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Robotic Sign Language Tutorial Device System

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Abstract

Sign language is an essential mode of communication for the hearing-impaired community yet learning it can be challenging for beginners due to the need for consistent practice and accessible instructional tools. Traditional learning methods often rely on human instructors or static illustrations, which may not provide sufficient engagement or real-time reinforcement. To address this gap, this study aims to design and develop a Robotic Sign Language Tutorial Device using an ESP32-controlled mechanical hand equipped with servo motors and display. The device demonstrates letters and words in Filipino Sign Language (FSL), accompanied by a small LCD display that shows the corresponding text. The robotic hand with a screen provides learners with visual reinforcement, allowing them to associate hand gestures with written language. The system was evaluated for accuracy in sign formation and the clarity of text output. Results indicate that the prototype consistently produced accurate signs based on comparisons with standardized Filipino Sign Language references and enabled intuitive touchscreen navigation as evidenced by successful user task completion, supporting its effectiveness as an assistive educational tool. The Robotic Sign Language Tutorial Device thus presents a low-cost, accessible solution that can enhance independent learning and bridge communication barriers for both hearing-impaired and hearing learners.

Keywords: *sign language, robotics, education, accessibility, inclusivity.*

1.0 Introduction

Filipino Sign Language (FSL) is the main means of communication among hearing-impaired students in the Philippines and is recognized as the country's national sign language (Republic Act No. 11106, 2018; Tolentino, 2025). Unfortunately, a large number of hearing-impaired individuals face obstacles in receiving an adequate education in FSL. These obstacles include: lack of qualified instructors; insufficient materials and resources for learning FSL; and an emphasis on teaching students to verbally communicate in Filipino and/or English in the classroom (Bulatlat Contributors, 2025; Deaf Education Council, 2024). Because of these barriers, many hearing-impaired children are deprived of the opportunity to learn sign language and face the negative impact of this deprivation on their cognitive, social, and emotional growth.

Research is showing that robotic-assisted systems can positively impact student learning of Individuals with disabilities by allowing students access to consistent modelling of FSL gestures; Interactive engagement with robotic technology; and the opportunity to endlessly practice primitives (Pnevmatikos et al., 2022; Georgiev et al., 2024). In addition, gamified video-game applications of sign language have proven helpful at motivating children with hearing loss as well as improving their retention and recall of sign language through interactivity, multimedia, etc (Saman et al., 2019). As a result, these recent findings demonstrate how advancements in robotics and interactive technology can be used to address the future shortage of qualified teachers in the field of FSL while providing improved access and engagement for FSL learners.

The combination of mechatronics and robotics into the area of language education has produced devices that can faithfully replicate finger movements based on anatomical design, emulating sign language. With servo motors and tendons controlling robotic hands, many hand shapes used in FSL can be produced in exacting detail, with added functionality allowing for visual feedback via screens, thus providing a more comprehensive, multimodal educational experience for students (Rios et al., 2023; Almeida, 2023; Kumar, et al., 2020). While researchers are exploring these types of technologies for sign languages such as American Sign Language and Japanese Sign Language, there is still a clear lack of research/development in working with Filipino Sign Language, providing the opportunity for further investigation (Cruz et al., 2022; Tanchoco, 2022).

Although major advances have occurred in technology, lack of access to complete FSL instruction will still impact the Philippine educational system's ability to offer FSL services to students with hearing impairments. Many hearing-impaired students will not be able to reach their full potential due to the variations in the availability of teachers by region throughout the nation, as well as the differences in teacher-trained skills, along with the availability of instructional materials (Bulatlat Contributors, 2025; Tolentino, 2025). Due to this reason, affordable, innovative solutions must be created that will assist the human teacher, provide a consistent learning experience to students with hearing impairment, and create incentives for students with hearing impairment to participate.

The current project proposes developing a portable, tabletop animatronic hand capable of demonstrating the FSL alphabet, numbers, and common words to fill these gaps. Its interactive features, including demonstration and quiz modes, combine precise servo-driven finger movements with dual visual feedback—making learning accessible and encouraging early language development for hearing-impaired students and their families. This approach also helps address the shortage of qualified FSL teachers.

The overall goal of this project is to fill a need for accessible FSL instruction by developing an innovative, interactive robotic sign language tutor. As such, this device is designed to improve student learning outcomes through increased engagement and interaction with the tutor (robot). It will also assist educators (teachers, educators), parents (formally), and students (children/families), in teaching and learning FSL, while creating an inclusive learning environment that meets diverse cultural needs. The development of this robotic tutor will be instrumental in helping to close the substantial gap in available FSL teachers in this country—and ultimately provide equitable access to language resources for all students.

2.0 Methodology

2.1 Research Design

This study employed a Design and Development Research approach. The primary focus of the research was the design, development, implementation, and validation of a Robotic Sign Language Tutorial Device, rather than hypothesis testing or theory verification. This approach was selected because the study's objective was to create a functional assistive educational prototype and evaluate its technical performance, usability, and feasibility as a learning tool.

2.2 Participants and Sampling Technique

Participants were involved in the study solely for system validation, needs assessment, and usability evaluation, and not as the main focus of the research. Convenience sampling was employed due to the accessibility of the evaluation.

2.3 Research Instrument

The study utilized multiple research instruments appropriate to the approach. The primary instrument of the study was the robotic system itself, consisting of an animatronic hand controlled by ESP32, servo motors, and a TFT touchscreen display. A researcher-made survey questionnaire was then used to collect respondents' perceptions regarding the perceived usefulness and acceptability of a robotic FSL tutor, motivation and interest in interactive learning tools, challenges in traditional FSL instruction, and the overall performance of the robotic system.

The survey consisted of Likert-scale items and open-ended questions. It was used strictly for needs assessment and usability perception, not for measuring learning outcomes or effectiveness. Simple identification tests were used to measure participants' recognition of selected FSL letters before and after interaction with the device, as well as after a 24-hour retention period. Observational notes and rating scales were also used during system testing to document the functionality, ease of use, portability, accuracy, and reliability of the system.

2.4 Data Gathering Procedure

Data gathering was conducted in several phases. The first phase is the needs assessment phase to collect information on learning challenges, instructional gaps, and user expectations regarding a robotic sign language tutor. Responses were collected voluntarily and anonymously. The robotic device was then assembled and programmed with predefined FSL gesture datasets. An expert validator reviewed the gestures performed by the robotic hand, and servo angles were adjusted until the gestures were deemed understandable and accurate. Ten participants then underwent the educational testing phase, in which they followed a procedure. First is the pre-test, where the participants identify 5 randomly selected FSL letters using images. After this is a 15-minute guided session using Demonstration mode. Then, a post-test in which they identified signs using the Quiz mode. A follow-up test was conducted 24 hours later to test retention. The final phase is the evaluation phase, in which the participants rated the system using a five-point scale (Poor to Excellent) on functionality, accuracy, ease of use, portability, and reliability.

2.5 Data Analysis Procedure

Data analysis in this study was primarily descriptive, consistent with the research design. Survey responses were analyzed using frequencies and percentages to summarize perceptions and needs. Pre-test, post-test, and retention test results were compared descriptively to observe changes in sign recognition. Accuracy rates of the robotic hand were computed by comparing correctly performed signs against expected gestures. Evaluation responses were summarized using weighted mean percentages to identify strengths and areas for improvement.

2.6 Ethical Considerations

Ethical standards were observed throughout the study. Participation in surveys and testing was voluntary, and informed consent was obtained before data collection. No personal identifying information was collected from participants. All responses were anonymized and used solely for academic and development purposes. The robotic device posed minimal risk, as it was used only for demonstration and interaction under supervision.

3.0 Results and Discussion

This chapter presents the outcomes of the prototype development, testing, and evaluation of the Robotic Sign Language Tutorial Device. It details the physical realization of the design, the functionality of its core systems, and a discussion of its performance based on the objectives and constraints outlined. The results are analyzed to determine the success of the project and to identify areas for potential development.

Table 3.1 *Accuracy results from empirical evaluation.*

	Total Signed	Total Expected	Accuracy (%)
Numbers	9	9	100
Alphabets	13	26	50
Words/ Phrases	5	5	100
Total/ Average	27	40	67.5

Table 3.1 shows the accuracy results of the prototype based on the empirical analyses it has gone through. The table shows that the accuracy measured for the prototype is based on three types of gesture categories consisting of (1) Numbers (2) Alphabets (3) Words or phrases (expressions). Each category is compared to how many of the signs the user executed correctly and how many signs the user was expected to complete; thus arriving at the percentage of accuracy within that category.

In terms of achieving complete accuracy, the prototype has achieved perfect accuracy (100%) for both numbers and words or phrases. This data reflects that the prototype is consistent at executing simple and predefined gestures. Unfortunately, the alphabet category had the lowest accuracy at (50%), which may be due to the more complex nature of creating the gesture (more specific finger movements/hand positioning). The complexity of creating a gesture is greater in relation to the number of variables associated with an alphabet.

Overall, the prototype achieved an average accuracy of 67.5%. This concludes that, while the prototype is effective when using simpler gestures, the results indicate that further improvement is needed for the accuracy of alphabet signing. Improvements in servo alignment, movement timing and accuracy in gesture control should be performed, which would yield improved accuracy. Although the system was limited in many ways, the prototype still meets its objective. A few more enhancements of the prototype will improve its precision and dependability.

Table 3.2 *Responses from a qualitative evaluation of the robotic system.*

	Excellent	Very good	Good	Fair	Poor	Rating
Functionality	2	8	4	1	0	74.7%
Accuracy	1	6	5	3	0	66.7%
Ease of use	3	10	2	0	0	81.3%
Portability	4	7	3	1	0	78.7%
Reliability	1	5	6	2	1	64.0%

Number of respondents (n): 15

Table 3.2 presents the results of the qualitative evaluation of the robotic system. Indicates how well users perceived the quality of the Robotic System. For each category (Functionality, Accuracy, Ease of Use, Portability, & Reliability) the respondents were given a five-point scale, with 1 being "poor" and 5 being "excellent". Each criterion was then computed to determine the overall score of the system.

Ease of use received the highest mark from all categories, with a rating of 81.3%. It indicates that a large majority of respondents felt that the system was fairly easy to learn and use. Portability with 78.7% of scores demonstrates that a significant number of participants experienced, for example, it being easy to carry. Functionality scored 74.7%, demonstrating that the system can accomplish the tasks assigned properly at ease.

Accuracy (66.7%) and Reliability (64.0%) scored the lowest, indicating the system's areas for improvement such as gesture recognition precision and consistent operation of the system. Overall, the evaluation shows satisfactory performance results with room for further optimization.

4.0 Conclusion

This study demonstrates how robotics can facilitate inclusive language learning for both hearing and hearing-impaired individuals. The project uses a servo-driven mechanism along with a touchscreen interface that is attached to a robotic hand modeled after human anatomy. It advances the fields of assistive and educational robotics by developing and designing an interactive robotic sign language tutorial device tailored to Filipino sign language (FSL) that is inexpensive yet effective. It bridges the gap caused by limited access to educational FSL materials, especially in underprivileged areas in the Philippines.

The robotic tutor serves as an effective supplementary learning device that supports independent practice, visual reinforcement, and learner engagement from an educational standpoint. The robotic tutor's dual-mode design allows user to learn different FSL signs in demonstration mode and test their understanding in quiz mode, aligning with inclusive education principles and the goals of Republic Act No. 11106. Another thing that further enhances its suitability for schools, homes, and community-based learning is its portability and affordability.

The study highlights the role of assistive robotics as a complement to human instruction in terms of practice. Overall, this project provides a foundation for future research and demonstrates the potential of robotics to promote accessible and inclusive FSL education.

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