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PAPER

Augmented Reality in Elementary Education: System Architecture for Implementing an Interactive and Immersive E-Learning Application

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ABSTRACT

Early childhood language acquisition is crucial, but complex scripts such as Bengali present challenges. BIPLOB, an Android-based augmented reality (AR) application, seeks to revolutionize language learning by introducing interactive 3D models and meticulously recorded audio pronunciations. Targeting both engagement and accuracy, BIPLOB addresses issues encountered by traditional methods. Its optimized workflow offers a replicable framework for future AR-based language learning applications, especially for complex scripts. BIPLOB paves the way for immersive and effective early language acquisition through the transformative power of AR technology.

KEYWORDS

augmented reality (AR), e-learning, 3D modeling, interactive application, immersive technology

1 INTRODUCTION

The early years of childhood education hold immense significance, shaping the very foundation of language development and paving the path for future academic success. Traditional methods, while venerable, are being challenged by the burgeoning landscape of learning. Augmented reality (AR) emerges as a game-changer, offering immersive and interactive experiences with the potential to revolutionize the way young minds learn languages. This study delves deep into harnessing the transformative potential of AR in teaching the Bengali alphabet to elementary learners. The study focuses on BIPLOB, an android-based AR application specifically designed for engaging and effective acquisition of the Bengali alphabet.

Bengali, one of the world's most spoken languages, presents unique challenges for young learners due to its intricately rich script and phonetic system. The intricate

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character shapes, as explored by M. Rahman et al. (2019) [1], and the pronunciation complexities, highlighted by M. Maniruzzaman (2006) [2], pose a challenge that traditional methods might struggle to address effectively. BIPLOB aims to bridge these gaps by utilizing AR technologies to develop an engaging and accessible learning environment customized to the specific requirements of learning the Bengali alphabet.

This work draws upon a substantial body of study highlighting the effectiveness of AR in learning. Y. A. Alkhabra et al. (2023) [3] demonstrate that AR applications can significantly enhance learning retention, while C. Yangın Ersanlı (2023) [4] highlight their ability to improve pronunciation accuracy and learner motivation. In the context of AR, specifically, Y. Koumpouros (2024) [5] showcases the potential of AR in promoting engagement in education, paving the way for the development of BIPLOB. Additionally, the emergence of large language models like ChatGPT (Ipek et al., 2023; Karakose et al., 2023; Athanassopoulos et al., 2023) [6–8] opens new possibilities for personalized learning and adaptive feedback within AR applications, potentially further enhancing the effectiveness of applications in this segment.

BIPLOB utilizes marker-based tracking through Vuforia (D. E. Kurniawan et al., 2018) [9] to trigger the display of interactive 3D models of Bengali letters upon recognition. These models, developed using Autodesk 3ds Max (Dangi, P. et al., 2023) [10], provide a tangible and visually engaging representation of the characters, as emphasized by Klement, M. et al. (2023) [11] in their study. By seamlessly integrating with the Unity game engine (J. Pernas-Álvarez et al., 2024) [12], BIPLOB immerses learners in a captivating environment that fosters exploration and engagement, aligning with the findings of G. Lampropoulos et al. (2022) [13] on the importance of gamification in AR-based learning. Additionally, incorporating VEP triplet count analysis of 3D Bangla alphabets (Ghosh et al., 2020) [14] could improve character recognition accuracy and optimize the AR experience.

To further enhance engagement and pronunciation accuracy, BIPLOB incorporates high-quality audio clips for each letter. Recognizing the technical limitations in Bengali language processing (M. Karim et al., 2013) [15], the development team opted for a meticulous approach by recording professional voiceovers to ensure authenticity and clarity. The research conducted by K. Mohamadkhani et al. (2013) [16] on the impact of using audio to enhance listening comprehension has been a valuable source of information. Their work emphasized the importance of high-quality audio production, leading to an improved language learning experience. This study addresses three critical questions:

Research Question 1: Which workflow is most effective for developing an AR-based Android application for teaching Bengali alphabets to elementary learners? Inspired by the work of S. Madhankumar et al. (2021) [17] on AR-based mobile application development for education and training systems, the researchers seek to identify the most efficient and learner-centric approach for BIPLOB's development.

Research Question 2: What process should be followed to produce high-quality audio clips for integration with an AR-based language learning application? Drawing insights from the research of D. Campbell et al. (2009) [18] on audio quality assessment, this work aims to establish a replicable process for ensuring audio fidelity in BIPLOB.

Research Question 3: What is the optimal average file size for audio clips (for Bengali alphabets) to ensure smooth functionality and accessibility on Android devices? Considering the findings of M. Hort et al. (2022) [19] on optimizing file size for mobile applications, the researchers in this study aim to establish the optimal balance between audio quality and file size to ensure smooth performance on Android devices.

By addressing these key questions through rigorous analysis and testing, researchers aim to optimize the design and development of BIPLOB and establish a replicable framework for future AR-based language learning applications, especially in the context of complex scripts such as Bengali. This work builds upon the existing study in AR language learning while addressing the specific challenges of Bengali, contributing to its continued evolution and innovation. Research works that did not have a specific focus on language learning but utilized AR as a tool for creating innovative educational solutions or contributing to this field, such as the study on self-regulated learning and mobile AR by Chusnul et al. (2020) [20], the AR-supported tool for studying anatomy by Orlando et al. (2024) [21], and the 3D coloring quiver application based on AR for fostering early childhood creativity by Kisno et al. (2022) [22], have been valuable sources for gathering ideas on how this work on AR in elementary education can be conducted.

The remaining sections of this paper will discuss the technical details and strategies involved in the development of BIPLOB. Section 2 outlines the proposed model's system architecture, while Section 3 discusses the detailed workflow of implementation phases. This paper concludes with Section 4.

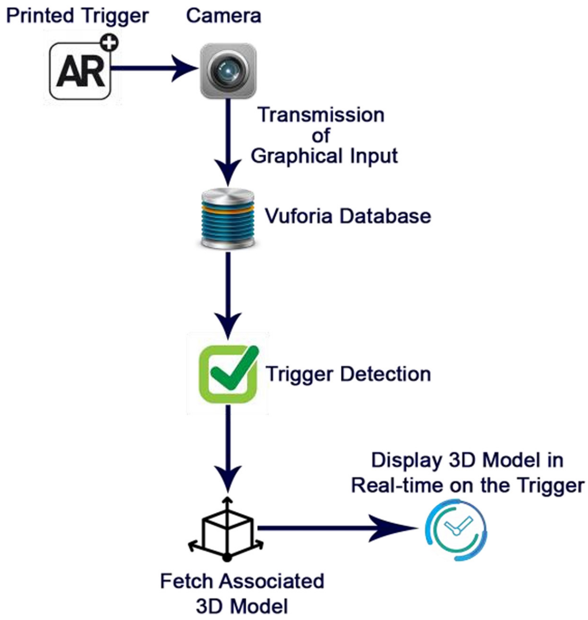

Fig. 1. System architecture of BIPLOB

2 PROPOSED MODEL

The system architecture of BIPLOB, as depicted in Figure 1, showcases its multi-segmented model. Initially, AR triggers are printed on paper, but they can also be applied to various surfaces as long as the pattern matches the database for successful recognition. The BIPLOB app activates the device camera, enabling it to capture graphical inputs from the printed trigger. These inputs are then transmitted to the Vuforia database, where a search is conducted to find a suitable match. Once a match is found, the associated 3D model linked to the trigger is retrieved. In the final stage, the retrieved 3D model is seamlessly displayed in real-time on the AR trigger, creating an immersive AR experience. This process enables users to interact with the virtual object overlaid on the physical trigger, merging the digital and real-world environments.

3 DETAILED WORKFLOW OF IMPLEMENTATION

Researchers chose the Android platform for this study because of its wide usability and improved mobility. This option allows both teachers at school and parents at home to use the application for their children's development. The Bengali language consists of vowels and consonants, and BIPLOB provides a comprehensive solution for learning both. This system facilitates children's interaction with three-dimensional virtual alphabets, as illustrated in Figure 2, using a straightforward and user-friendly approach. By simply accepting triggering inputs from the device's camera, ideally from an Android-operated smartphone, children can engage with virtual alphabets and enhance their learning experience. This platform ensures accessibility and convenience for both educators and parents, fostering a collaborative environment for children's language development.

Fig. 2. 3D characters during preparation inside virtual environment

The 3D Bengali letters were modeled using Autodesk 3ds Max software. These models were exported to the *.fbx format for seamless integration into the Unity game engine, along with a predefined target list of Bengali letters stored in the Vuforia database. This paper includes tables containing a comprehensive list of trigger symbols derived from the Bengali alphabet, along with their corresponding English pronunciations. Table 1 lists the complete set of 11 vowels and 39 Bengali consonants. By utilizing Autodesk 3ds Max for creating and exporting 3D models to *.fbx format and leveraging the capabilities of Unity and Vuforia, researchers successfully integrated the 3D-modeled Bengali letters into an interactive environment. This integration facilitates language learning and exploration.

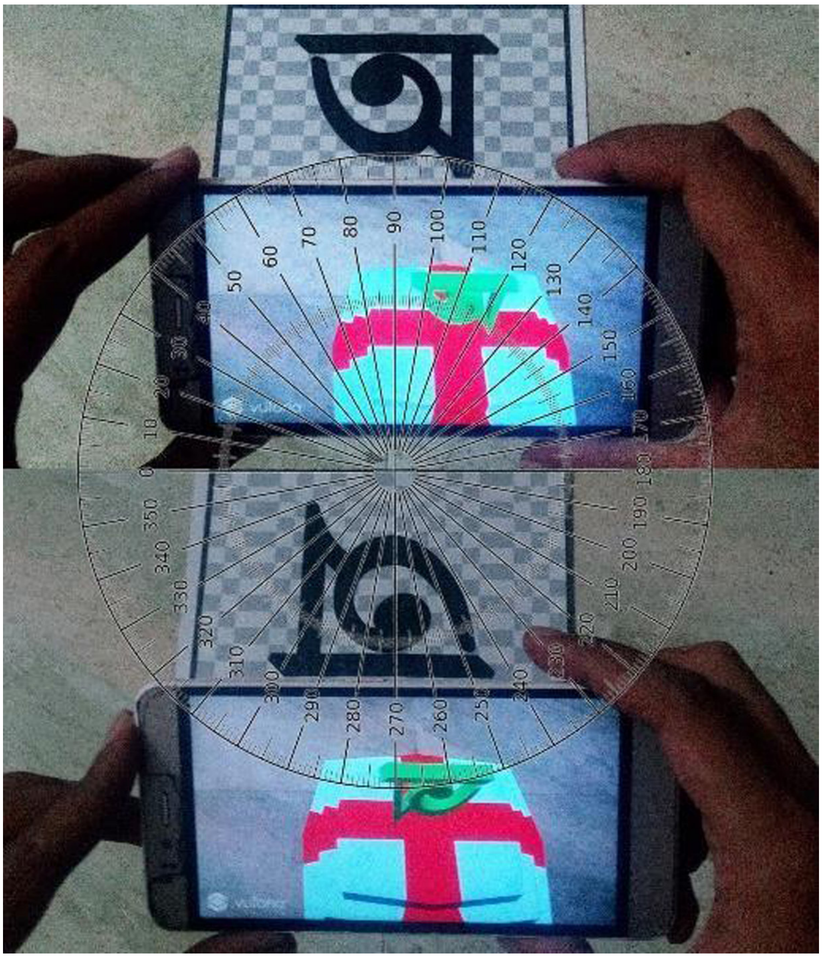

Fig. 3. Successful trigger input from various angles

BIPLOB eliminates the need for users to undergo any inconvenience, such as changing the interface or switching between applications, as it maintains a consistent environment for vowels and consonants. The design of the entire package is remarkably well executed, making the orientation of the triggering input irrelevant. To illustrate, let's consider the example of the initial letter Shor-E-Aww (অ), which can be positioned at a 90-degree or 270-degree angle relative to the user's device. Regardless of the angle, BIPLOB consistently detects the trigger and presents the corresponding 3D model, as illustrated in Figure 3. This seamless functionality ensures that users can effortlessly interact with the system without needing to make any adjustments or adaptations. Unlike the majority of Android-based apps, BIPLOB functions without needing an Internet connection while in operation. This is because the required database and 3D models are already installed on the device during the application installation process. Therefore, users can utilize this application without any concerns about data connection or Internet connectivity during its usage.

An additional notable feature of this application is its ability to audibly pronounce the virtual 3D alphabet when triggered by input. This functionality enables children to simultaneously observe the intricacies of a letter while hearing its accurate pronunciation through the device's speaker. During the initial stages of BIPLOB's development, researchers believed that generating the pronunciation would be a straightforward task, considering the abundance of text-to-speech (TTS) generators available today. Initially, they experimented with several automated TTS solutions to generate the pronunciations. However, in most cases, the results were disappointing. For instance, although IBM Watson generates excellent audio output, it does not support Bengali. Similar issues arose when they explored options such as oddcasts and natural readers. Although Google Translator was able to pronounce Bengali, the output sounded robotic, and, most importantly, the pronunciations were not accurate.

When developing an app for child education, ensuring high quality is imperative. Therefore, researchers adopted a direct and straightforward approach to address this challenge. Within their laboratory, they set up an audio recording system and enlisted the help of a professional voice artist. Together, they meticulously recorded voiceovers for each individual alphabet, which were subsequently integrated into the complete system within the Unity game engine. By taking this meticulous approach, they prioritized delivering exceptional quality in the app. They recognized the significance of providing accurate and engaging voiceovers to enhance the educational experience for children.

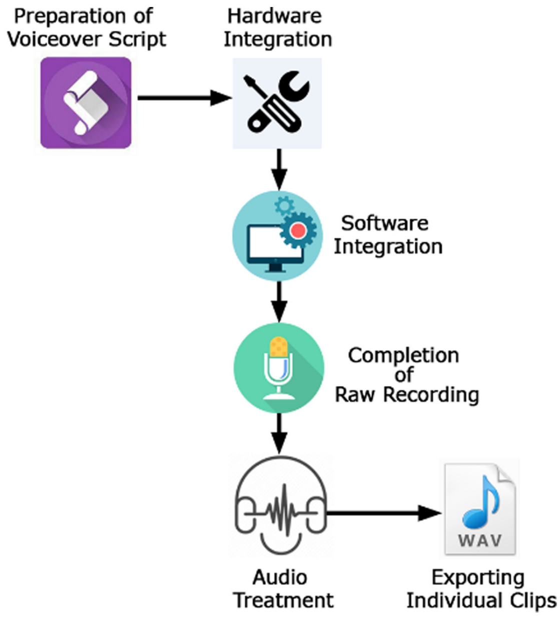

Fig. 4. Process flow of audio production for BIPLOB

Figure 4 clearly outlines the specific stages that the researchers have gone through during the audio production for this project. Stage 1, which involved preparing the voiceover script, was not a challenge for them, as they only needed to use the pronunciation of the Bengali alphabet. No additional introduction or conclusion auditory narratives were included. Stage 2 focused on integrating various hardware components to capture the audio clips. Researchers used a condenser microphone for this project, which was connected to a PC via a standard audio interface. Since they had the opportunity to use a full-fledged PC during audio recording, they gained some extra advantages. For example, there was no need to hassle with transferring raw files from one device to another. Thus, no additional compatibility issues were raised on either the hardware or software end. For reference, the production PC they used had an Intel Core i7-7700K processor operating at 4.20 GHz and equipped with 16 GB of RAM. The GPU in this setup was powered by an NVIDIA GeForce GTX 1060 6GB card, which is not the latest or flagship card, but it certainly served its purpose smoothly. This same setup was used to develop the main application (BIPLOB). In stage 3, proper bridging was established between the audio recording software and the hardware. Researchers relied on Audacity, a freeware audio recording software, for this project. During stage 4, the actual audio recording took place, and multiple takes were recorded for each Bengali alphabet to ensure the highest level of quality. Any audio recording aimed at high-quality production must undergo some basic processing. This treatment helps remove any unwanted noise from the audio, enhances the clarity of the clip, and boosts the audio level. In stage 5, they performed those treatments within the interface of Audacity software. Researchers particularly focused on compressor, hard limiter, equalizer, and noise reduction features for the treatment, and indeed, they achieved excellent results. In stage 6, when the audio clips were free from all impurities, they were exported individually to *.wav file format at a bit rate of 1536 kbps.

When the entire audio package was ready, researchers made some interesting observations. There was a variety in file sizes for the exported *.wav clips, even though almost all of them had a similar duration of 1 second. The last Bengali alphabet, Chandro Bindu, was the only exception, taking 2 seconds to pronounce and occupying the highest file size of 448 KB. The smallest file size recorded was 222 KB for the first Bengali alphabet, Shor-E-Aww. Entire findings related to this discussion are presented in Table 1. It is important to note that the average file size of the audio clips used in this project is 293.7 KB. Future researchers and developers in this domain can use this number as a reference for their own projects.

Table 1. Bengali alphabet with pronunciation, vowel/consonant classification, audio clip duration and file size

SL.	Alphabet with Pronunciation	Category	File Size of Recorded Clip (KB)	Duration of Recorded Clip (sec.)
01	অ (Shor-E-Aww)	Vowel	222	1
02	আ (Shor-E-Aa)	Vowel	259	1
03	ই (Srossho-E)	Vowel	309	1
04	ঈ (Dirgho-E)	Vowel	337	1
05	উ (Srossho-Uo)	Vowel	354	1
06	ঊ (Dirgho-Uo)	Vowel	341	1
07	ঋ (Ree)	Vowel	317	1
08	এ (Aee)	Vowel	254	1
09	ঐ (Oii)	Vowel	309	1
10	ও (Ooo)	Vowel	285	1
11	ঔ (Ow)	Vowel	254	1
12	ক (Kaww)	Consonant	278	1
13	খ (Khaww)	Consonant	293	1
14	গ (Gaww)	Consonant	267	1
15	ঘ (Ghaww)	Consonant	285	1
16	ঙ (Ymoaww)	Consonant	254	1
17	চ (Caww)	Consonant	306	1
18	ছ (Chaww)	Consonant	306	1

(Continued)

Table 1. Bengali alphabet with pronunciation, vowel/consonant classification, audio clip duration and file size *(Continued)*

SL.	Alphabet with Pronunciation	Category	File Size of Recorded Clip (KB)	Duration of Recorded Clip (sec.)
19	জ (Borgio-Jaww)	Consonant	315	1
20	ঝ (Jhaww)	Consonant	285	1
21	ঞ (Yeoaww)	Consonant	291	1
22	ট (Taww)	Consonant	230	1
23	ঠ (Thaww)	Consonant	237	1
24	ড (Daww)	Consonant	289	1
25	ঢ (Dhaww)	Consonant	265	1
26	ণ (Mordhan-Aww)	Consonant	306	1
27	ত (Taww)	Consonant	306	1
28	থ (Thaww)	Consonant	237	1
29	দ (Daww)	Consonant	261	1
30	ধ (Dhaww)	Consonant	283	1
31	ন (Dontoaww)	Consonant	359	1
32	প (Paww)	Consonant	224	1
33	ফ (Phaww)	Consonant	254	1
34	ব (Boaww)	Consonant	287	1
35	ভ (Bhoaww)	Consonant	328	1
36	ম (Moaww)	Consonant	302	1
37	য (Yontojaw)	Consonant	311	1
38	র (Roaww)	Consonant	320	1
39	ল (Loaww)	Consonant	320	1
40	শ (Talobshaww)	Consonant	315	1
41	ষ (Mordhana-Shaww)	Consonant	361	1
42	স (DontonaShaww)	Consonant	289	1
43	হ (Haww)	Consonant	269	1
44	ড় (Hraww)	Consonant	248	1
45	ঢ় (Hraww)	Consonant	250	1
46	য় (Yontoshaww)	Consonant	320	1
47	ৎ (Khondo-Taww)	Consonant	343	1
48	ং (Anushor)	Consonant	252	1
49	ঃ (Bishorgo)	Consonant	350	1
50	ঁ (Chandro Bindu)	Consonant	448	2

Based on this study, there are some recommendations for further study to be conducted. AR-based projects such as BIPLOB cover two major stages of asset development. One is visual, and the other one is auditory. In the visual development stage, 3D models are created, and audio clips are produced in the audio development stage. In both of these stages, currently available technology allows the developer to deploy extremely high-quality audio clips and 3D files. At an individual level, they are undoubtedly crisp, but their high quality comes with a unique set of trade-offs. Mostly, this trade-off is visible in file size. If the individual audio-visual components are uncompressed and very large in file size, they may end up making the final AR application more memory-intensive. Thus, it may face problems operating on entry-level devices. So, a proper balance between quality and memory size must be considered for the smooth operation of the final application. This study has a gap in including user testing data, which is expected to be covered in subsequent studies. That study will provide more insights into the user experience.

4 CONCLUSION

In conclusion, BIPLOB presents a novel and highly engaging approach to teaching the intricacies of the Bengali alphabet to elementary learners. By seamlessly integrating cutting-edge AR technology with high-quality 3D models and meticulously recorded audio pronunciations, BIPLOB fosters interactive learning environments that spark curiosity and enhance retention. The comprehensive system architecture and optimized workflow provide a replicable framework for future AR-based language learning applications, especially for complex scripts such as Bengali. While further study exploring user testing data and trade-offs between file size and quality is vital, BIPLOB undoubtedly paves the way for revolutionizing early language acquisition through the transformative power of immersive technology.

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