detected	Successful
Sino?	Detected	Successful
Bakit?	Detected	Successful
Oo	Detected	Successful
Mahal Kita	Detected	Successful
Konti Lang	Detected	Successful
Pakisuyo	Detected	Successful
Ikaw	Detected	Successful
Pasensya Na	Detected	Successful
Ang Sarap	Detected	Successful
Mabuti	Detected	Successful
Paalam	Detected	Successful
Hindi	Detected	Successful
Ewan ko	Detected	Successful
Ang Lamig	Detected	Successful
Biro	Detected	Successful
Ako	Detected	Successful
Ito	Detected	Successful
Sila	Detected	Successful

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Speech Recognition Function

This table showed the results of the speech recognition function of the device to successfully detect Filipino speech.

Table 4: Filipino Word Detection

FSL Hand Gesture	Audio Device Detection	Status
Ano?	Detected	Successful
Saan?	Detected	Successful
Sino?	Detected	Successful
Bakit?	Detected	Successful
Oo	Detected	Successful
Mahal Kita	Detected	Successful
Konti Lang	Detected	Successful
Pakisuyo	Detected	Successful
Ikaw	Detected	Successful
Pasensya Na	Detected	Successful
Ang Sarap	Detected	Successful
Mabuti	Detected	Successful
Paalam	Detected	Successful
Hindi	Detected	Successful
Ewan ko	Detected	Successful
Ang Lamig	Detected	Successful
Biro	Detected	Successful
Ako	Detected	Successful
Ito	Detected	Successful
Sila	Detected	Successful

For the test, the microphone performed as expected. It accurately recognized Filipino speech. While the microphone was being tested, no issues were found.

Translation Function from Hand Gesture to Speech Testing

This table shows the results of the translation function of the device to convert the text output from the initial translation phase to speech output.

Table 5: Validity of translating the detected FSL hand gestures into Filipino speech through an audio output module.

FSL Hand Gesture	System Response (Audio Output)	Audio Device Detection	Status
Ano?	Ano?	Detected	Successful
Saan?	Saan?	Detected	Successful
Sino?	Sino?	Detected	Successful
Bakit?	Bakit?	Detected	Successful
Oo	Oo	Detected	Successful
Mahal Kita	Mahal Kita	Detected	Successful
Konti Lang	Konti Lang	Detected	Successful
Pakisuyo	Pakisuyo	Detected	Successful
Ikaw	Ikaw	Detected	Successful
Pasensya Na	Pasensya Na	Detected	Successful
Ang Sarap	Ang Sarap	Detected	Successful
Mabuti	Mabuti	Detected	Successful
Paalam	Paalam	Detected	Successful
Hindi	Hindi	Detected	Successful
Ewan ko	Ewan ko	Detected	Successful
Ang Lamig	Ang Lamig	Detected	Successful
Biro	Biro	Detected	Successful
Ako	Ako	Detected	Successful
Ito	Ito	Detected	Successful
Sila	Sila	Detected	Successful

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The device was able to voice out the corresponding Filipino words. It was able to convert the FSL hand gesture into Filipino speech properly. There were no problems encountered during this test.

Table 6: Validity of translating the detected FSL hand gestures into Filipino text through a display module.

FSL Hand Gesture	System Response (Display Output)	Audio Device Detection	Status
Ano?	Ano?	Detected	Successful
Saan?	Saan?	Detected	Successful
Sino?	Sino?	Detected	Successful
Bakit?	Bakit?	Detected	Successful
Oo	Oo	Detected	Successful
Mahal Kita	Mahal Kita	Detected	Successful
Konti Lang	Konti Lang	Detected	Successful
Pakisuyo	Pakisuyo	Detected	Successful
Ikaw	Ikaw	Detected	Successful
Pasensya Na	Pasensya Na	Detected	Successful
Ang Sarap	Ang Sarap	Detected	Successful
Mabuti	Mabuti	Detected	Successful
Paalam	Paalam	Detected	Successful
Hindi	Hindi	Detected	Successful
Ewan ko	Ewan ko	Detected	Successful
Ang Lamig	Ang Lamig	Detected	Successful
Biro	Biro	Detected	Successful
Ako	Ako	Detected	Successful
Ito	Ito	Detected	Successful
Sila	Sila	Detected	Successful

The device was able to display the corresponding Filipino words through the LCD. It was able to convert Filipino speech into Filipino text properly. There were no problems encountered during this test.

Full System Testing

This table showed the results of the whole system testing, which included the functionalities of the prototype.

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Table 7: Full System Test Result

Methods	Trials										Success Rate
	1	2	3	4	5	6	7	8	9	10	
Did the system detect hand gestures based on FSL through a camera?	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	100%
Did the system translate the detected FSL hand gestures into Filipino text through a display module?	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	100%
Did the system translate the detected FSL hand gestures audio through an audio output device?	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	100%
Did the system detect Filipino speech	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	100%
Did the system translate the	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	100%
Filipino speech into text through a display module?	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	30/30 words	100%

The device was able to accomplish all the objectives with a 100 percent success rate. It was able to have successful marks all throughout the tests. There were no problems encountered during the full system testing. However, the hand of the signer should be at least one meter from the camera to read the hand gesture properly. The hand should also move slowly when performing hand gestures for the system to correctly identify the hand gesture of the FSL and display the correct output.

Software

The system interfaces are presented below:

Software Evaluation

Table 9 displays the software evaluation used to determine whether the system is acceptable. The system met the necessary requirements as evidenced by the Functional Suitability score of 4.52, or "Very Functional". The testing showed that the desired outcomes were obtained. This demonstrated that the software module functions correctly during the examination. Additionally, the composite mean for performance efficiency was 4.62, or "Very Efficient," indicating that the response and processing times met consumers' expectations. Usability was rated as "Very Usable" with a composite mean of 4.58. This indicates that the user thought the program was user-friendly and an appropriate tool for their needs.

This indicates that it was tested for stability during the testing and determined to be usable when required. During the breakdown, it was discovered to be simple to recover from. Additionally, Security received a 4.65, or "Very Secured," rating, indicating that the system is secure, can maintain the confidentiality of the data without alteration, and may be made available as needed.

Additionally, the respondents' judgment yielded a general weighted mean of 4.60, or "Very Good". This indicates that the users thought the system to be quite satisfactory.

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Table 8. Results of Software Acceptability Test applying ISO/IEC 25010:2011

Indicators			
Characterisitics	Sub-Characterisitics	Mean	Remarks
A. Functional Suitability			
	1. functional completeness	4.63	
	2. functional correctness	4.40	
	Composite Mean	4.52	Very Functional
B. Performance Efficiency			
	1. time behavior	4.62	
	Composite Mean	4.62	Very Efficient
C. Usability			
	1. appropriateness recognizability	4.65	
	2. learnability	4.59	
	3. operability	4.56	
	4. user Interface Aesthetics	4.54	
	Composite Mean	4.58	Very Usable
D. Reliability			
	1. maturity	4.50	
	2. availability	4.67	
	3. recoverability	4.67	
	Composite Mean	4.61	Very Reliable
E. Security			
	1. confidentiality	4.63	
	2. integrity	4.69	
	3. authenticity	4.63	
	Composite Mean	4.65	Very Secured
	General Weighted Mean	4.60	Very Good

Table 9. Summary of Results of Software Acceptability Test

Indicators	
Characterisitics	Composite Means Summary
A. Functional Suitability	4.52
B. Performance Efficiency	4.62
D. Usability	4.58
E. Reliability	4.61
F. Security	4.65
General Arithmetic Mean	**4.60**

Summary

By building a bidirectional communication device that can understand both FSL gestures and speech and translate this information to text/audio and text output, respectively, using artificial intelligence, this study aimed to facilitate effective communication between signers and non-signers. This study's FSL translation device had special capabilities like real-time FSL gesture and speech detection, FSL motions for simple words converted into text and audio output, and speech converted into text output.

Twenty carefully chosen Filipino words were used in the device's training to improve the recognition and translation capabilities. The device's identification and translation capabilities passed individual testing with flying colors. The camera and microphone were tested as part of the hardware. The results of the hardware tests showed that both the FSL gestures and the verbal input could be successfully detected and recognized. On the other hand,

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the software testing included the translation of speech input to text output also displayed on the LCD, as well as the translation of FSL motions to audio output and the translation of FSL gestures to text output through the display module.

Conclusion

Based on the design and evaluation of the system, the researcher arrived at the following conclusions:

The system that can detect hand gestures based on FSL through a camera and translate the detected FSL hand gestures into Filipino text through a display module was designed and developed. The device's identification and translation capabilities passed individual testing with outstanding results. The camera and microphone were tested as part of the hardware. The results of the hardware tests showed that both the FSL gestures and the verbal input could be successfully detected and recognized. The software testing, on the other hand, entailed converting FSL gestures to text output via the display module, FSL gestures to audio output, and vocal input to text output is also shown using the LCD.

The system that translates the detected FSL hand gestures audio through an audio output device was developed and tested. The system developed in this study's FSL translator was able to detect FSL hand gestures through the camera, translate the detected FSL hand gestures into Filipino text displayed through a display module, read out the text output into speech using an audio output device, detect Filipino speech input through the microphone, and successfully translate the text output into spoken Filipino.

The system was tested acceptable taking a result of 4.60 mean or "Very Successful" with the aid of ISO 25010:2011 standard.

Recommendations

The use of this technology in many other industries may be further enhanced by efforts to expand the number of words it can recognize.

Reduced size and a larger LCD may enhance the portability and readability of the gadget due to its design. The device could be made smaller to conserve space.

A faster processor may improve the device's performance by enabling the system to recognize hand gestures more quickly and provide results more quickly. This will speed up communication between signer and non-signer.

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