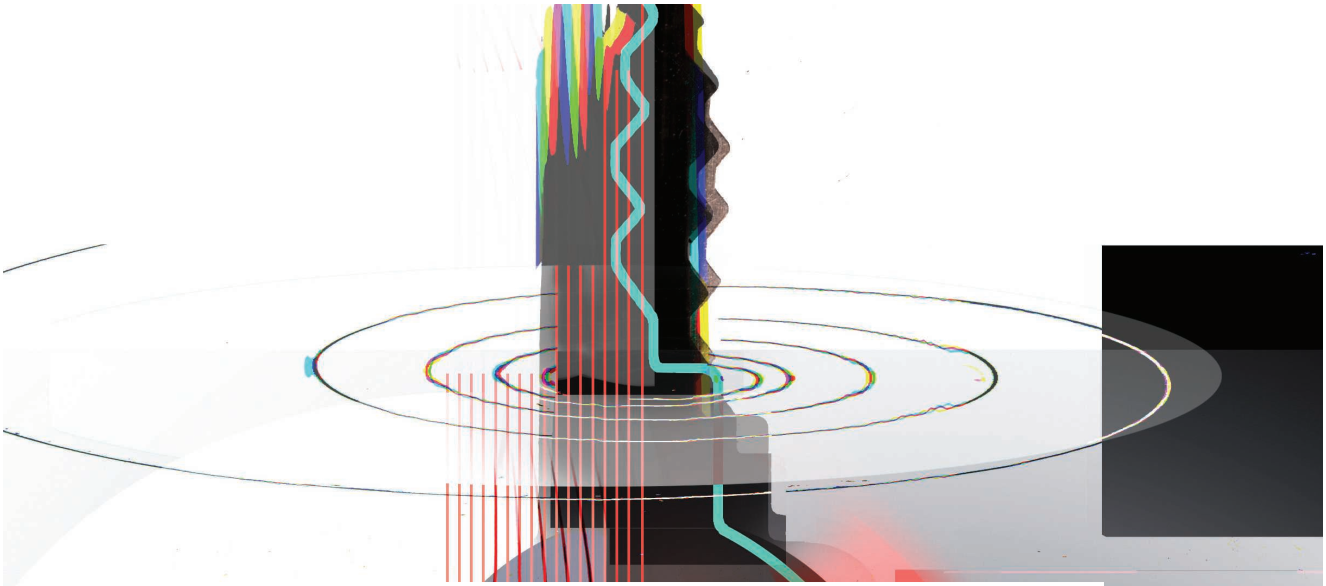

Indian Sign Language Generation System

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Sign language (SL) is used by people with a hearing impairment. To bridge the gap between those who do and do not use SL, we developed a system for real-time translation of the natural language into Indian SL. The system, tested using the BiLingual Evaluation Understudy score, has 95% accuracy.

A World Federation of the Deaf report (https://wfdeaf.org) highlights that around 70 million deaf people in the world need some measure to cater their communication needs. Because spoken languages or audio communication have always had a certain dominance in society, those with a hearing impairment feel isolated. Moreover, most information generated for the masses is conveyed through writing or verbal communication. Hence, the population with hearing impairments, which relies on lipreading or other dedicated visual stimuli, finds it difficult to comprehend general information in public places such as airports, railway stations, banks, and hospitals. Thus, some initiative, which would strengthen sign language (SL) and make it accessible to the hearing impaired, is required.

Considerable research work has been done to bridge this communication gap. But nearly all the results have some limitations, making them unsuitable. Most solutions developed so far are stand-alone systems, which are only accessible by a single user, while other systems are not scalable or restricted only to a single language. A few of the systems have environmental constraints as well, and, hence, the research done so far has been less fruitful for people with impaired hearing. Thus, there is a need for a solution that would generate SL automatically from text or speech. Such a solution could improve the lives of

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those with a hearing impairment and give them access to information they were missing previously.

The proposed system is an automatic SL generation system that can convert text or speech in the Hindi or English languages into its equivalent SL animation. The system uses the Hamburg Notation System (HamNoSys) and Signing Gesture Mark-up Language (SiGML) for storing Indian Sign Language (ISL) symbols, which is further displayed to the user using avatar animation. The system supports both text and speech as inputs and has a scalable vocabulary. The proposed system will help unite the world and promises an inclusive future wherein the knowledge and skills of those with a hearing impairment will also be harnessed for human growth and development.

THE PROPOSED SYSTEM IS THE FIRST ONLINE BILINGUAL SYSTEM AVAILABLE FOR ISL GENERATION BECAUSE NO SUCH SYSTEM CURRENTLY EXISTS FOR REAL-TIME COMMUNICATION.

INTRODUCTION TO SL

SL could be defined as a medium of communication through gestures. It was developed to help people with impaired hearing. They utilize their facial expressions, hand movements, and body gestures to communicate with others. SL is a complex natural language that has its own phonology, morphology, language structure, and sentence structure. Like other languages, even SL has regional influences; there are various types of SL, including American Sign Language (ASL), British Sign Language (BSL), and ISL. Around 4 million Indians use ISL, and while ISL has its own locale influence on different regions of India, it shares the same grammar across the nation.

Every language has a prescribed vocabulary that is analyzed using phonemes, whereas signs in SL are analyzed through cheremes. There are basically two kinds of cheremes: manual and nonmanual. Manual cheremes include hand-shape, hand location, orientation, and movements while the nonmanual cheremes are comprised of facial expressions, eye movements, as well as head and body postures. ISL comprises both one-handed and two-handed signs, which are denoted using one dominating hand or both hands, respectively. The two-handed movements are categorized as type 0 and type 1 signs. In type 0 signs, both hands are active, whereas in type 1 signs, one of the two hands is dominant. Both type 0 and type 1 can be static or dynamic in nature. To understand a language, it is necessary to know its rules of grammar; the next section describes the key features of ISL grammar.

ISL grammar

ISL has its own grammar known as ISL grammar.[1] Sinha[2] has elaborated on some of the main features of ISL grammar, which are as follows.

Each sign in ISL is finger spelled or coinage. The signs of personal names are either finger spelled or based on the physical appearance of an individual. Finger spelling can be used for acronyms, abbreviations, clippings, and even for those words that have not been assigned any sign. ISL does not use any inflections (gerunds, suffixes, or others); rather, it suggests the use of root words only. The use of helping verbs and conjunctions is also restrained in ISL. It has some specific spatial indices of time for denoting tenses.[2] A signer represents the past tense using a backward motion of a hand, stretched toward him or her, and he or she represents the future tense using a forward motion of the hand, that is, stretched away from him or her. ISL supports a combination of multiple words for representing a unified sign. Some aspects are represented as sentence finals as, for example, when representing a question; in that case, the interrogatory word is always placed at the end of sentence and followed by nonmanual expressions (like eyelid, eyebrow, mouth, shoulder, and facial movements).[3] Negation in sentences is also denoted as sentence finals and, hence, “not” is placed at the end of such sentences.[4]

RELATED WORK

Researchers have been studying SL generation systems for the last couple of decades. The important directions in this research work are reported in this section.

Elliott et al.[9] developed the Virtual Signing, Animation, Capture, Storage, and Transmission (ViSiCAST, see http://www.visicast.cmp.uea.ac.uk/) system for multilingual sign translation from English text language to European SLs like BSL, Deutsche Gebärdensprache (DGS; German), and Nederlandse Gebarentaal (NGT; Dutch). This system uses virtual signing technology for 3D animation.

SignSynth was developed by Grieve-Smith to provide weather information. It has a modular architecture that takes inputs in either ASCII–Stokoe notation or Roman/ASCII–Stokoe text, and it uses virtual reality modeling language (VRML) to generate 3D animation (https://www.panix.com/~grvsmth/signsynth/demos/). The Essential Sign Language Information on Government Networks (eSign) was developed by Hanke et al.[8] for multilingual sign translation from English to BSL, DGS, and NGT (http://www.visicast.cmp.uea.ac.uk/eSIGN/index.html). eSign uses various coding systems to describe different components of signing like manual and nonmanual components.

Piccarillo et al.[11] developed an SL system for public address and emergency alerts called Signtel (http://www.signtelinc.com/asl-emergency-alert-system.html). It takes English as an input and translates it into ASL using prerecorded sign videos. Kar et al.[4] built the INdian Gestural Interaction Translator (INGIT) system for the machine translation of Hindi speech to ISL. The framework was developed for railway reservations and uses hybrid formulaic grammar-based framework. Say It Sign It (SiSi, see https://www.youtube.com/watch?v=RarMKnjqzZU) was developed as part of the IBM project by Glauret et al.[12] (http://aquavalens.org/documents/3523509/3529270/Say+it+sign+it+case+study.pdf). It provides the interface for generating BSL from speech and renders it using an message queuing telemetry transport avatar. It automatically generates SL for radio, television, and telephone calls.

Dasgupta et al.[5] developed a framework for the machine translation of English text to ISL.[5] The system displays final ISL sentences as prerecorded video streams. Dicta-Sign was developed by Matthes et al.[13] (https://www.sign-lang.uni-hamburg.de/dicta-sign); this system makes online communications more accessible for users who are hearing impaired. They can play a sign using the sign look-up tool and see the corresponding signs in four languages—BSL, DGS, Greek Sign Language, and French Sign Language.

ProDeaf (http://www.prodeaf.net/), developed by Correa et al.[14] enables communication between people who do not understand SL and those with impaired hearing. The system recognizes phrases and words spoken in Portuguese and translates them into the corresponding signals in the Brazilian SL using virtual characters. The Malayalam to ISL translation system was developed by Joy and Balakrishnan.[6] It helps disseminate information to deaf people in public places like railways, banks, and hospitals. Using a rule-based approach, this system maps outputs generated by stemming module to the animation module for 3D animation.

Goyal and Goyal[7] developed an ISL video dictionary using synthetic animation. The dictionary can be used to translate spoken or written English sentences into ISL animation. It uses eSignEditor for writing HamNoSys of a sign and a 3D avatar for ISL animation.

Based on this review, we concluded that the available systems are limited to domains, and there are no publicly online systems available for generating ISL from either the Hindi or the English language sentences.

The system we propose uses HamNoSys, SiGML, and 3D avatar animation for generating ISL; these tools are discussed in next section.

MILLIONS OF SUCH PEOPLE MAY FEEL ISOLATED AND DEJECTED DUE TO THE LACK OF COMMUNICATION AND LEARNING AIDS.

PRELIMINARIES

To process SL, some written representation is required. To serve this purpose, the proposed system uses HamNoSys notation for denoting the signs in written form. Further, it uses SiGML and avatars for producing 3D animation of signs. All are discussed below.

HamNoSys was developed by Prillwitz et al.[15] Hanke et al.[8] further introduced a fourth version for writing SLs. HamNoSys is a phonetic-based notation system, which was initially handwritten but can also be understood by the machine. HamNoSys represents both manual and nonmanual signs. It can describe the manual features by defining hand shape, location, orientation, and hand movement. It provides a symmetry operator for representing

TABLE 1. The HamNoSys, SiGML, and avatar animation of the word *you*.

Word	HamNoSys	SiGML	Avatar animation
You		<sigml> <hns_sign gloss="you"> <hamnosys_nonmanual> </hamnosys_nonmanual> <hamnosys_manual> <hamfinger2/> <hamthumbacrossmod/> <hamextfingero/> <hampalml/> <hambetween/> <hampalmdr/> <hamchest/> <hammoveo/> <hamsmallmod/> </hamnosys_manual> </hns_sign> </sigml>	

nonmanual components of two-handed signs. HamNoSys represents head, mouth, and eye movements using nonmanual signs. It has approximately 200 iconic characters.

Systems based on HamNoSys are more flexible, scalable, and robust than other notations (https://aslfont.github.io/Symbol-Font-For-ASL/ways-to-write.html). The proposed system uses HamNoSys notation to generate ISL.

SiGML was developed at the University of East Anglia for specifying signing sequences in the ViSiCAST project. SiGML converts HamNoSys into XML tags.

Table 1 depicts the SiGML of *you* with its HamNoSys and avatar animation. In between the SiGML tag <*sigml*>, both nonmanual and manual signs are described. The tag <*hamnosys_nonmanual*> shows facial expressions and <*hamnosys_manual*> includes the hand shape, finger orientation, palm orientation, hand location, hand touch, and hand movement.

A Web Graphics Library (WebGL)-based avatar has been used to play the sign. SiGML is given as an input to a 3D animation rendering server to generate animation frames. These frames describe the static pose of the avatar.[9] It represents the signs in the form of 3D avatar animation, as shown in Table 1.

THE ARCHITECTURE OF THE PROPOSED SYSTEM

The architecture of the proposed system for generating SL from a text or voice input is discussed in this section. At a closer level, the system is divided into five modules that work in parallel to generate SL, as shown in Figure 1. The proposed system can be accessed online (at http://www.islfromtext.in) and an Android application *Sanket* is freely available for download from the Google Play store.

User input

The proposed system can accept user input in two languages, namely, Hindi and English. The inputs can be numbers, words, or sentences.

The user can input in English directly, but to give an input in Hindi language, the user has two options. Inputs can either be entered using transliteration for Hindi words or the user can paste Hindi words or sentences directly in the interface for Hindi language.

The mobile application and website also have an built-in voice interface into which the user can feed English sentences or words without typing. A speech recognizer enables this function. Android has its own speech to text application programming interface (API), which is included in the application and, further, a listener is used to synthesize speech when recognition-related event occurs. For incorporating voice data into the web application, a browser-based web speech API is used, which is offered through a secure connection.

Parsing

To parse input, the UDPipe parser API[10] is used for the English and Hindi sentences. The user input is broken down into sentences. Each sentence is parsed using UDPipe parser (http://ufal.mff.cuni.cz/udpipe) to extract information. The parser uses universal dependency, part-of-speech (POS) tags for parsing an English or Hindi sentence. It also lemmatizes words based on their morphological information and further breaks them down into chunks as list of words.

Processing inputs according to ISL grammar

The list of words obtained is further filtered to remove punctuation and stop words like *is*, *am*, *are*, and so forth, as shown in Figure 2(a). The processed outputs are arranged into a data structure in the form of root words, tags, and tense information. This data structure is used for further processing the words based on tense, aspect, and the modality of sentences according to ISL grammar rules. This processing follows subject–object–verb order, as shown in Table 2.

According to ISL grammar, a speaker is represented as a signer whereas in the number aspect, it finger spells each digit. For handling the

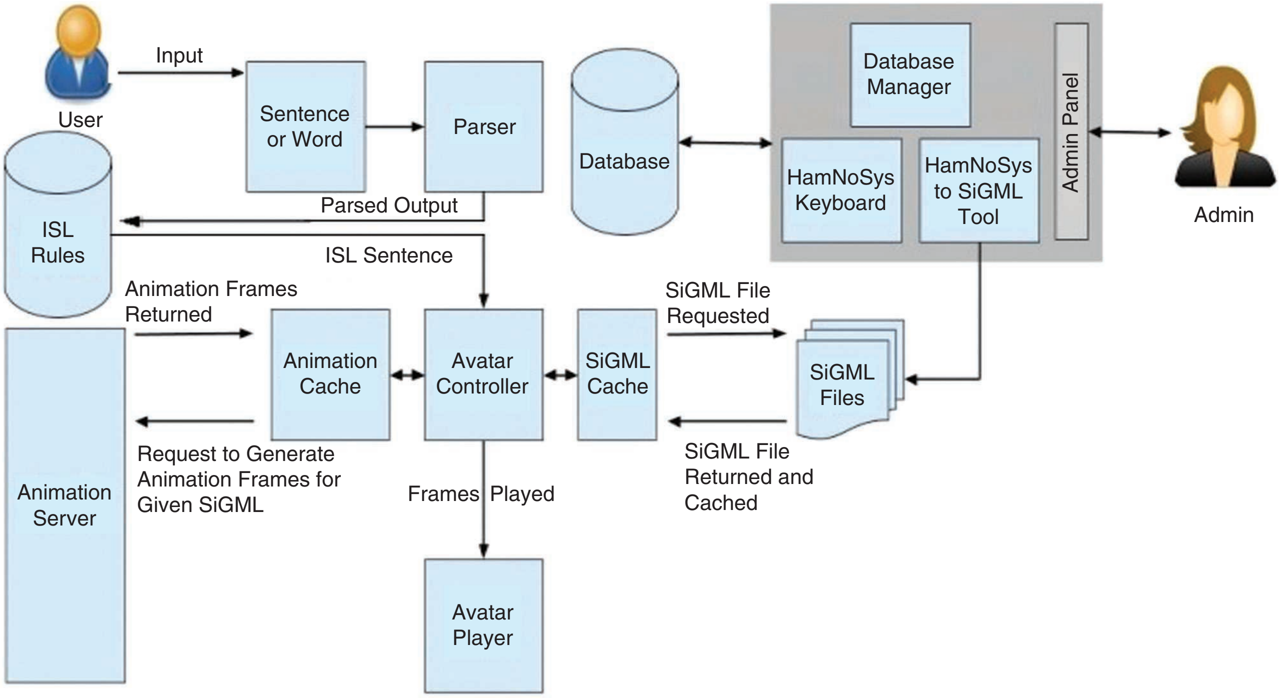


FIGURE 1. The system architecture.

tense of a sentence, the sign of past and future is used before signing the sentence. Similarly, for interrogative and negative sentences, the question word and negation are always placed at the end of sentences. For each of these aspects, a database for ISL grammar rules is developed and implemented in Python based on the output of the ISL sentence. The database applies all the important rules of ISL grammar like word reordering, removal of stop words, handling negations, and question words at end of sentences, which are discussed in the section "ISL Grammar."

Table 2 describes the input sentence, its morphological information produced by the parser, aspects of ISL grammar, and the avatar animation of the corresponding ISL sentence generated by the proposed system.

Extraction of HamNoSys

A database of the ISL dictionary is developed manually through the admin panel by the sign language experts. The admin panel provides the interface for adding, deleting, and modifying the HamNoSys for each word. Two thousand words are stored in the database with their corresponding Hindi words. The database also stores more than 300 commonly used simple sentences. Each word entry is searched in the database. If the word is present, its corresponding HamNoSys is fetched from the database. After fetching the HamNoSys of each word, it is converted into an SiGML file, as discussed next.

Generation of SiGML

When the HamNoSys of a word is developed and stored in the database, its SiGML file is generated and added automatically to the server with the help of the HamNoSys-to-SiGML conversion module.

All SiGML files are stored on the file server. This makes them accessible to the avatar controller. SiGML files can be accessed via both HTTP and FTP protocols. To access SiGML files via HTTP, the avatar controller makes an Asynchronous JavaScript and XML.2 request. These SiGML files are then passed onto the avatar controller module.

The avatar controller

The SiGML files are treated as an input to the avatar controller. The avatar controller works in two steps. First, it tries to find the SiGML file for the word received as an input. If the word is not found in the database, then it is broken down into alphabets, and a SiGML file

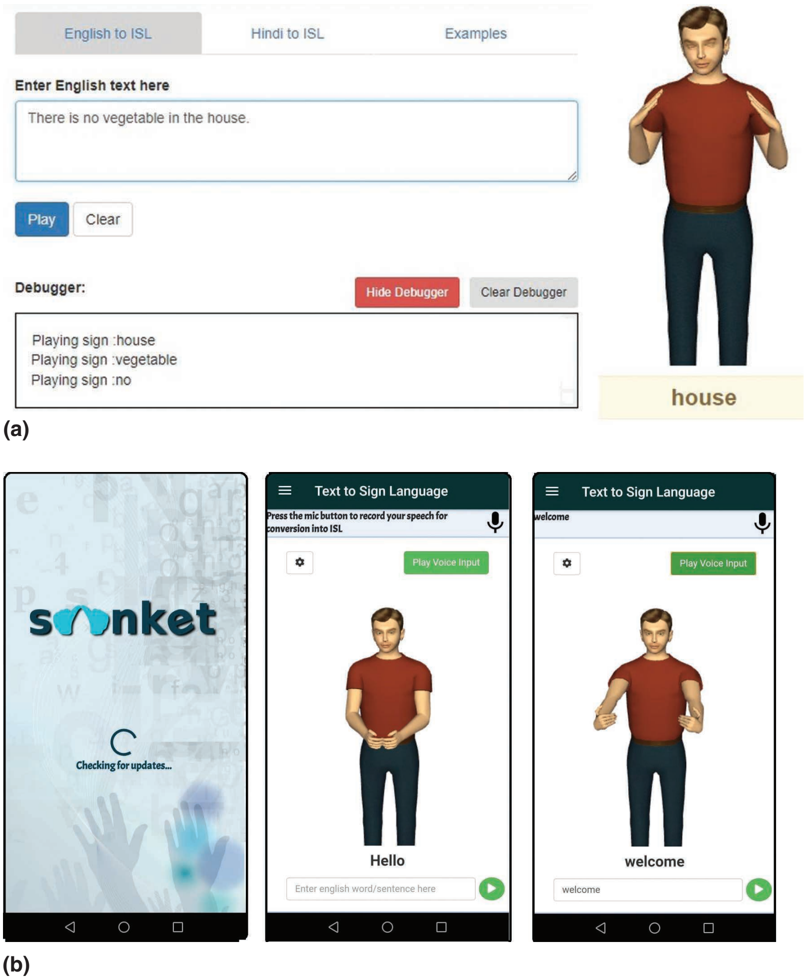


FIGURE 2. (a) The user interface and (b) the mobile application *Sanket*.

for each alphabet is fetched from the SiGML cache. Word/alphabet-to-SiGML mapping is used to download SiGML files from the SiGML file server; those files are sent to the animation server for rendering, which plays its sign as 3D avatar animation.

The implementation of the proposed system is shown below, with an example sentence:

Example sentence:

There is no vegetable in the house. (1)

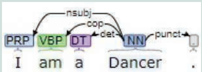
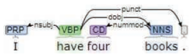
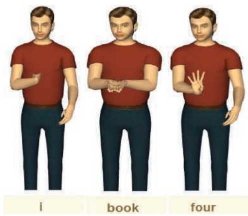
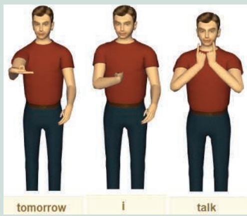
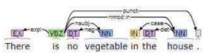
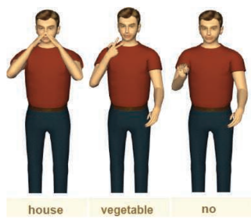
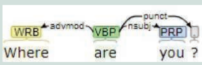
Sentence (1) is given as an input by the user, and, after parsing, it generates seven chunks: *There*, *is*, *no*, *vegetable*, *in*, *the*, *house*. As discussed in the section "ISL Grammar," ISL uses only root words, therefore, *there*, *is*, *in*, and *the* are eliminated. Thereafter, word reordering is performed according to ISL grammar, and the sentence generated is "house vegetable no," as depicted in Figure 2(a). Using HamNoSys and SiGML, its avatar animation is played. Similarly, other aspects of ISL are explained in Table 2.

THE FEATURES OF THE PROPOSED SYSTEM

The proposed system has various features like compatibility and flexibility and is easily accessible to users. They are discussed as follows.

- The system has both a web interface and a mobile app. Figure 2(a) depicts the web interface (www.islfromtext.in) through which a user can give inputs in English or Hindi and the ISL output is generated using 3D avatar animation.
- The mobile application *Sanket*, as shown in Figure 2(b), has a feature for speech to text. This application is also available in the Google Play store.
- The system has a separate interface for handling the database where the administrator can add, delete, search, and modify words using various filters. Using this interface, ISL signs can be easily created, deleted, or updated.
- It uses real-time HamNoSys for representing gestures instead of prerecorded videos, which provides flexibility in terms of the generation of signs.
- It has a special keyboard for creating signs and a module for automatically converting HamNoSys to SiGML.
- It has the corpus of 2,000 words and approximately 300 sentences. The system offers many filters, which the administrator can easily search for a specific word in the corpus.
- The system uses WebGL for fast 3D avatar animation and makes it compatible with all browsers.
- The avatar API has also been developed; it provides various

TABLE 2. Example sentences with their HamNoSys and avatar animation.

Input text	Morphological information	Type	Avatar animation
I am a dancer.		Person	
I have four books.		Number	
I will talk tomorrow.		Tense	
There is no vegetable in the house.		Negation	
Where are you?		Question	

functionalities for avatar animation, including playing the animation of a word or sentence, speeding animation up or down, monitoring animation speed, replaying animation, releasing the lock of the avatar, and checking for errors. These functions can be integrated with other applications.

EVALUATION

To ensure the smooth functioning, accuracy, and quality of SL generation, two types of evaluation were performed: a BiLingual Evaluation Understudy (BLEU) score for sentences and manual evaluation of words and sentences. The details of these evaluations are as follows.

The proposed system has a rich corpus of 800 most commonly used sentences in the English language. For each sentence, the ISL experts manually generate an output based on ISL grammar. Further, this output is compared with the output generated by the proposed system using its BLEU score. The BLEU score is a measure to compare system-generated sentences based on their similarity with the manual output of SL experts. The score always lies between zero and one, where one denotes resemblance in sentences and zero means dissimilarity between them. Hence, the BLEU score is computed using

$$\text{BLEU} = BP * \exp\left(\sum_{n=1}^{N} w_n * \log p_n\right). \quad (2)$$

Here BP is the penalty for sentence length, p_n is the modified n-gram precision, and w_n equals $1/N$.

After the assignment of a BLEU score to each sentence, an average of

TABLE 3. A comparative analysis of the existing and proposed systems.

Systems	Name	Corpus size	Grammar used for parsing	Undertaking technique	Online accessible	Access type	URL	Transliteration
S1	TEAM	Small	Syntactic transfer based, tree adjoining grammar parser	Synchronous tree adjoining grammar	No	None	NA	No
S2	VisiCAST	Medium	Head-driven phrase structure grammar	HamNoSys, SiGML	Yes	Public	http://www.visicast.cmp.uea.ac.uk/	No
S3	SignSynth	NA	ASCII–Stokoe notation	Web 3D or VRML	Yes	Public	https://www.panix.com/~grvsmth/signsynth/	No
S4	eSign	Large	Linguistic representation	HamNoSys, SiGML	Yes	Public	http://www.visicast.cmp.uea.ac.uk/eSIGN/index.html	No
S5	Signtel	Large	Example-based translation	Audio synchronization with SL videos	Yes	Public	http://www.signtelinc.com/first-sign-language-pa-and-emergency-alert-system-eas.html	No
S6	INGIT: Hindi to ISL	Small	Ellipsis resolution	Ellipsis resolution, HamNoSys	No	None	NA	No
S7	SiSi	NA	–	MQTT and microbroker	Yes	Private	http://mqtt.org	No
S8	English to ISL	Small	Transfer grammar rule	Morphological analyzer, Transfer lexicon	No	None	Not available	No
S9	Dicta-Sign	Large	Linguistic representation	HamNoSys and SiGML	Yes	Public	http://www.sign-lang.uni-hamburg.de/dicta-sign/portal/lang_inform.html#box	No
S10	ProDeaf	NA	–	Avatar animation	Yes	Private	http://www.prodeaf.net	No
S11	Malayalam to ISL	Small	POS	Morphological analyzer, optimizer	No	None	NA	No
S12	English to ISL	Medium	Probabilistic context-free grammar	HamNoSys, 3D avatar animation	No	Private	NA	No
S13	Proposed system	Medium	Context-free grammar, Computational Paninian grammar	HamNoSys, 3D avatar animation	Yes	Public	http://www.islfromtext.in	Yes

Note. NA: not available.

these scores is calculated. This average is a clear estimate of the translation quality of the system. On evaluating the proposed system, an average BLEU score of 0.95 was achieved.

For more robust testing of the system, a manual evaluation was performed; it involved six ISL experts who evaluated 2,000 words. For each of these words, avatar animation was played. Based on the accuracy and resemblance with the real ISL sign, the ISL experts awarded a score on the scale from 1 to 5. A score of 5 denotes exact similarity, 4 means good, 3 represents average interpretation, 2 means poor, and 1 denotes very poor. For computing the final scores, a weighted mean was used, as given in (3). The resulting score on evaluating the words of the corpus was 4.3, which denotes a great performance by the proposed system:

$$\bar{x} = \sum_{i=1}^{n} \frac{w_i * x_i}{w_i}. \quad (3)$$

Here, w represents the weight, that is, the number of sentences or number of words having a score of x.

Apart from these tests, a sample of 800 commonly used sentences, including simple, interrogative, declarative, and negative, was also tested. This test was manually performed by ISL experts to ensure that the reordering of words in a sentence generated by the system was consistent with per ISL grammar rules. Based on the performance of each of these sentences, they were assigned a score on a scale from 1 to 5. The final weighted mean of the 800 sentences was 3.9, denoting average performance.

Based on the tests, the proposed system achieved a BLEU score of 0.95 or a weighted mean of 4.3 for words and 3.9 for sentences. Evidently, the system delivers a great performance and generates good quality ISL signs. Thus, this system is a great learning and communication aid for those with a hearing impairment.

COMPARISON OF THE EXISTING AND PROPOSED SYSTEMS

A comparative study, based on features, SL grammar usage, tool availability, was done for the existing SL generation system and the proposed system, as depicted in Table 3.

From the analysis, we conclude that the proposed system is the first online bilingual system available for ISL generation because no such system currently exists for real-time communication. The main features of the proposed system that make it unique are its rich vocabulary database, admin panel to handle the database, HamNoSys-to-SiGML conversion module, 3D avatar animation, speech to ISL. and general architecture, which can be extended to other languages.

In this study, we proposed a solution for catering to the communication needs of people with impaired hearing. Currently, millions of such people may feel isolated and dejected due to the lack of communication and learning aids. To solve this problem, this study discusses an automatic ISL generation system that takes Hindi and English sentences as inputs and outputs corresponding sign animation using ISL grammar rules. The system consists of separate parsers to tackle Hindi and English sentences and, further, implements ISL grammar rules. To produce the 3D animation, WebGL technology is used that integrates HamNoSys and SiGML for storing and retrieving signs. To assess the robustness of the system, testing was performed with the help of SL expert manual evaluations and BLEU scores. The system ensures excellent performance and attained a high BLEU score during the testing phase. Thus, the system would prove to be a great tool for learning and communication with people with a hearing impairment, and it can be a stepping stone to an inclusive world.

In the future, the HamNoSys corpus should be expanded, and the proposed system should be able to handle even complex sentences in both the English and Hindi languages. C

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