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Term Paper: *A Framework for Bangla Text-to-Sign Language Conversion: Bridging Communication Gaps through Accessible Technology*

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Table of Contents

Abstract: Particularly in Bangladesh, where the technological support for Bangla Sign Language (BdSL) is limited, the communication gap between the broader society and nonspeaking individuals remains a persistent barrier. Meanwhile, global advancements have yielded systems for real-time sign language translation, such as TESSA and IBM's ASL avatar, where Bangla lacks an end-to-end framework. Using natural language processing and animated visualization, this paper describes how Bangla text is developed to Bangla Sign Language (BdSL) translation system. A modular framework which processes sentences written in Bangla with natural language processing (NLP) has been proposed, with BdSL compatible structure and visually animated avatars ensuring both linguistic accuracy and accessibility; particularly for educational, governmental and healthcare purposes.

Keywords: Bangla Sign Language (BdSL), natural language processing, linguistic mapping

CHAPTER 1: INTRODUCTION

Sign Language is a controlled and systematic mode of communicating which involves different gestures, facial interactions and body articulation to express oneself. It is the main medium of communication of nonspeaking persons especially the deaf or the hard of hearing. In contrast to hearing people who learn how to talk since they are babies, nonspeaking people have hindrances to language learning because they cannot hear.

In the case of this population, the sign language becomes crucial to the cognitive, social, and emotional formation. It is estimated that 466 million people or about 6.1 percent of the global population have hearing impairments [1]. This problem in Bangladesh is even worse as it is shown that about 34.6 percent of the whole population is affected to a certain extent as it has 49.2 million people. Among them, 1.2 percent have severe hearing loss (which is characterized by severe hearing loss of at least 70 dB) [2].

To these people, Bangla Sign Language (BdSL) acts as the main language of communication amongst the communities. BdSL is a vibrant language with its own grammar, syntax, and rich cultural heritage, serving over 200,000 deaf Bangladeshis [3] There is always a problem of communication between the deaf and other people in society, and this has posed to be a great challenge in a developing country like Bangladesh. This disparity cuts across such vital grounds as education, healthcare, and employment, with deaf people often lacking access to treatment or education and commonly facing discrimination.

The relationship between socioeconomic status and the deaf experience in Bangladesh involves various complex factors that significantly impact the quality of life, access to education, healthcare, and economic opportunities for deaf individuals. Conventional ways of dealing with such problems are based on human interpretation. Nevertheless, such interpreters are not easily found, creating significant barriers to integrating the deaf community into mainstream society

and preventing more than 200,000 hearing and speech-impaired people from accessing the mainstream workforce in Bangladesh. As long as the sign people use sign language as their medium of communication with general people, it's important to express their social, emotional, and linguistic growth. Nationwide there is diversity, and language plays a crucial role here. Globally, around 7,000 distinct languages are spoken [4], and there are different sign languages in different countries; in particular, British Sign Language (BSL) [5] and American Sign Language are different from each other from grammatical or linguistic aspects. As sign language is known to a limited number of people, it creates a problem in communicating with the general people. Current research indicates that effective Bangla text-to-sign language conversion systems must address several technological challenges, including skin tone variations, hand orientation differences, background interference, and complex grammatical structures inherent in both spoken Bangla and Bangla sign language (BdSL) [6].

Furthermore, the development of lightweight models that maintain high accuracy while operating on resource-constrained devices could facilitate access to sign language interpretation technology [7]. This framework emphasizes current research findings and proposes a comprehensive approach to Bangla-text-to-sign language conversion that addresses both technical challenges and practical implementation considerations; by utilizing cutting-edge techniques and incorporating insights from linguistic research on BdSL, this work seeks to contribute to the development of more effective, accessible communication technology for the deaf community in Bangladesh [8].

CHAPTER 2: LITERATURE REVIEW

Sign There has been exponential growth in sign language technology worldwide in comparison with the mainstream systems like American Sign Language (ASL) and British Sign Language (BSL). Advanced software like TESSA (Text and Sign Support Assistant) and IBM's ASL avatar leverage the power of natural language processing (NLP), basic grammatical structure, and 3D animation to convert oral or text language into real-time sign language output with unparalleled deaf and hard-of-hearing accessibility [9][10]. These models make use of advanced computational methods like natural language parsing, syntactic parsing, and motion handling algorithms to convert sign language strings in a continuous, uninterruptable manner. Besides providing ease in communication, the technology also empowers the user by removing the need for human interpreters in daily communication. Deep-learning-based sign language synthesis with transformer models and motion-capture synthesis recently introduced the fluidity and nativeness in sign language avatars [11][12].

While technology in both BSL and ASL is advancing, Bangladesh's native language, Bangladesh Sign Language (BdSL), languishes far behind in leveraging technology support. In the early stage, some local efforts, e.g., Islam et al. and Hasan et al., tried to begin efforts for a BdSL's system for generation and recognition from image processing as well as by a rule-based

system [13][14]. These systems suffer from a number of weaknesses: single-word recognition-limited, non-real-time compatible, grammatical structures, and sentence-level semantic content-ignorant. To this, they also couldn't incorporate recent innovations on the recent breakthroughs in Bangla NLP as those had taken revolutionary leaps and steps by using tokenizers, part-of-speech (POS) tagger, dependency parsers, and translation models [15]. Recent progress in Bangla NLP, e.g., [16], brings state-of-the-art transformer-based models for understanding text in Bangla, which would be usable for BdSL generation but one that is unexplored in sign language systems. Not being able to introduce the innovations into assistive communication systems is a testament to the enormous gap between central NLP efforts and extension to deaf individuals in Bangladesh. This indicates a need for a critical urgency for end-to-end system in general bridging the gap in text processing in Bangla and dynamic generation in sign language.

Differing from the earlier attempts, this system must utilize morphological, syntactical, and text processing in Bangla and subsequent generation of corresponding sign gesture simulation—in either avatar-based 3D, video-based animation, or sensor-based input. Recent progress in other low-resourced sign languages, i.e., Indian Sign Language (ISL) and Arabic Sign Language (ArSL), has shown promising results with hybrid deep learning and synthesis in motion [17][18], from which a road map may be borrowed for BdSL technology. These challenges can be overcome, and future studies can make real-time or bi-directional text-to-sign and sign-to-text a possibility that meets the linguistic and cultural demands of BdSL. Such reports indicating adoption of NLP, machine learning, and algorithms for animation to create a comprehensive Bangladesh text-to-sign system for precision, expansion, and accessibility to Bangladesh's deaf population are filled with unexploited potential.

CHAPTER 3: RESEARCH GAP

In spite of occasional efforts at BdSL recognition, there is an acute shortage of realizing a real-time, context-aware, end-to-end translation from Bangla to BdSL that copes with grammatical differences (e.g., SOV word order vs. non-linear syntax of BdSL) and morphological-syntactic conversion for appropriate, fluent signing [13][14][19][20]. Existing systems also do not possess real-time processing, smartphone support, and 3D avatar-based animation—features proven to improve accessibility in ASL/BSL but absent in BdSL systems [21]. Furthermore, prior work fails to connect the dots between Bangla NLP innovations (e.g., tokenization, handling inflections) and BdSL generation, thus resulting in oversimplification or incorrect outputs [22][23]. Societal exclusion—in education and in the provision of healthcare—also underscores the need for an affordable, scalable solution that is aligned with Bangladesh’s linguistic, as well as technological, settings [24].

CHAPTER 4: RESEARCH QUESTION

This research aims to develop a real-time text-BdSL system by addressing two critical issues: How to convert Bangladesh's Subject-Object-Verb (SOV) syntax into the flexible BdSL syntax without loss in grammaticality through the use of dependency parsing and morphology-based morphological analysis? and What NLP components (e.g., tokenizers, POS taggers) and transfer learning methods (from well-resourced sign languages like ASL) can facilitate BdSL translation with low training data [13][15][25]? In visualization, we investigate whether skeleton models or 3D avatars offer the optimal balance of real-time performance with BdSL dynamism [21]. For accessibility, mobile optimization for low-bandwidth networks and offline support is required, with user-oriented design taking into account regionally varying dialects and deaf community engagement. Institution collaboration (e.g., educational, healthcare) for scaleable launches also shall be explored for making the system bridge Bangladesh's deaf community linguistic, technological, and social gaps.

CHAPTER 5: OBJECTIVES

This project suggests developing an end-to-end real-time translation system that accepts text input in Bangla and outputs accurate Bangladesh Sign Language (BdSL) outcomes. The system would address fundamental linguistic challenges in transposing the Subject-Object-Verb word order in Bangla to the space-based grammar of BdSL [19], combined with resource-abundant sign languages transfer learning [25] and cutting-edge natural language processing techniques [22] for processing semantics. In visualization, we would employ optimized 3D avatar technology [19][26] with the capacity for displaying natural signing motions with real-time performance. It would develop a system optimized for real-world application in educational, healthcare, and public services applications [24], with mobile-first optimization due to Bangladesh's limited infrastructure [27].

- Develop an accurate and real-time Bangla-BSL converter.
- Create an accessible and user-friendly app/web portal.

CHAPTER 6: MATERIALS & METHODOLOGY

In this paper, we aim to build a web-based application to convert Bangla text into Bangla Sign Language (BdSL) in two modes. In the first mode we will be converting the text into sign language word by word & for the second mode we will be going for finger spelling where each character will be sign spelled.

6.1 Data Set

For word-based conversion we are using dataset from BdSLW - 11 (Bangladeshi Sign Language Words dataset) which provides 11 sign words [28] & for character-based conversion we have Ishara-Lipi which provides images for Bangla letters [29].

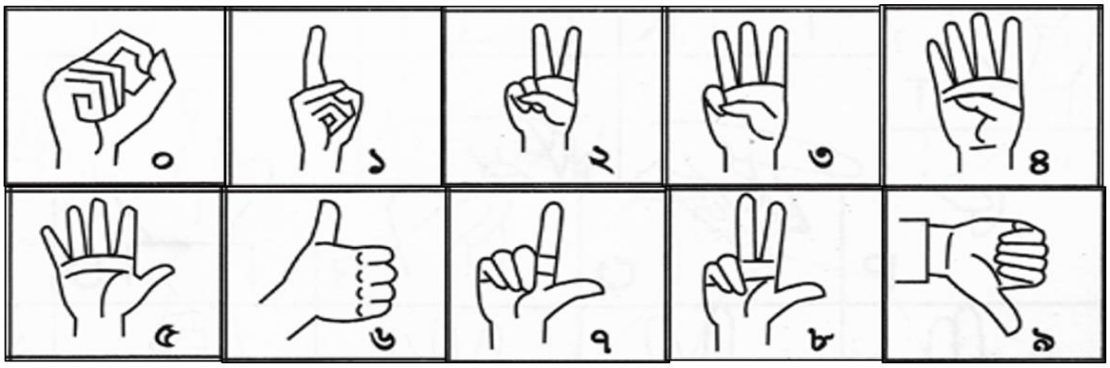

Fig 4.1.1: BdSL Digit- (CDD Standard) [30]

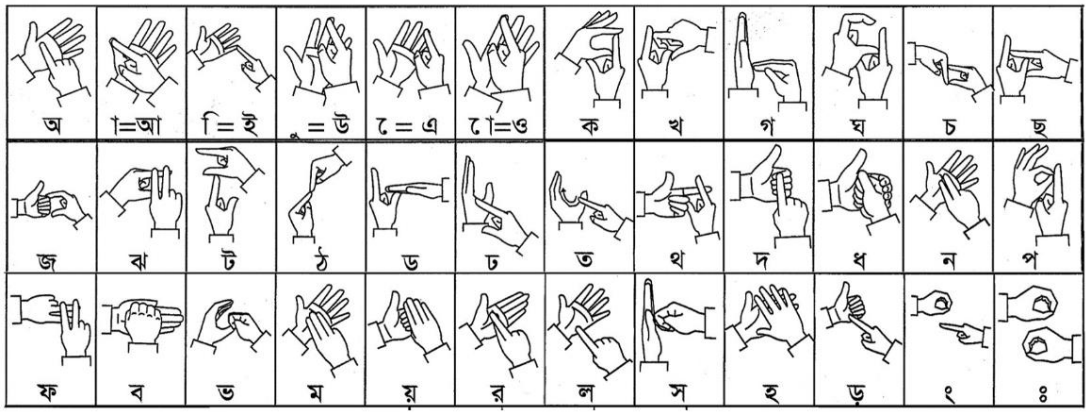

Fig 4.1.2: BdSL Characters- (CDD Standard) [31]

6.2 Process

First the user inserts the sentence into the system that he wants to translate. Then he must choose whether he wants it to be converted into word-based sign language or character-based sign language. If the user selects character-based conversion, upon clicking the convert button, the system will fetch the sentence, then process it to be broken to induvial character. After determining each character, the system will retrieve images corresponding to every character and show it on the screen.

Input (Text) ⟶ Sentence to Character ⟶ Character Map ⟶ Sign Retrieve ⟶ Output

If the user chooses to convert his Bangla text to sign language word by word then the system will divide the fetched sentence into words and search the database to find appropriate image related to the word and show it on screen. If the desired word is not found then the system will resort to fingerspelling for the unfound word.

Input (Text) → Sentence to Word → Word Map →
- → Word Found → Sign Retrieve → Output
- → Word Not Found → Character Map → Sign Fetch → Output

For the interface, we are using HTML5 and CSS3 for better responsiveness and availability irrespective of all devices [32][33]. And as for the core functionality of the system we are going to use JavaScript to implement all the crucial logic [34]. As for the database, two primary categories data were introduced which are demonstrated below:

```
signDatabase = {
  'finger': {
    // Character-to-image mappings
    'অ': 'signs/10.png',
    'আ': 'signs/11.png',
    // ... complete character set
  },
  'word': {
    // Word-to-image mappings
    'তুমি': 'signs/তুমি.jpg',
    'ভালো': 'signs/good.jpg',
    // ... vocabulary set
  }
}
```

Fig. 4.2.1 demonstrates how the whole system works, how Bangla text is converted to Bangla Sign Language (BdSL) based on the chosen mode of conversion.

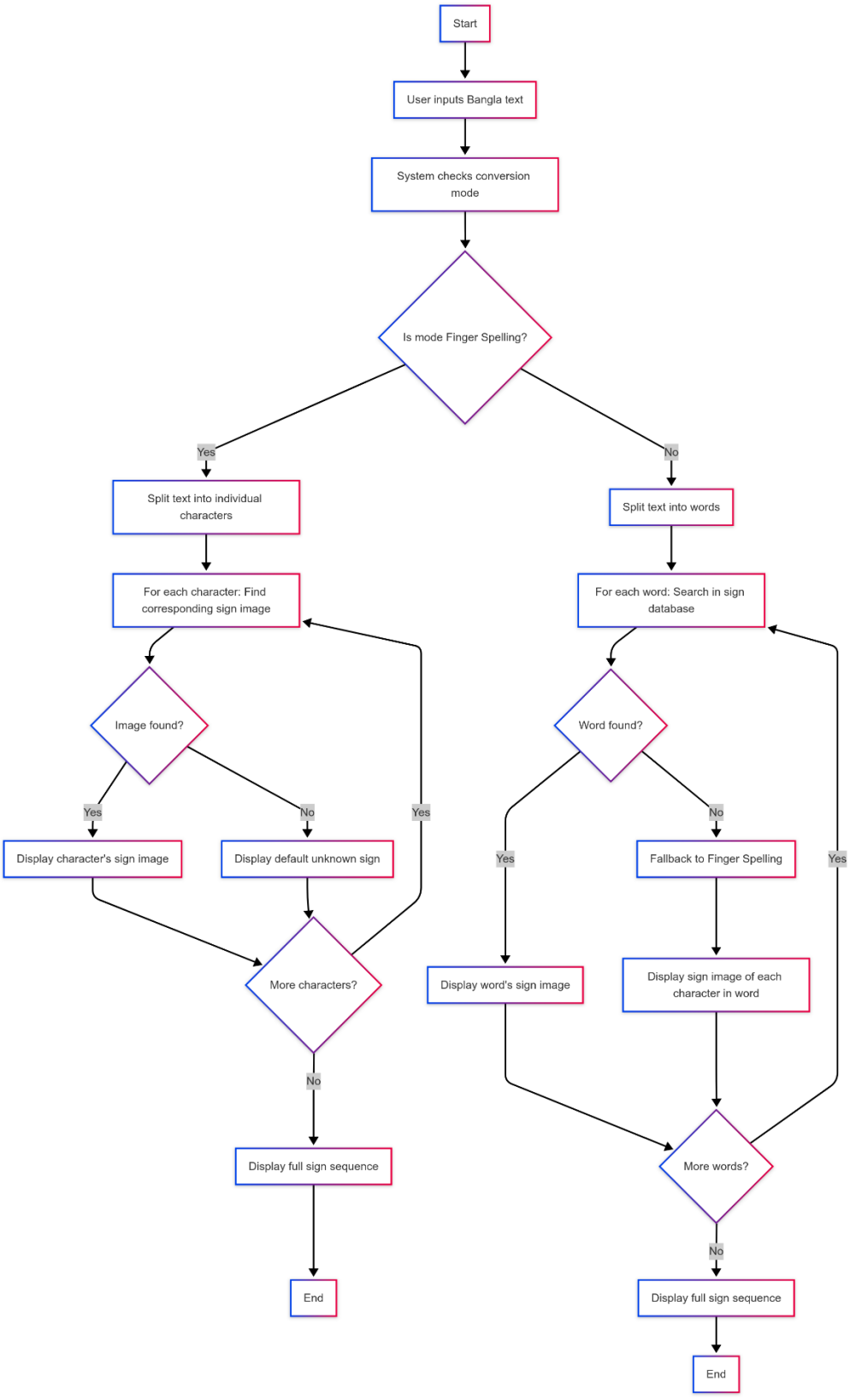

Fig. 4.2.1: Bangla text to Bangla Sign Language (BdSL) Conversion Flowchart

CHAPTER 7: RESULT & DISCUSSION

Fig. 5.1 showcases the interface to the web-based application for the Bangla text to Bangla sign-based language. The user must put in the sentence and select one of the two modes to translate into sign language.

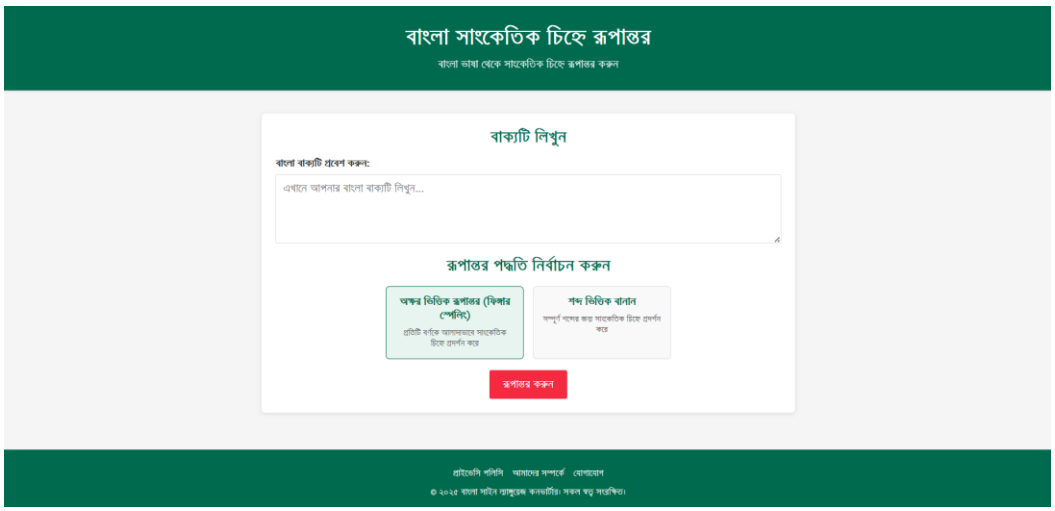

Fig 5.1: Interface to the Bangla text to BdSL

Conversion Logic:

The first system fetches the sentence to be converted then chooses one of the two modes where Finger Spelling is accomplished with `convertToFingerSpelling(text)` function and word-based conversion is done through `convertToWordSigns(text)` function.

```
// Process the text based on selected conversion type
            if (selectedConversionType === 'finger') {
                convertToFingerSpelling(text);
            } else {
                convertToWordSigns(text);
            }

            // Show results section
            resultsSection.style.display = 'block';

            // Scroll to results
            resultsSection.scrollIntoView({ behavior: 'smooth' });
        });
```

Algorithm 1: Finger Spelling

```
// Convert text to finger spelling (character by character)
        function convertToFingerSpelling(text) {
            for (let ink = 0; ink < text.length; ink++) {
                const cha = text[ink];

                // Handle spaces
                if (cha === ' ') {
                    createSignElement('', ' ');
                    continue;
                }

                let imagePath;

                // Check if we have this character in our database
                if (signDatabase.finger[cha]) {
                    imagePath = signDatabase.finger[cha];
                } else {
                    imagePath = signDatabase.default;
                }

                createSignElement(imagePath, cha);
            }
        }
```

Algorithm 2: Word-based text Conversion

```
// Convert text to word signs
        function convertToWordSigns(text) {
            // Split text into words (simple split by space for demo)
            // In a real app, you'd need more sophisticated tokenization
            const wordd = text.split(/(\s+)/);

            for (let ink = 0; ink < wordd.length; ink++) {
                const wor = wordd[i];

                // Handle spaces
                if (wor === ' ') {
                    createSignElement('', ' ');
                    continue;
                }

                if (wor.trim() === '') continue;
```

```
            let imagePath;

            // Check if we have this word in our database
            if (signDatabase.word[wor]) {
                imagePath = signDatabase.word[wor];
            } else {
                // If word not found, fall back to finger spelling
                convertToFingerSpelling(wor);
                continue;
            }

            createSignElement(imagePath, wor);
        }
    }
```

Fig. 5.2 and Fig. 5.3 respectively depict the result for character-based conversion (finger spelling) and word-based conversion successfully without any form of error. The spaces between the words are portrayed as blank spaces on the screen.

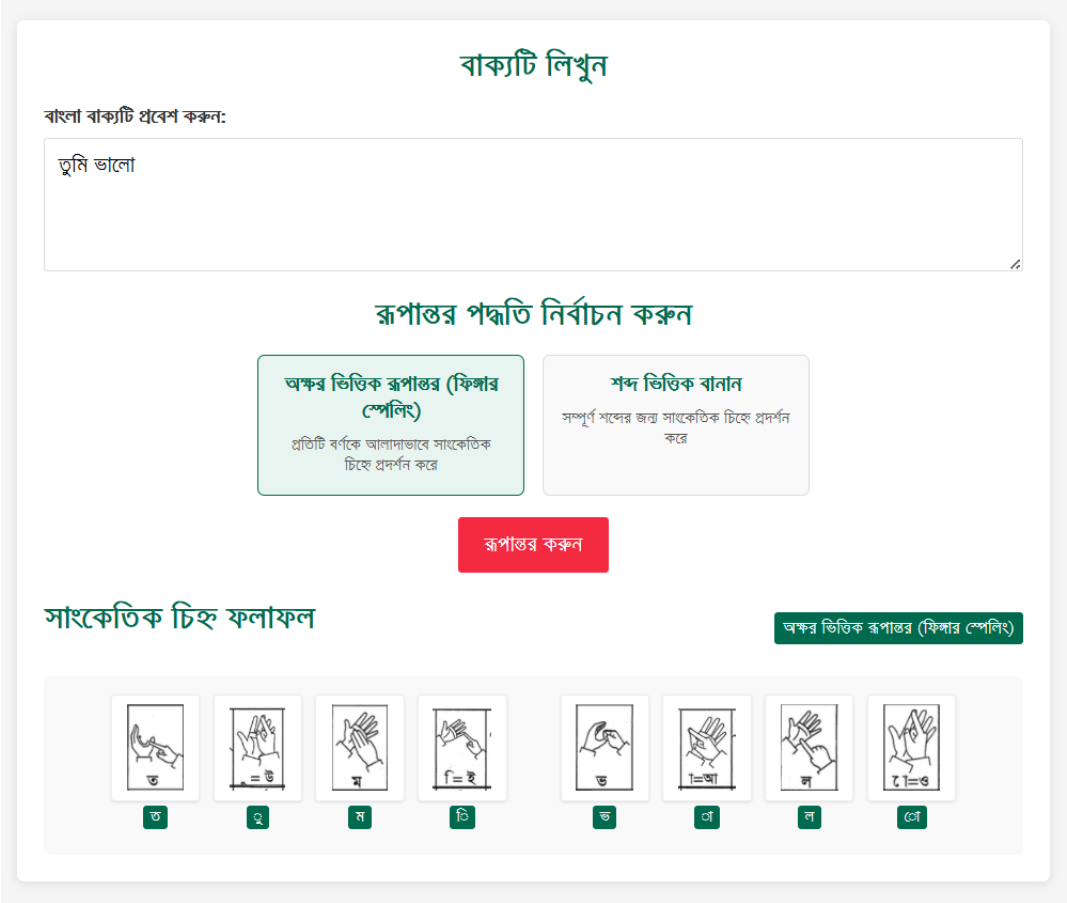

Fig 5.2: Finger Spelling of Bangla Text

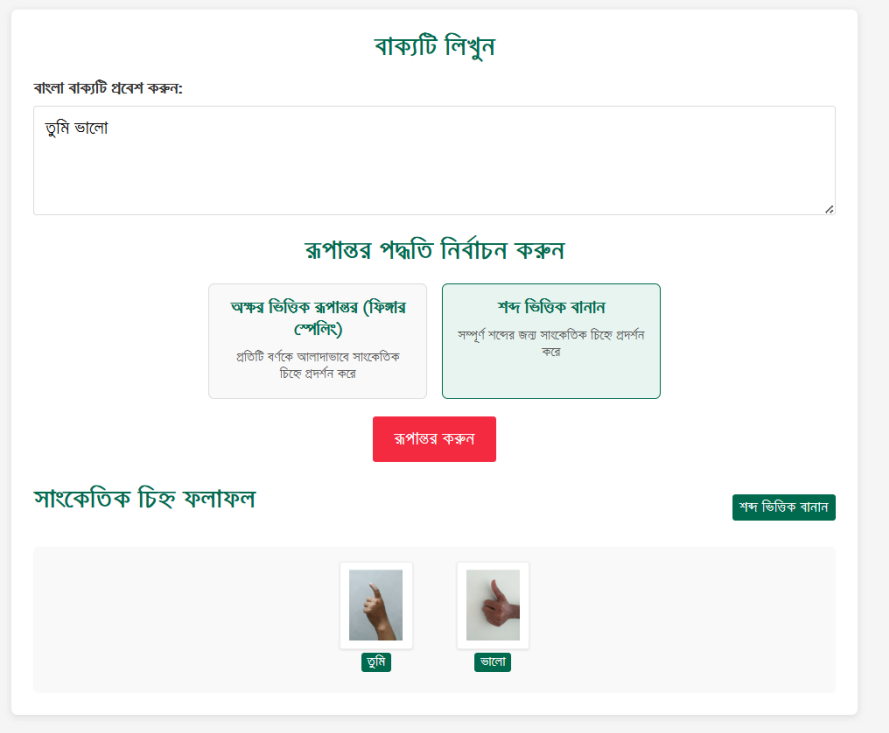

Fig 5.3: Word Based Sign Language Conversion of Bangla Text

As database for word-based text to sign language conversion is limited we aimed to convert the words that are not found in the collection of images to be converted into sign language with the help of finger spelling by dividing them into characters and fetching corresponding images. Fig. 5.4 shows the successful portrayal of our desired action.

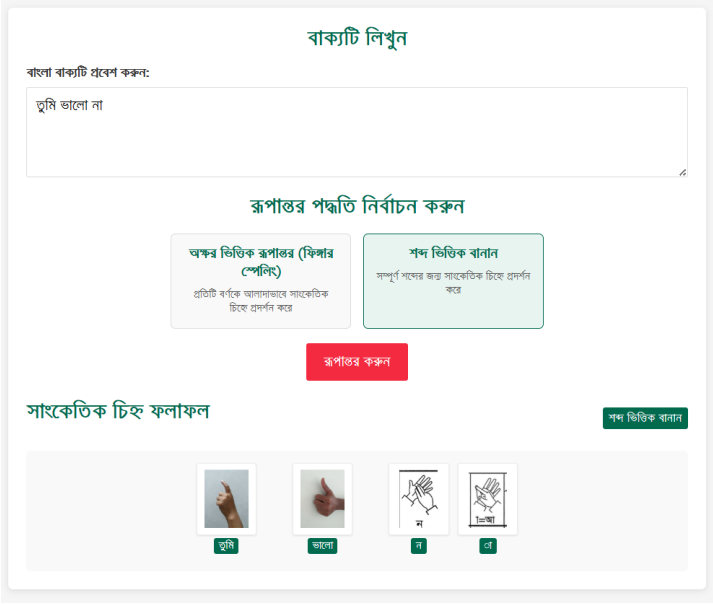

Fig 5.4: Word Based Sign Language Conversion with Finger Spelling of Unfound Bangla Word

CHAPTER 8: CONTRIBUTION

Our initiative has revolutionary impact by pioneering Bangladesh's first-ever real-time text-to-BdSL system that successfully transcribes complex Bangla grammar to natural sign language. The technology shatters essential barriers in education (opening up digital learning opportunities), healthcare (provisioning accurate doctor-patient communication), and public services (providing equal provision to government services) - sectors in which deaf populations currently experience extreme exclusion. It is universally covered through mobile responsiveness, with the open system supporting future innovations for other excluded signing languages.

Together with technology, we're also building a co-designed inclusive ecosystem with deaf community partners and institutions. By replacing human interpreters with a solution that is permanently available, we're facilitating independent living, creating employment, and ensuring social inclusion. This initiative is changing attitudes towards disability as well as building a scalable model for linguistic justice - making assistive technology a catalyst for basic human rights and dignity.

CHAPTER 9: FUTURE WORK

As our database was very small for word-based Bangla text conversion, the application of the web-based application was limited for this case. We aim to extend the dataset and implement the word-based conversion independently without relying on the Finger Spelling algorithm. Then the process to convert text to sign language will be like the following:

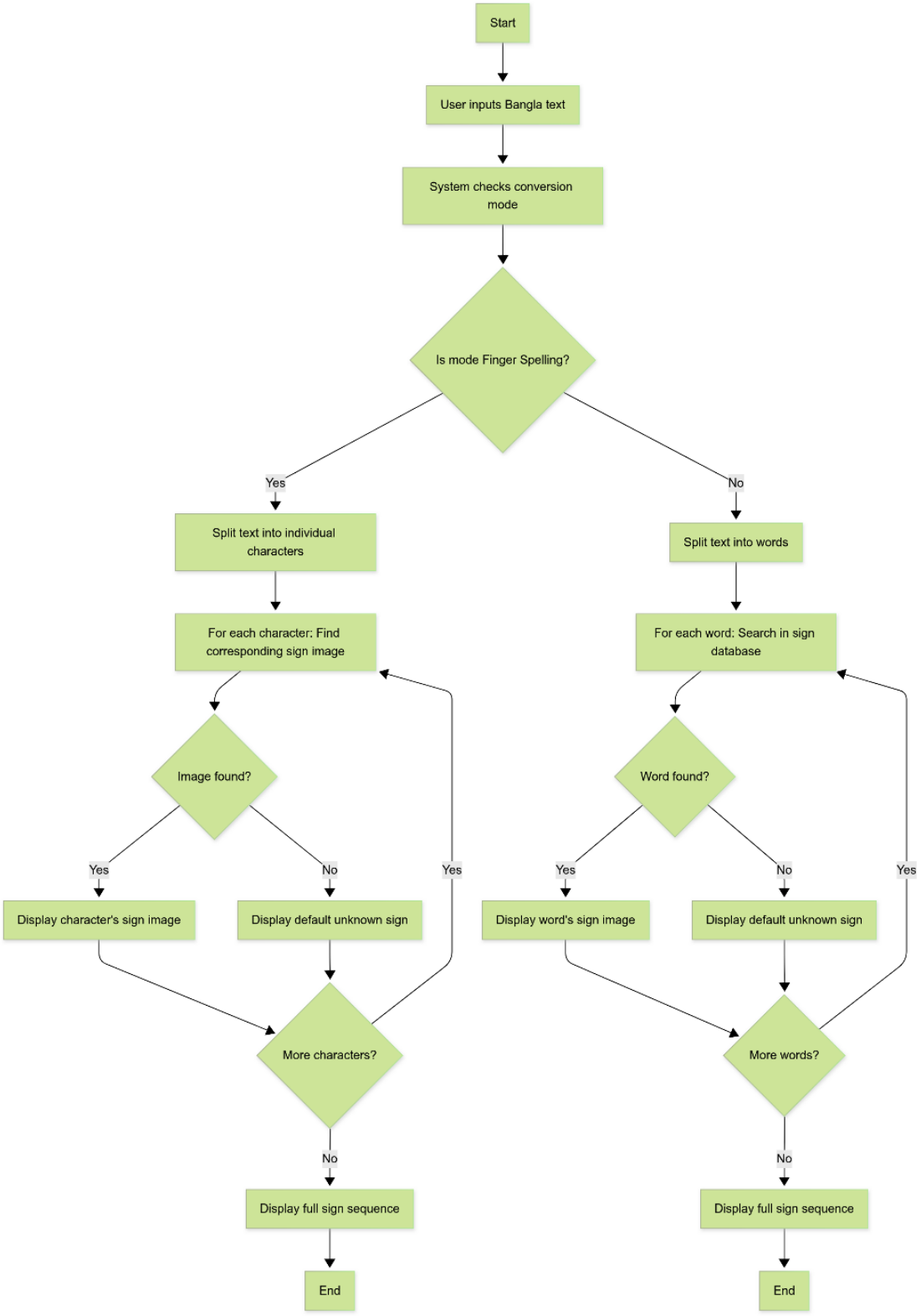

Fig. 6.1: Proposed Bangla text to Bangla Sign Language (BdSL) Conversion Flowchart

CHAPTER 10: CONCLUSION

This paper spotlights the necessity for a real-time Bangla text-to-sign language conversion framework to support the communication needs of nonspeaking individuals in communities in Bangladesh. International advancements in sign language translation systems have effectively demonstrated the effectiveness of natural language processing while Bangla sign language (BdSL) remains underrepresented in terms of technological support and existing local initiatives are limited to static signs with grammar aware translation, real time interactivity and user friendliness. Identifying the key technological, linguistic, and accessibility-related gaps, the paper proposes a framework that integrates natural language processing with animated avatar-based visualization for BdSL. The goal is to preach inclusivity in essential sectors such as education, public services, and healthcare, along with bridging the digital divide.

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