



Assistive e-learning technologies for special needs education with mobile sign language applications and deep learning-based recognition

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Abstract

This study explores the integration of assistive e-learning technologies designed to enhance educational accessibility for Deaf and hard-of-hearing learners. Specifically, it examines three innovative systems: (1) a mobile sign language application based on the Kitabah method for teaching Quranic literacy, (2) a deep learning-based sign language recognition (SLR) system using ResNet-18 for recognizing Arabic Hijaiyyah letters, and (3) a mobile sign language dictionary aimed at improving communication and literacy for Deaf learners. The Kitabah-based mobile application integrates Arabic script with sign language gestures, providing an interactive learning experience. A deep learning model (ResNet-18) is employed for sign language recognition (SLR), achieving 98% accuracy. The mobile sign language dictionary offers gesture-based learning content with usability testing yielding a System Usability Scale (SUS) score of 78.06, indicating effective user interaction. Results from user testing indicate significant improvements in learning outcomes: 85% of participants reported increased comfort with digital learning tools, 82.5% rated the system effective for learning sign language, and 90% reported improved recognition of sign words. The study demonstrates the potential of assistive e-learning technologies to create adaptive and accessible learning environments for students with special needs. This research contributes to the development of inclusive, AI-powered e-learning solutions that enhance the learning experience for Deaf and hard-of-hearing learners.

Keywords

Deep learning, Sign language recognition, Assistive learning, Special needs education, Mobile learning, Inclusive education

Introduction

People with hearing and speech disabilities (PHSD), often referred to as deaf and hard-of-hearing individuals, face significant educational challenges due to the predominance of auditory-verbal teaching methods in traditional educational systems. In the context

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of Quranic education, these challenges are even more pronounced. The Quranic literacy of PHSD individuals remains underdeveloped, not only due to communication barriers but also because of the lack of tailored pedagogical tools and resources. The Quranic curriculum, which traditionally relies heavily on auditory methods of recitation, poses an especially complex challenge for PHSD learners who primarily rely on visual learning [1].

Traditionally, Quranic literacy has been taught through verbal recitation, which disadvantages PHSD learners. For these learners, education that incorporates visual-motor learning methods is critical. However, current learning tools fail to sufficiently integrate these visual methodologies, often limiting their access to accurate and comprehensive Quranic education. The integration of visual cues, gestures, and sign language has proven beneficial in other educational contexts for PHSD learners, but in Quranic education, this approach remains underexplored and underdeveloped [2], [3]. As a result, PHSD learners remain deprived of inclusive tools that could make Quranic education accessible.

While several studies and efforts have focused on integrating sign language recognition systems, most of them have not addressed the unique challenges posed by Quranic literacy, which includes specific orthographic features and recitation rules. Existing sign language recognition (SLR) technologies primarily focus on American Sign Language (ASL) [4] or Bahasa Isyarat Indonesia (BISINDO) [5], [6], which are designed for conversational communication. These systems typically emphasize the recognition of static signs. They are not tailored to the specific needs of religious education, particularly Quranic instruction, which requires a much more nuanced approach to sign language representation.

The Kitabah method, developed by the Indonesian Ministry of Religious Affairs, represents a significant advancement in Quranic education [7]. This method maps Arabic letters, diacritics, and punctuation to visual hand gestures, supporting a visual-motor learning model that aligns with the needs of PHSD learners. Although the Kitabah method has proven effective in classroom settings, its implementation in digital or scalable platforms is limited [8]. The absence of mobile applications or AI-driven recognition tools designed around the Kitabah method leaves a gap in accessible Quranic education for PHSD learners.

Simultaneously, recent advances in artificial intelligence (AI) and deep learning have demonstrated strong potential for sign language recognition. These technologies, including advanced learning models such as convolutional neural networks (CNNs) and transfer learning, have been shown to achieve high accuracy in static and dynamic sign language gesture recognition [9], [10]. However, the application of deep learning-based SLR to Quranic education, particularly for recognizing Arabic script and associated gestures, remains underexplored in the current literature. These gaps in both pedagogical tools and technical applications have resulted in the underrepresentation of PHSD learners in Quranic education.

The need for a solution that integrates assistive learning technologies for deaf and hard-of-hearing learners is evident. Recent developments in mobile applications for sign language learning have demonstrated the potential to overcome communication and accessibility barriers. Mobile applications offer an interactive, portable alternative to traditional learning resources, such as printed or video-based sign language dictionaries [11]. Moreover, by integrating AI-powered gesture recognition, these mobile platforms can provide real-time feedback, further enhancing their utility as learning tools for PHSD learners.

One promising development is the integration of deep learning-based SLR with mobile applications that use sign language gestures to teach Quranic literacy. A deep learning-based system could facilitate the recognition of static Arabic letters in sign language, thereby enhancing the accuracy and adaptability of learning systems for PHSD learners. By employing a model such as ResNet-18 with transfer learning, such a system can achieve high recognition accuracy for Arabic script, which is crucial for teaching Quranic literacy [12]. This research builds on this potential, combining the Kitabah method with deep learning-based sign language recognition to provide a more inclusive educational experience for PHSD learners.

In addition to enhancing Quranic literacy, there is a clear need for mobile sign language dictionaries that improve communication and literacy for deaf learners. Such dictionaries can facilitate not only Quranic education but also broader communication across various domains. The integration of gesture recognition, video demonstrations, and interactive feedback in these dictionaries can serve as powerful tools to bridge the communication gap faced by deaf and hard-of-hearing individuals [13]. While some sign language apps exist, they often fail to integrate Quranic literacy or address the specialized needs of PHSD learners, further underscoring the need for more targeted solutions.

The combination of mobile sign language applications, deep learning-based SLR, and comprehensive dictionaries could significantly improve the learning outcomes for PHSD students. Such a multifaceted approach provides PHSD learners with the opportunity not only to learn Quranic literacy but also to engage in broader communication and learning across various domains. Advances in mobile technology and AI have enabled such integrated systems, offering new avenues to empower individuals with PHSD [14].

Furthermore, these technological advancements hold promise for improving educational outcomes for PHSD learners. Previous studies have shown that personalized and accessible learning environments especially those that provide visual and interactive learning experiences enhance learner engagement and retention [15], [16]. By providing a customized learning journey, these technologies can support the diverse learning needs of PHSD students, helping them overcome barriers to education that traditional methods cannot.

However, despite these promising developments, there remains a lack of comprehensive studies that integrate the Kitabah method, sign language recognition, and mobile learning tools to provide an inclusive educational framework for Quranic literacy. This gap in both theoretical and applied research presents a significant opportunity for innovation, particularly for AI-powered learning technologies designed to meet the specific needs of deaf and hard-of-hearing learners. Therefore, this study aims to bridge these gaps by developing and evaluating an integrated mobile learning platform that combines the Kitabah method with deep learning-based sign language recognition for teaching Quranic literacy.

The primary objective of this research is to develop an inclusive and adaptive mobile learning platform that integrates the Kitabah method with AI-powered sign-language recognition to enhance Quranic literacy among PHSD learners. Specifically, this study aims to: (1) Design and implement a mobile application based on the Kitabah method for teaching Quranic literacy, (2) Develop a deep learning-based sign language recognition system to recognize Arabic Hijaiah letters accurately, (3) Evaluate the usability and effectiveness of the integrated platform through user testing, and (4) Assess the impact of the developed system on learning outcomes, communication, and literacy among deaf and hard-of-hearing learners.

This study employs a mixed-method approach that integrates both software development and machine learning techniques. The first part of the methodology involves designing and developing a mobile application based on the Kitabah method, with a focus on functionality, usability, and accessibility. The second part of the methodology involves building and training a deep learning model for sign language recognition using a dataset of Arabic Hijaiah letters. The system's effectiveness will be evaluated through usability testing using the System Usability Scale (SUS) and user feedback. At the same time, the model's performance will be assessed using standard metrics, including accuracy, precision, and recall.

Method

This study employs a multi-phase approach that integrates two distinct components to improve educational accessibility for deaf and hard-of-hearing learners. The first component focuses on developing a Kitabah-based mobile learning application to teach Quranic literacy. The second component centers around the design and evaluation of a deep learning-based SLR system for recognizing static Arabic gestures corresponding to Quranic letters. In addition to these two components, a third initiative a mobile sign language dictionary was developed to enhance communication and literacy among the Deaf and mute communities. These components, while developed independently, work synergistically to achieve the overarching goal of improving educational accessibility for deaf and hard-of-hearing learners.

Materials and tools

The arabic hijaiyah sign language dataset, comprising 7,856 images of 31 distinct Arabic sign language gestures (ArSLA), was used to train a deep learning-based sign language recognition model. This dataset ensures a diverse range of hand shapes, lighting conditions, and skin tones, enabling the model to generalize effectively across different scenarios. Such diversity is crucial for accurate gesture recognition, a key aspect of the study.

In the mobile learning application, the Kitabah method was employed to develop visual sign language content to support Quranic literacy. This method, issued by the Indonesian Ministry of Religious Affairs, maps Arabic letters, diacritics, and punctuation to visual hand gestures resembling the written form of Arabic. The mobile application integrates 32 Arabic letters, including diacritical marks and punctuation, each linked to a corresponding gesture video. These videos are an integral part of the app, providing users with visual and motoric cues to reinforce their learning [17]. This interactive approach ensures that users can associate each Arabic letter and symbol with its corresponding sign language visual representation.

The Android Studio integrated development environment (IDE) was used for developing the mobile learning application. Java was selected as the primary programming language for developing the application to ensure compatibility with Android devices running version 5.0 or higher [18]. The app features essential functions, such as interactive gesture videos and quizzes, to support the acquisition of Quranic literacy. The system design followed a waterfall process, as illustrated in Figure 1, which outlines the step-by-step development from needs analysis through maintenance. This structured approach ensures that the app remains user-friendly and accessible to deaf learners [19].

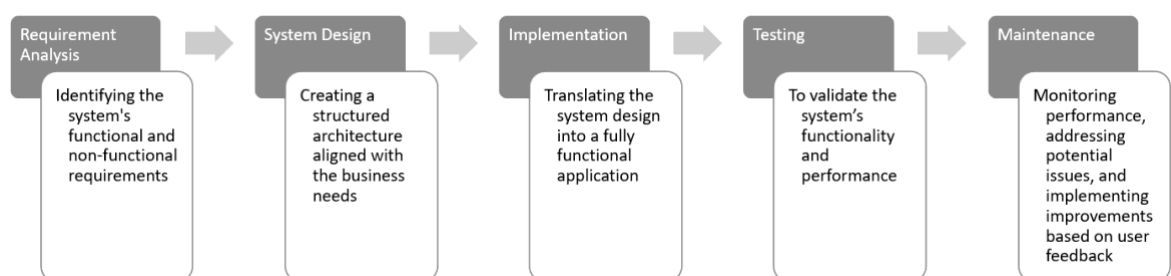


Figure 1. Waterfall development process for the quranic sign language mobile learning application

For the deep learning-based sign language recognition system, the TensorFlow and Keras frameworks were used to build the model. The model architecture is based on ResNet-18, a well-established deep learning architecture known for its efficiency in image classification. The ResNet-18 model was selected for its ability to maintain high performance while being computationally efficient, an important consideration when working with large image datasets. A transfer learning approach was employed, in which pre-trained ImageNet weights were used to initialize the model, and the final classification layer was adapted to classify the 31 Arabic Hijaiyyah gestures [20]. This

method enabled the model to leverage knowledge from large-scale datasets, such as ImageNet, thereby improving its generalization for sign language recognition.

The mobile application was tested on multiple Android devices with Android 5.0 or later to ensure accessibility to a wide range of users. For the deep learning model, a GPU-enabled server was used to expedite training, which is critical for processing the large image dataset and optimizing the model [21]. This hardware setup enabled efficient training of the ResNet-18 model, allowing for rapid iteration and fine-tuning.

Approach I- Kitabah-based mobile learning application

The development of the mobile application in this study follows the Kitabah method issued by the Indonesian Ministry of Religious Affairs. This method maps Arabic letters, diacritics, and punctuation marks to corresponding visual hand gestures, offering an interactive, visual approach to learning the Arabic script. The Kitabah method's core idea is to use gestures that closely resemble the written Arabic characters, creating a more accessible and engaging way for Deaf and hard-of-hearing learners to master Quranic literacy [22]. This approach not only aids learning but also supports better understanding and retention of Arabic characters through visual-motor learning techniques.

The mobile application development process adhered to a structured waterfall model (Figure 1), guiding the project from the initial needs analysis through to the final maintenance phase. This model was chosen for its clarity and step-by-step approach, ensuring all phases were completed before moving on to the next. The process began by identifying the learners' needs and the application's functional requirements.

In the needs analysis phase, functional requirements were consolidated around three primary learner-facing capabilities: (1) the ability to display 32 Arabic letters with their corresponding sign language gestures, (2) the inclusion of curated gesture videos for each letter to reinforce learning, and (3) interactive quizzes designed to test the learner's knowledge and provide immediate feedback. These features aim to enhance the learning process by providing both visual and motor cues that support memorization and recognition of Arabic letters. Additionally, non-functional requirements focused on ensuring the application's visual accessibility, Android device compatibility, and consistent navigation to provide a smooth, intuitive experience. Table 1 outlines the functional and non-functional requirements and provides further details on the design specifications.

The system design phase involved creating Unified Modeling Language (UML) diagrams to ensure that the app's learning flow was both simple and accessible. Use-case and activity diagrams were developed to represent user interactions and the system's internal logic. These diagrams visually captured how learners would navigate through the app and interact with its core features. Figure 2 illustrates the use case for the Kitabah application, detailing the user journey from the main menu through both the

“Learn Letters” and “Interactive Quiz” modules, ensuring that all interactions were logically structured to facilitate easy use and engagement.

Table 1. Functional and non-functional requirements for the Kitabah Application

Requirement Type	Requirement Description	Purpose
Functional	Display 32 Hijaiyyah letters with sign gestures	Enables learners to recognize each letter visually
Functional	Playback of gesture videos for each letter	Reinforces learning through visual cues
Functional	Interactive quizzes to test knowledge	Provides formative feedback to learners
Non-Functional	High contrast, large fonts, clear layout	Supports learners with visual or cognitive challenges
Non-Functional	Android device compatibility (Android 5.0+)	Ensures broad usability on commonly available devices

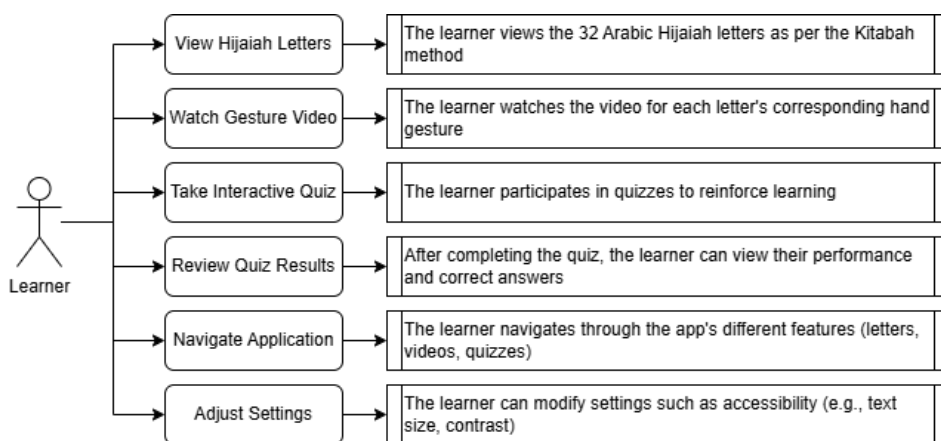


Figure 2. Use case diagram of user navigation in the Kitabah App

The mobile application was implemented using Android Studio with Java, ensuring compatibility with Android devices running version 5.0 or higher. The design focused heavily on accessibility, using high contrast and large font sizes to cater to learners with visual or cognitive challenges. The learn letters module included a Hijaiyyah keyboard, an input field, and a gesture-video player linked to the Kitabah assets. The Quiz Module was designed to present image-based items with immediate feedback, offering users an interactive way to test their knowledge of the letters and reinforce learning.

To validate the mobile application’s functionality, black-box testing was conducted across key user flows to ensure all core features worked as expected. A verification matrix was used to organize the testing scenarios and expected outcomes, ensuring thorough coverage of all functionality before final implementation. Table 2 presents the black-box test matrix for core flows, which includes scenarios such as launching the app, selecting “Learn Letters,” watching a gesture video, and answering quiz questions. The results from this testing confirmed that all major components of the application passed the verification checks, ensuring the app was ready for user evaluation.

This systematic approach to developing and testing the Kitabah-based mobile learning application ensures that the end product is not only functional but also optimized for

accessibility and usability, making it a reliable tool for teaching Quranic literacy to Deaf and hard-of-hearing learners.

Table 2. Black-box test matrix for core flows

Test Case ID	Test Scenario	Expected Outcome	Status
TC-01	Start the app and view the main menu	The main menu loads, and options for Learn Letters are visible	Passed
TC-02	Select “Learn Letters”	The app displays 32 Hijaiyyah letters and corresponding gesture videos	Passed
TC-03	Watch a gesture video	The selected video plays without errors	Passed
TC-04	Take an interactive quiz	The quiz interface loads, and questions appear	Passed
TC-05	Answer a quiz question	After selecting an answer, the app displays correct/incorrect feedback and progresses	Passed
TC-06	Review quiz results	The app shows the total score and provides feedback on correct and incorrect answers	Passed
TC-07	Adjust accessibility settings	The settings page opens, and changes (font size, contrast) apply correctly	Passed

Approach II- Deep-learning sign language recognition (SLR)

This approach focuses on developing a deep learning-based Sign Language Recognition (SLR) model specifically designed to recognize static Arabic letters. The model is intended to serve as the foundation for future recognition tasks, particularly for Quranic recitation, which will involve dynamic gestures. The methodology for building the SLR model follows a systematic approach: dataset preparation, preprocessing, model architecture selection, training, and evaluation.

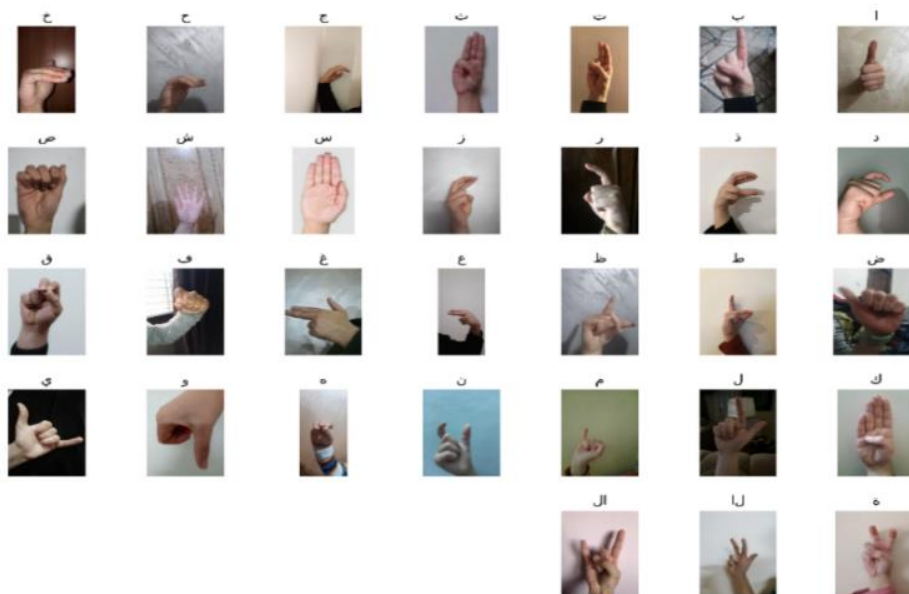


Figure 3. Representative samples from the Arabic sign language dataset.

The Arabic sign language dataset used to train the SLR model consists of 7,856 RGB images, each representing one of the 31 distinct static hand gestures corresponding to the Arabic Sign Language Alphabet (ArSLA). These images were sourced from various platforms, including educational institutions serving deaf students, sign language textbooks, and video-based resources [23]. The dataset was designed to reflect a

diverse set of hand shapes, skin tones, and lighting conditions, which were crucial in ensuring that the model could generalize well across various real-world scenarios. The dataset's diversity is essential for training a robust model that can accurately recognize Arabic gestures across diverse environmental settings.

Figure 3 illustrates representative samples from the arabic sign language dataset, highlighting the variations in hand shapes, skin tones, and background configurations. These images help ensure the model learns the distinctive features of each gesture despite differences in input conditions, such as lighting or hand position.

Before training, the images underwent several preprocessing steps to prepare them for the deep learning model. Each image was resized to a uniform 224×224 pixels, ensuring consistent input size across the entire dataset. This step ensures that the model can process each image with the same level of detail.

To improve model robustness and reduce overfitting, the images were normalized by scaling the pixel values to a standard range. Additionally, data augmentation techniques such as random rotations and horizontal flips were applied to introduce variations in the images [24]. These augmentations were specifically chosen to simulate different orientations of hand gestures, further increasing the diversity of training data and helping the model generalize better to unseen instances of sign language gestures.

For the SLR model, we selected the ResNet-18 architecture, a deep convolutional neural network known for its effectiveness in image classification. ResNet-18 was chosen for its computational efficiency, ability to handle deep architectures via residual learning, and high performance in image recognition tasks.

The model was initialized using pre-trained weights from ImageNet, a well-established large-scale image dataset. This transfer learning technique enabled the model to leverage knowledge from general image classification tasks, thereby improving performance and accelerating training. After initializing with ImageNet weights, the model's final classification layer was modified to output 31 classes, corresponding to the 31 Arabic Hijaiyyah gestures.

The ResNet-18 model was trained using a transfer learning approach, with pre-trained weights fine-tuned for the Arabic sign language dataset. The Adam optimizer was used to minimize the loss function, with an initial learning rate of 0.001 to ensure stable convergence. The model was trained for 30 epochs with a batch size of 32.

To prevent overfitting, early stopping was used during training. This technique monitors the model's validation performance. It halts training after a set number of epochs if no improvement is observed, to avoid unnecessary computations and potential overfitting to the training data. This ensured that the model achieved optimal performance without being overly tailored to the training set.

The performance of the SLR model was evaluated using several key metrics, including accuracy, precision, recall, and F1-score [25]. These metrics are crucial for evaluating the

model's ability to recognize Arabic sign language gestures accurately. Accuracy measures the overall percentage of correct predictions, while precision and recall evaluate how well the model identifies positive instances and avoids false negatives. The F1-score, which is the harmonic mean of precision and recall, provides a balanced measure of the model's performance across both dimensions.

The evaluation metrics are crucial for understanding the model's ability to generalize across different hand gestures and real-world conditions, ensuring it can be reliably used for educational purposes and other practical applications in the future.

Approach III- Mobile sign language dictionary

This approach focuses on developing a mobile sign language dictionary to enhance communication and literacy for Deaf and mute individuals. The methodology comprises several key steps: identifying the application requirements, followed by data collection, design, development, and thorough testing to ensure the application meets the needs of the target users.

The first step in developing the mobile sign language dictionary was conducting a requirement analysis. The application needed to address several core functions: gesture recognition, a comprehensive sign language dictionary, multimedia support (including images, text, and videos), and user accessibility. To ensure the application effectively met users' needs, consultations were held with sign language experts, special education teachers, and potential users, including Deaf individuals and educators [26]. This collaborative process ensured that the application would be comprehensive and user-friendly. The primary goal was to create a tool that would not only aid in sign language learning but also serve as a practical communication aid for individuals who are deaf or mute.

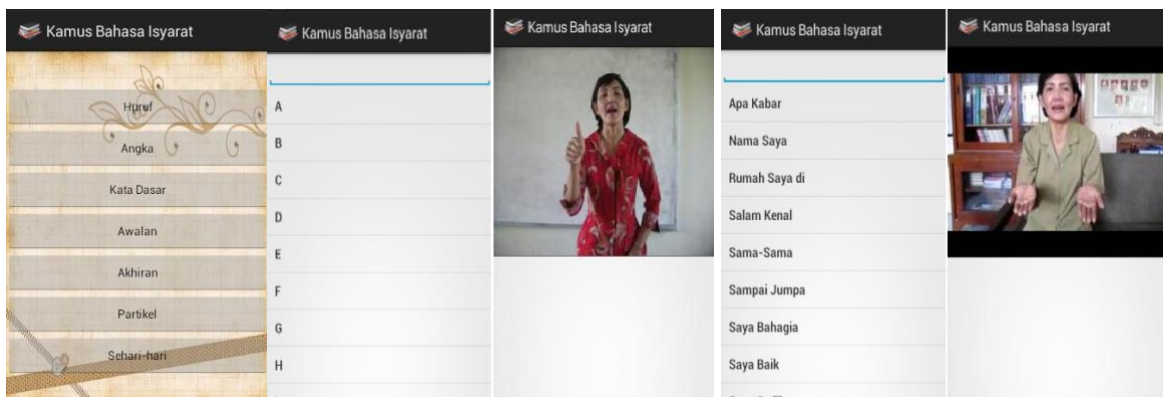


Figure 4. Main interface of the mobile sign language dictionary application

Figure 4 illustrates the main interface of the mobile sign language dictionary application, showing how the core elements, such as the dictionary and video demonstrations, are presented in a user-friendly manner. The interface was designed to be intuitive, with large buttons and clear text for easy navigation. Interactive elements were also included to allow users to practice and learn gestures through engaging, hands-on experiences.

The next phase involved collecting sign language data to populate the dictionary with accurate, comprehensive content. Data were collected from multiple sources, including educational institutions specializing in teaching sign language to deaf students, video resources, and consultations with sign language experts. The dataset includes not only alphabetic gestures but also commonly used words and phrases, ensuring that the dictionary offers a wide range of useful vocabulary for daily communication. This comprehensive data collection process aimed to ensure that the dictionary could serve as both an educational tool and a practical resource for everyday use.

In this phase, ethical considerations were also prioritized, ensuring that the content was accurate and culturally appropriate. All data collection was conducted with participants' consent, and the application was designed to respect and reflect the diversity of sign languages used across communities.

Once the requirements and data were established, the mobile application design and development commenced. The application was developed using Android Studio, with Kotlin/Java employed as the programming languages to ensure the app's compatibility with a broad range of Android devices. The user interface (UI) was carefully designed to be intuitive and straightforward, enabling users to easily navigate the dictionary and find the sign language gestures they need.

The design focused on accessibility, ensuring that users with varying degrees of visual or motor abilities could effectively use the application. This included incorporating high contrast visuals, large buttons, and text-based descriptions for each sign gesture. Interactive elements were integrated to allow users to view and practice gestures via embedded video demonstrations. These videos played a crucial role in supporting the learning process by providing visual cues that aligned with the text and images.

Additionally, firebase was utilized for cloud storage and database management, ensuring that the application's content could be easily updated and that users had access to an up-to-date database of sign language entries. The use of cloud technology also enabled scalability, allowing the database to be expanded with new signs and languages in future updates.

After development, the application underwent extensive testing to ensure its functionality, usability, and accuracy. This phase included both unit and integration testing to verify that all components of the application, including the search feature, video playback, and database retrieval, worked seamlessly. Additionally, user acceptance testing was conducted with a group of deaf and hard-of-hearing users, sign language experts, and educators. These testers provided valuable feedback on the application's usability and content accuracy.

The feedback gathered during this testing phase led to several revisions to improve the overall user experience. For instance, adjustments were made to the user interface to enhance its intuitiveness, and bug fixes were implemented to improve the app's performance. The iterative testing and revision process ensured that the final version of

the application met the expectations of both the target users and sign language experts.

The problem of enhancing educational accessibility and communication for deaf and hard-of-hearing learners was addressed through the integration of three innovative approaches: the development of a Kitabah-based mobile learning application for Quranic literacy, the design of a deep learning-based sign language recognition (SLR) system, and the creation of a mobile sign language dictionary. Each component was developed systematically, with a focus on user accessibility, educational effectiveness, and technological innovation. The Kitabah-based application bridges the gap between visual learning and Quranic education, while the SLR model offers a robust tool for recognizing Arabic sign language gestures. The sign language dictionary further enhances communication and literacy by providing a comprehensive and interactive resource for deaf and mute individuals. By combining these technologies, the study created a multifaceted solution that addresses the specific needs of Deaf and hard-of-hearing learners, offering them a comprehensive, adaptive, and accessible learning environment. The methods outlined here ensure that the approach is both scalable and replicable, with the potential to further develop and refine it to meet the educational needs of this community.

Results

The results of this study are presented across three main components, each aimed at enhancing accessibility and learning outcomes for deaf and hard-of-hearing learners. The first component, the Kitabah-based mobile learning application, was designed to integrate Arabic script with sign language gestures to support Quranic literacy. The second component focused on the development of a deep learning-based sign language recognition (SLR) model, which aimed to recognize Arabic Hijaiah gestures. The third component, a mobile sign language dictionary, was developed to improve communication and literacy for deaf learners by incorporating multimedia content. Each component underwent comprehensive testing to evaluate its functionality and usability, with results showing promising outcomes across both usability and educational effectiveness. The following subsections provide more detailed results from each component of the research.

Kitabah-based mobile learning application

The Kitabah-based mobile learning application was designed to enhance Quranic literacy among deaf and hard-of-hearing learners by providing an accessible, interactive learning platform. This mobile application, as shown in [Figure 5](#), aims to integrate the Kitabah method, which visually associates Arabic letters, diacritics, and punctuation marks with corresponding sign language gestures. To validate its functionality and usability, the application underwent rigorous testing, including black-box testing and usability testing using the System Usability Scale (SUS) [\[27\]](#).

The application underwent black-box testing to evaluate the functionality of critical user flows. During testing, the app's core features, including Arabic letter display, gesture videos, and quizzes, were thoroughly evaluated. The test cases included scenarios such as starting the app, navigating the main menu, selecting the "Learn Letters" feature, watching the corresponding gesture videos for each Arabic letter, and completing the interactive quizzes. The app successfully displayed the 32 Arabic letters along with the associated gesture videos for each letter, ensuring that the learning content was both accessible and accurate. Additionally, the interactive quiz feature was tested, providing users with immediate feedback based on their responses. The application's overall functionality passed all test cases, confirming that all features operated as expected without any significant errors. These results ensure that the app effectively serves its purpose of teaching Quranic literacy through an engaging visual and motoric learning system.



Figure 5. User interface of the kitabah-based mobile learning application

To assess the mobile application's usability, feedback was collected from deaf and hard-of-hearing users using the System Usability Scale (SUS). The SUS is a widely used tool for evaluating software user-friendliness, and it was employed here to ensure the app was intuitive and easy to navigate [28], [29], [30], [31]. The app achieved an average SUS score of 78.06, which indicates a high level of usability. This score means that the mobile application is user-friendly and effectively meets the needs of its target audience. Users reported that the interface was simple to use, with straightforward navigation and accessible features, particularly for those with visual or cognitive impairments. The high SUS score reflects the app's success in offering a learning tool that is both effective and accessible for Deaf and hard-of-hearing learners, thus supporting its goal of improving Quranic literacy through visual learning cues.

The Kitabah-based mobile learning application passed functional testing with all core features working as intended. Additionally, the application received a strong SUS score of 78.06, indicating that it is both usable and practical in providing a learning experience for deaf and hard-of-hearing learners. These results validate the app's design and implementation as a reliable educational tool for teaching Quranic literacy through visual and interactive methods. The high usability score further supports the

application's potential to enhance accessibility and learning outcomes for individuals with PHSD.

Deep-learning sign language recognition (SLR)

The deep-learning-based sign language recognition (SLR) model was developed to recognize the 31 static Arabic Hijaiyyah gestures using the arabic sign language dataset. This dataset consists of 7,856 images, each representing a distinct Arabic letter in sign language. The model was evaluated based on standard performance metrics, including accuracy, precision, recall, and F1-score, to determine its effectiveness in accurately recognizing and classifying the gestures.

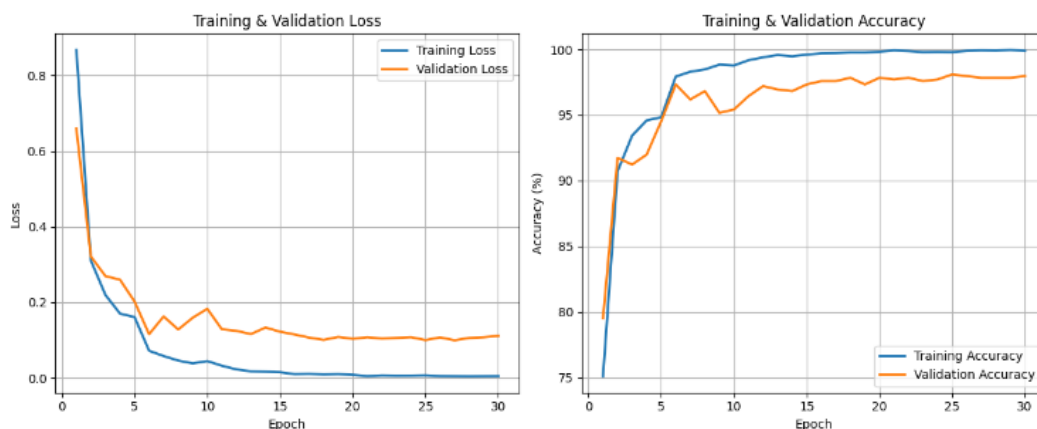


Figure 6. Accuracy and loss trends for ResNet-18 in training and validation phases over 30 epochs

The model demonstrated exceptional performance, achieving an overall accuracy of 98%, as shown in Figure 6, which indicates that it correctly recognized the Arabic Hijaiyyah gestures in the majority of cases. The precision and recall for most of the 31 classes were consistently high, underscoring the model's ability to classify the gestures accurately. Specifically, the precision for most classes was perfect (1.00), indicating that the model accurately classified most positive instances without producing false positives. Likewise, the recall for each class was similarly high, with the model effectively identifying the correct gesture in most instances.

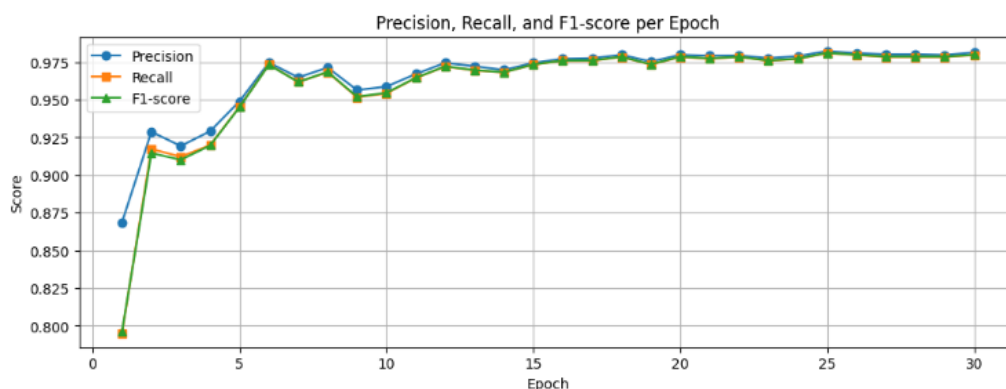


Figure 7. Evaluation of the ResNet-18 Architecture on Multi-Class Hijaiyyah Sign Language Data

However, a few classes exhibited slightly lower performance. For example, classes 5 and 16 showed marginally lower precision and recall due to visual similarities in their

gestures. These gestures, such as ‘Ayn and Ghayn, and Dhāl and Ṭā’, are similar in appearance, which made them more challenging for the model to differentiate accurately. Despite these minor discrepancies, the F1-score, which combines precision and recall, remained consistently high for most classes, further validating the model’s robustness (Figure 7).

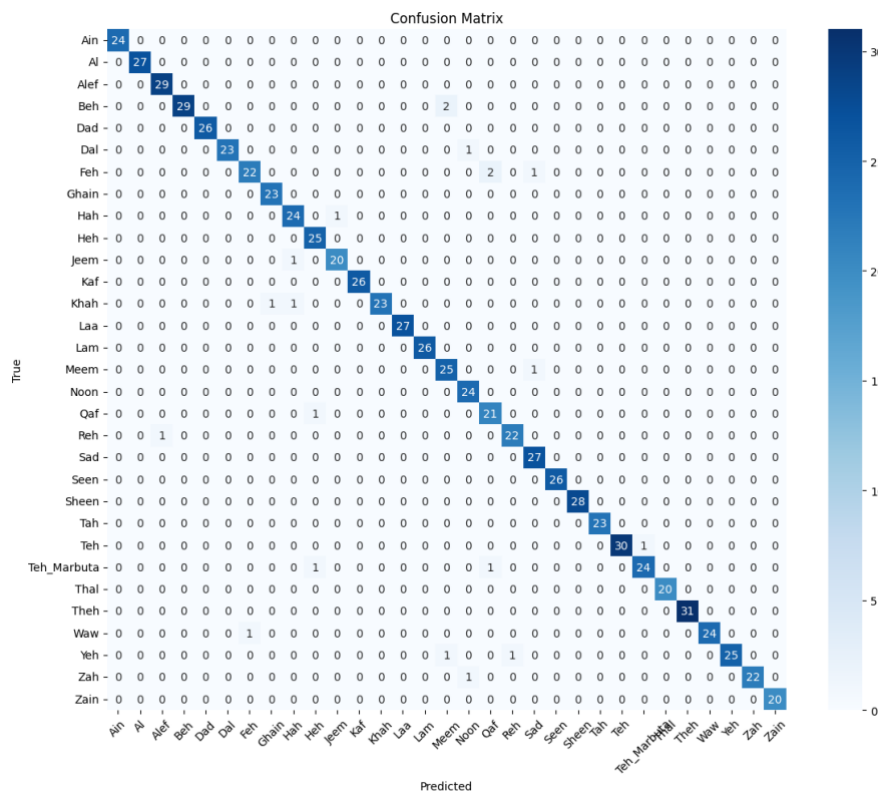


Figure 8. Confusion matrix illustrating the prediction results of the ResNet-18 Model

The confusion matrix serves as a valuable tool for understanding where the model is performing well and where it needs improvement (Figure 8). While the model successfully classified most gestures, these misclassifications highlight areas for potential improvement, such as increasing the dataset’s diversity to include more varied representations of these similar gestures or incorporating dynamic gesture recognition in future work to better handle gestures with subtle differences.

The SLR model achieved high accuracy (98%), precision (1.00 for most classes), and recall, demonstrating its robustness in recognizing the 31 Arabic Hijaiyyah gestures. The model performed exceptionally well overall, with only minor misclassifications between visually similar gestures. The confusion matrix provided more profound insight into misclassifications, showing that they occurred primarily between gestures that share visual similarities. These results confirm the effectiveness of the deep learning-based approach for sign language recognition, while also pointing to areas for improvement through dataset expansion and more refined gesture recognition techniques.

Mobile sign language dictionary

The mobile sign language dictionary was developed to improve communication and literacy for individuals who are deaf or mute. The app’s effectiveness was evaluated

through a series of tests, including unit testing, integration testing, and user acceptance testing, as well as gathering quantitative usability feedback.

The dictionary's core functionalities, including gesture recognition, multimedia support (videos, images, and text), and search/navigation, underwent unit testing to ensure that individual components functioned as expected. All components passed the unit tests, confirming that the app was functioning correctly. Additionally, integration testing was conducted to ensure that the features worked together seamlessly, and no major integration issues were identified.

For user acceptance testing, feedback was gathered from a group of deaf and mute individuals, educators, and sign language experts. Participants were asked to use the dictionary to navigate through the system, engage with multimedia content, and test the gesture recognition. The feedback provided valuable insights into the application's functionality and usability.

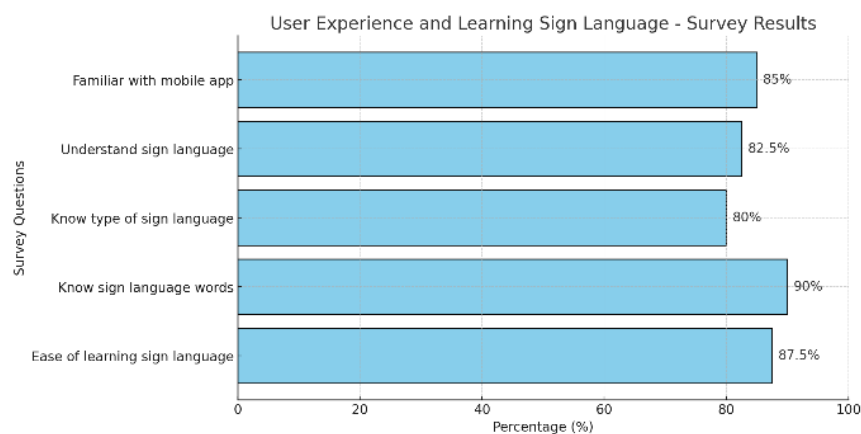


Figure 9. Perceived mobile application familiarity based on user experience evaluation

To assess the application's usability, a series of structured surveys and feedback forms was distributed to users, as illustrated in Figure 9. Based on this, 85% of participants reported an increased comfort with mobile learning tools after using the application. Furthermore, 82.5% of users found the app effective for learning sign language, and 90% indicated that the dictionary helped them improve their recognition of sign language words. These results suggest that the dictionary is not only helpful but also significantly enhances users' learning outcomes.

In addition to the quantitative survey data, qualitative feedback from users indicated that the inclusion of video demonstrations was especially appreciated, as it provided a visual, interactive learning experience. Many participants noted that the ability to view the correct gesture for each word and phrase made it easier for them to learn and remember the signs. The interactive elements, which allowed users to practice gestures and navigate the dictionary content, were also praised for keeping learners engaged.

The application's design, featuring large buttons, clear text, and intuitive navigation, received positive feedback for its accessibility and ease of use. Participants also noted that the search and navigation features were intuitive, enabling them to locate specific

signs or gestures quickly. The inclusion of multimedia content (videos, images, text) significantly enhanced the learning experience.

The mobile sign language dictionary proved to be an effective tool for deaf and mute individuals. The 85% increase in user comfort with mobile learning tools, 82.5% effectiveness in learning sign language, and 90% improvement in sign-word recognition suggest that the application is well-suited to its educational purpose. The app's multimedia features and interactive elements were particularly praised for enhancing engagement and improving the learning experience, confirming that the dictionary fulfills its goal of strengthening communication and literacy for its users.

Discussion

This study aimed to integrate assistive e-learning technologies to improve educational accessibility for deaf and hard-of-hearing (PHSD) learners. The research developed three distinct components: a Kitabah-based mobile learning application for Quranic literacy, a deep learning-based sign language recognition (SLR) system, and a mobile sign language dictionary. The results from each component demonstrate their effectiveness in achieving the goal of enhancing communication, literacy, and Quranic education for PHSD learners. The Kitabah-based application achieved a high System Usability Scale (SUS) score of 78.06, indicating excellent usability; the SLR model showed an impressive 98% accuracy; and the mobile dictionary demonstrated significant improvements in learning outcomes, with 85% of participants reporting increased comfort with digital learning tools.

The Kitabah-based mobile learning application demonstrated strong usability, achieving an average SUS score of 78.06. This score is considered above average in usability studies, indicating that the application is both user-friendly and effective in meeting users' needs. Compared with previous studies on mobile applications for PHSD learners, which often report lower SUS scores due to complex interfaces or inaccessible features, this result highlights the app's success in providing an intuitive and engaging learning experience. The application passed all black-box tests, confirming that key features like gesture videos and interactive quizzes worked seamlessly. The 32 Arabic letters were correctly displayed, and users could access videos without encountering any technical issues. The high level of functionality and usability supports the potential of this application as a tool for improving Quranic literacy for deaf learners.

The deep learning-based SLR model demonstrated remarkable performance, achieving an overall accuracy of 98% in recognizing the 31 Arabic Hijaiyyah gestures. This result surpasses the accuracy achieved by many existing sign language recognition systems, which typically focus on broader sign languages like ASL or BISINDO. The precision and recall for most of the 31 classes were near-perfect, with precision reaching 1.00 for the majority of classes. This suggests that the model is highly accurate in classifying Arabic sign language gestures, making it a promising tool for Quranic education and other specialized sign language applications. The model's 98% accuracy highlights its potential

for use in real-world settings, where accurate recognition is crucial for educational purposes.

While the model performed exceptionally well overall, certain misclassifications did occur between visually similar gestures, such as 'Ayn (Class 16) and Ghayn (Class 17), and Dhāl (Class 25) and Ṭā' (Class 26). These misclassifications were expected, as the gestures for these Arabic letters share visual similarities. In the confusion matrix (Figure 8), it was observed that the model often confused these gesture pairs, highlighting areas for future improvement. One potential avenue for enhancing model performance is expanding the dataset to include more varied representations of similar gestures, such as incorporating different hand positions, orientations, or additional regional sign language variations. Additionally, future work could explore dynamic gesture recognition, which would be particularly beneficial for recognizing Quranic recitation gestures, such as those involved in Tajweed.

The mobile sign language dictionary was tested for its effectiveness in enhancing communication and literacy for deaf and mute individuals. The results of user acceptance testing revealed that 85% of participants reported increased comfort with mobile learning tools, indicating that the app helped users feel more confident using technology to support their learning. Additionally, 82.5% of participants found the dictionary effective for learning sign language, and 90% reported improved recognition of sign words. These quantitative results underscore the dictionary's role as an effective educational tool, confirming that it contributes significantly to both learning outcomes and communication accessibility for its users.

A key feature of the mobile sign language dictionary is the integration of multimedia content, particularly video demonstrations of sign gestures. This feature was highlighted in users' qualitative feedback, which emphasized the importance of visual learning cues for improving sign language comprehension. The 90% improvement in sign-word recognition suggests that video demonstrations are a more effective means of learning than static images or text alone. Previous studies have shown that multimedia elements, especially videos, can significantly enhance the retention and understanding of complex concepts, particularly for visual learners, such as deaf individuals. The success of this approach validates the importance of incorporating interactive multimedia in assistive learning tools.

The usability feedback from the mobile sign language dictionary was overwhelmingly positive. The app's design, which includes large buttons, clear text, and an intuitive navigation system, was appreciated by users for its accessibility. This is particularly important for deaf and mute individuals, who may have varying levels of familiarity with mobile technology. According to user feedback, the app's search and navigation features were intuitive, enabling users to locate signs and gestures quickly. These positive findings suggest that the application's design is highly effective in supporting both learning and communication, particularly for users with limited experience with mobile devices.

The integration of mobile learning technologies for deaf and hard-of-hearing (PHSD) learners presents a transformative opportunity for education. The results from the Kitabah-based mobile learning application and the mobile sign language dictionary confirm that mobile platforms can effectively address communication and literacy barriers faced by PHSD individuals. The high SUS scores for the Kitabah-based app and the positive usability feedback from the dictionary demonstrate that PHSD learners highly value mobile applications. These findings align with previous research that suggests mobile learning tools can significantly enhance engagement and retention among learners with special needs. Furthermore, the use of AI-powered gesture recognition in the SLR model provides a scalable solution to improve sign language literacy across diverse contexts.

The successful implementation of these three components the Kitabah-based mobile learning application, deep learning-based SLR model, and mobile sign language dictionary has significant implications for both educational and practical purposes. First, it shows that mobile technology and AI can play a pivotal role in making specialized education more accessible to PHSD learners. By integrating interactive, multimedia content, gesture recognition, and personalized feedback, these tools offer a more adaptive and accessible learning experience. The ability to accurately recognize Arabic sign language gestures and provide real-time feedback ensures that learners can engage with Quranic literacy and sign language in ways not possible with traditional methods.

While this study presents promising results, several limitations must be acknowledged. For instance, the SLR model currently focuses only on static gestures, limiting its applicability for recognizing dynamic gestures used in Quranic recitation. Future research could explore dynamic gesture recognition to extend the model's applicability to Quranic recitation, particularly for tasks such as Tajweed. Additionally, the dataset used in this study could be expanded to include a broader range of hand shapes, lighting conditions, and regional sign language variations, thereby improving the model's generalizability. Future work could also explore integrating these technologies into classroom settings, testing their scalability and effectiveness in large-scale educational environments.

Conclusion

This study introduces an innovative, integrated solution to enhance educational accessibility for deaf and hard-of-hearing (DHH) learners by combining three key technologies: a Kitabah-based mobile learning application for Quranic literacy, a deep-learning-based sign language recognition (SLR) system, and a mobile sign language dictionary. The novelty of this research lies in the seamless integration of these components, offering a comprehensive, adaptive learning environment that bridges gaps between Quranic education and everyday communication for DHH individuals.

The primary contribution of this study is the novel application of the Kitabah method in a digital format, which leverages AI-powered gesture recognition for Quranic literacy,

alongside a deep learning-based model for Arabic sign language recognition. The results highlight the significant effectiveness of these technologies, with the Kitabah-based app achieving high usability (SUS score of 78.06), the SLR model reaching an impressive 98% accuracy, and the dictionary significantly improving communication and literacy for DHH learners. These findings confirm the potential of combining mobile learning tools and AI to offer more inclusive, engaging, and effective educational solutions for DHH learners.

By integrating these innovative tools, this research provides a scalable, inclusive framework that not only addresses the educational needs of DHH learners but also facilitates communication and literacy through mobile technology. Future research could build on these findings by further enhancing the deep learning model to handle dynamic gestures, particularly for Quranic recitation, and by exploring the broader application of these tools across diverse educational contexts. This study sets the stage for further advancements in assistive e-learning technologies, fostering greater educational equity for learners with special needs.

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