Sign Math: Innovative E-Learning System for Deaf and Mute Students Using Machine Learning

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***Abstract*— Mathematics education for hearing-impaired students in Sri Lanka faces significant challenges due to language barriers and limited literacy. Most deaf children rely on sign language for communication, making it difficult to connect written words and signs with the Sinhala language. This research introduces SignMath, a web-based application designed to enhance mathematical learning for hearing-impaired students in primary schools. The platform integrates sign language, visual aids, and interactive features to improve shape comprehension, number recognition, and basic arithmetic operations. The system includes real-time sign recognition, interactive lessons, and assessments to evaluate students' progress. Additionally, SignMath incorporates machine learning algorithms to improve accuracy in sign detection and user experience. This paper discusses the research problems, objectives, methodology, results, and future implications of implementing SignMath in primary education.**

Keywords— Deaf education, Sign language, Interactive Learning, Mathematics, Visual Aids, E-learning, Machine Learning.

I. Introduction (*Heading 1*)

Mathematics is a fundamental subject for all students, but hearing-impaired children in Sri Lanka face considerable difficulties in learning mathematical concepts due to the lack of inclusive learning tools and language barriers. The majority of deaf students rely on Sri Lankan Sign Language (SLSL) for communication, making it challenging for them to understand mathematical concepts presented in written Sinhala. Many deaf students struggle with comprehension and often drop out due to difficulties in subjects like mathematics.

SignMath aims to bridge this gap by providing an interactive learning environment that incorporates sign language, visual aids, and assessment tools. The system employs artificial intelligence (AI) and machine learning (ML) to improve real-time sign detection, making learning more effective. The inclusion of gamified elements, quizzes, and interactive lessons ensures that students remain motivated and engaged in their learning journey.

II. LITERATURE REVIEW

A. Challenges in Deaf Education Existing studies highlight the challenges deaf students face in traditional learning environments. Most available mathematical e-learning platforms do not support sign language integration, limiting their accessibility to hearing-impaired students. Research on e-learning tools for special education suggests that visual and interactive methods significantly enhance students' understanding and retention of concepts. However, current solutions lack Sinhala-based sign language support, automated quizzes, and real-time sign recognition.

B. AI and Machine Learning in Education This research contributes by developing a Sinhala-based mathematical learning platform integrating sign language and advanced AI-based recognition for interactive assessments. Studies emphasize gesture recognition technology and deep learning models for enhanced sign language interpretation, ensuring a personalized and inclusive learning experience for deaf students.

III. METHODOLOGY

A. Data Collection Data is gathered from primary sources, including The School for the Deaf (Ratmalana), National Institute of Education (Maharagama), and special education centers. Sign language datasets for numbers, shapes, and arithmetic operations are collected and annotated.

B. System Development The platform is designed using React for the frontend, Firebase for database management, and TensorFlow for AI-based sign recognition. Key functionalities include:

- Interactive lessons using sign language videos and Sinhala text.
- AI-based real-time sign recognition to validate student responses.
- A quiz module for assessing students' understanding.
- Machine learning models for improving gesture recognition accuracy.

C. Training the AI Model The model is trained on a dataset comprising hand signs for numbers and arithmetic symbols using OpenCV for image processing and Convolutional Neural Networks (CNNs) for classification. The dataset consists of labeled images of different mathematical signs and gestures, collected from video recordings of sign language experts. Image preprocessing techniques such as noise reduction, background subtraction, and edge detection are applied to enhance image clarity before feeding them into the model.

To improve classification accuracy, data augmentation techniques such as rotation, scaling, and flipping are used to create variations in the dataset. The CNN model is designed with multiple convolutional layers, max-pooling layers, and fully connected layers to extract meaningful features from hand gestures. The activation function used is ReLU, and the final classification layer utilizes softmax for multi-class predictions.

Training is performed on Google Colab using TensorFlow and Keras frameworks, leveraging GPU acceleration for faster computation. The model is trained using a categorical cross-entropy loss function and optimized with the Adam optimizer. The training process includes validation and testing phases, where the model's performance is evaluated using accuracy, precision, recall, and F1-score. Hyperparameter tuning is conducted to optimize learning rates, batch sizes, and the number of epochs to achieve the best recognition accuracy. The final trained model is deployed within the SignMath platform for real-time sign recognition and feedback.

D. Evaluation & Testing The system is tested with teachers and students to measure usability, accuracy, and learning effectiveness. The evaluation process follows a structured approach with both qualitative and quantitative assessments.

1. **Student Engagement Levels** - Student participation and engagement are measured through observation, user interaction logs, and feedback surveys. Metrics such as time spent on the platform, number of completed lessons, and quiz attempts are analyzed to assess motivation and usability.
2. **Accuracy of Sign Detection** - The AI model's sign recognition accuracy is evaluated using test datasets collected from various sign language users. Performance is measured based on precision, recall, and F1-score, ensuring high reliability in gesture interpretation.
3. **Improvement in Mathematical Comprehension** - Pre-test and post-test assessments are conducted to analyze the impact of SignMath on students' mathematical learning. Statistical methods, including paired t-tests, are used to compare learning outcomes before and after using the platform.
4. **Performance Comparison of Different Machine Learning Models** - Multiple AI models, including CNN, RNN, and hybrid approaches, are tested to determine the most efficient model for sign recognition. Model performance is compared based on computational efficiency, recognition speed, and classification accuracy to ensure optimal results.

Additionally, real-time usability tests with teachers and students provide valuable insights into improving the system's design, functionality, and accessibility. Feedback from educators is incorporated to enhance the curriculum integration and instructional effectiveness of SignMath.

IV. RESULT AND DISCUSSION

A. Key Findings Preliminary results from pilot testing indicate a high engagement level among students, with a 70% increase in concept retention compared to traditional teaching methods. The AI model for sign recognition achieved an accuracy of 96.2% in identifying mathematical signs and numbers.

Additional insights from pilot testing revealed that students demonstrated a higher level of confidence in mathematical problem-solving after using SignMath. The interactive lessons and real-time feedback mechanisms significantly contributed to increased motivation and sustained interest in learning.

Teachers reported that the system improved classroom engagement, allowing for more efficient instruction and reducing the communication barriers between students and educators. The platform's AI-based sign recognition enabled instant validation of student inputs, reducing delays in comprehension and reinforcing learning concepts effectively.

Furthermore, quiz evaluations and post-learning assessments showed measurable improvements, with a 40% boost in problem-solving accuracy among students who actively participated in SignMath sessions. Long-term analysis suggests that incorporating adaptive learning mechanisms and additional sign recognition capabilities could further enhance the effectiveness of the platform in deaf education.Additionally, real-time usability tests with teachers and students provide valuable insights into improving the system's design, functionality, and accessibility. Feedback from educators is incorporated to enhance the curriculum integration and instructional effectiveness of SignMath.

B. Observations

- Students showed improved interaction and better retention of mathematical concepts.
- Teachers found the system useful in explaining abstract mathematical ideas.
- The AI model effectively recognized hand gestures in real-time, enabling instant feedback.
- Quiz evaluations revealed a 40% improvement in student performance over a three-month period.
- Comparison with traditional teaching methods showed enhanced comprehension and higher accuracy in responses.

The pilot testing results demonstrate the efficacy of integrating sign language and machine learning into mathematics education for hearing-impaired students. The interactive nature of the platform keeps students engaged while ensuring they receive accurate, real-time feedback, enhancing their learning experience.

a) Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation “Fig. 1”, even at the beginning of a sentence.

TABLE I. DATASET OVERVIEW

Dataset Type	***Number of Samples***	***Preprocessing Techniques***	***Sign Categories***
Hand signs for numbers	5000	Noise reduction, Edge detection	Numbers (0-9)
Arithmetic symbols	2000	Scaling, Rotation	+, -, *, /
Basic shapes	1000	Background subtraction	Square, Circle, Triangle

Fig. 1. Dataset overview for sign language recognition.

TABLE II. MODEL PERFORMANCE EVALUATION

Sign category	***Accuracy (%)***	***Precision (%)***	***Recall (%)***	***F1-Score (%)***
Numbers (0-9)	96.5	95.8	97.2	96.5
Arithmetic symbols	94.3	93.7	95.0	94.3
Basic shapes	97.1	96.3	97.8	97.0

Fig. 2. Model performance evaluation for sign language recognition.

TABLE III. STUDENT PERFORMANCE COMPARISON

Dataset Type	***Before SignMath***	***After SignMath***	***Improvement***
Concept retention (%)	50	70	40
Average quiz score (%)	60	84	40

Fig. 3. Comparison of student performance before and after using SignMath

V. CONCLUTION AND FUTURE WORK

A. Conclusion This research successfully developed SignMath, an innovative interactive learning environment tailored for hearing-impaired students in Sri Lanka. The system’s integration of sign language, AI-based sign recognition, and interactive quizzes significantly enhances mathematical learning outcomes. The positive feedback from teachers and students highlights the potential of SignMath to improve student engagement, retention, and mathematical comprehension.

B. Future Work

- Expanding the dataset to include more complex mathematical concepts.
- Implementing a mobile version of the platform for wider accessibility.
- Integrating speech-to-sign translation for better teacher-student communication.
- Partnering with government educational institutions to incorporate SignMath into the national curriculum.
- Enhancing the machine learning model with reinforcement learning to improve sign detection accuracy.
- Developing a personalized learning experience using AI-driven adaptive learning techniques.

By refining SignMath, we aim to provide a comprehensive and inclusive mathematical learning experience for hearing-impaired students, ensuring equal opportunities for quality education.

ACKNOWLEDGMENT

We extend our gratitude to The School for the Deaf (Ratmalana), National Institute of Education (Maharagama), and special education teachers who supported data collection and testing. Special thanks to our supervisors and mentors for their valuable insights and guidance in this research. Additionally, we appreciate the support of our research team, whose feedback was instrumental in evaluating the effectiveness of the system.

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