Sign Language Generation System Based on Indian Sign Language Grammar

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Sign Language Generation System Based on Indian Sign Language Grammar

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Sign Language (SL), also known as gesture-based language, is used by people with hearing loss to convey their messages. SL interpreters are required for people who do not have the knowledge of SL, but interpreters are not readily available. Thus, a machine-based translation system is required to translate the text into SL. In this article, a system is implemented for translating English text into Indian Sign Language (ISL). It acts as a tool for human-computer interaction and eliminates the need for an ISL human interpreter for communicating with people who have hearing loss. The system features a rich corpus of English words and commonly used sentences. It consists of components such as an ISL parser, the Hamburg Notation System, the Signing Gesture Mark-up Language, and 3D avatar animation for generating SL according to ISL grammar. The proposed system has been tested rigorously by SL users. The results proved that the proposed system is highly efficient and achieves an average score of accuracy (i.e., 4.2 for English words and 3.8 for sentences on a scale from 1 to 5). The performance of proposed system has also been evaluated using the BiLingual Evaluation Understudy score, which results in 0.95 accuracy. The proposed system and mobile application together has the potential to bring individuals with hearing loss and their entourage together.

CCS Concepts: • **Human-centered computing** → **Text input**; **Graphical user interfaces**; • **Information systems** → **Texting**; Multilingual and cross-lingual retrieval; • **Computing methodologies** → **Natural language generation**; • **Computer systems organization** → *Real-time languages*; • **Software and its engineering** → Parsers;

Additional Key Words and Phrases: Sign Language (SL), Indian Sign Language (ISL), hearing loss people, human-computer interaction, text to sign, communication, speech to sign

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1 INTRODUCTION

The advancement in Information and Communication Technology (ICT) has affected human life in all aspects. It has changed the manner in which humans work, manage business, study, travel, and communicate. For making its efficient use, there is a need to investigate how ICT can be used to help the hard of hearing community in defeating their communication issues. There are 7.7 billion people in the world,[1] of which approximately 70 million people are deaf according to the World Federation of the Deaf. People with hearing loss developed Sign Language (SL) to spread information among the community. SL is a complete language, like other languages, and is widely used for communicating with people with hearing loss. Approximately 200 SLs are used by the deaf community all over the world.[2] It is a gesture-based language, in which hand gestures, body gestures, and facial expressions are used to convey information. Anything communicated in spoken language can be easily communicated via gestures. SL is an independent language and is used all over the world with native differences, similar to spoken languages. SL varies from region to region—that is, the sign representation of a word might vary in its native SL.

Today, there is not any international standard for SL, and thus to communicate with people across the globe, one has to learn the native SL. Every region has its own SL interpretation. However, some signs are universal. For example, the sign for *Sun* is the same in American Sign Language (ASL), British Sign Language (BSL), and Indian Sign Language (ISL). The sign for *Sun* is shown in Figure 1.[3] In India, an individual with hearing loss uses ISL as a communication medium. There are 1.3 million users of ISL in India.[4] ISL has its own syntax and grammar just like any other natural language [1]. The signs used in ISL are classified in two categories: one-handed and two-handed signs. Further, these are categorized as static and dynamic signs [2]. A sign involving any kind of movement is known as a dynamic sign, and a sign without movement is known as a static sign. Every sign in SL is categorized into manual and non-manual signs. Signs that use facial and body expression are called *non-manual signs*, and signs that does not consist of these expressions are called *manual signs*. Communication with individuals with hearing loss is not possible without a translator if the person does not have the knowledge of SL. Moreover, the conversation loses its privacy due to involvement of the SL interpreter, and there are limited ISL experts in India [1]. Hence, there is a need to develop a system that can generate ISL from English text. This would aid in communicating with individuals with hearing loss. Therefore, building up a system that interprets English text into its corresponding SL interpretation and gives output in the form of an animation will significantly affect the hard of hearing community in India.

To abridge this communication gap, plenty of research work has been carried out, including INGIT [2], English to ISL [1, 9, 11, 12, 14, 17], Hindi to ISL [16], Malayalam to ISL [13], and Punjabi to ISL generation [15]. However, each one of them has its own limitations, making them incompatible for use in day-to-day life. The majority of systems that have evolved are not flexible and are confined to a single language, whereas other systems have a limited corpus. Most of the systems offer only a word-sign search-based approach. In some systems, pre-stored phrases and videos are used for SL generation. A few systems have domain and environmental restrictions. Thus, research so far has been less productive for individuals with hearing loss. Therefore, the requirement for a solution that could generate SL naturally from speech or text was considered, which could improve the lives of people with hearing loss and would help them gain knowledge. Presently, there

[1] http://www.worldometers.info/world-population/.
[2] https://isilanguagesolutions.com/2019/04/15/interesting-facts-about-american-sign-language/.
[3] https://spreadthesign.com/in/.
[4] https://www.npr.org/sections/goatsandsoda/2018/01/14/575921716/a-mom-fights-to-get-an-education-for-her-deaf-daughters.

(a) (b) (c)

Fig. 1. Sign for *Sun* in ASL (a), BSL (b), and ISL (c).[3]

are more than 566 million mobile Internet users,[5] and most of the people use the English language for browsing the Internet in India. Thus, the proposed system has been designed considering English as the input language. A web interface and a mobile app for generation of SL have also been developed, which is the first of its kind and portable.

In this article, a system is presented through which natural language (i.e., English text) is translated into 3D ISL animation. To the best of our knowledge, it is the first fully available system for public usage. For implementing this system, a Hamburg Notation System (HamNoSys)-based corpus was developed [3]. Moreover, a rule-based parser was also developed to generate ISL based on its grammar. This system is efficient for people who do not know SL and feel that it is difficult to communicate with individuals who have hearing loss. The proposed system can be used at various places, such as banks, post offices, bus stations, railway stations, and airports, for communicating and sharing information. It can be used to provide information and will aid in the exchange of knowledge. Further, it can also be used in schools and colleges for educational purposes. Therefore, the system will play a vital role in bridging the gap and eliminating all of the obstacles to communicate with individuals who have hearing loss. Moreover, the proposed system can be accessed anywhere via the web or mobile interface.

The article is organized as follows. A literature review on gesture-based generation systems is presented in Section 2. ISL grammar and its various aspects are presented in Section 3. Further, Section 4 highlights the techniques used by the proposed system, and Section 5 discusses the features of the proposed system. Section 6 describes the HamNoSys-based ISL corpus, and Section 7 highlights the working of system and rules used for translation of natural language into ISL with example sentences. Section 8 depicts results on the basis of its quality evaluation of the parser and sign generation, and Section 9 includes the error analysis of the proposed system. A comparative study of ISL generation systems is depicted in Section 10, and limitations of the proposed system are discussed in Section 11. Our concluding remarks about the proposed system and future scope are presented in Section 12.

2 LITERATURE REVIEW

For the past few decades, researchers have been working on the development process of SL generation systems. Milestones achieved in the research done in this area are discussed in this section.

A speech or text to SL translation system known as ZARDOZ was developed by Veale and Conway [4]. The system follows an interlingua approach with a blackboard architecture. The cross-modal machine translation system converts English into native SL, such as Irish, British, and American SL, using interlingua representation and the Doll Control Language (DCL)

[5] https://imrbint.com/images/common/ICUBE%E2%84%A2_2019_Highlights.pdf.

animator [4]. It uses various methods to analyze both the verbal input and its corresponding gestural output generated by the system.

Zhao et al. [5] developed Translation from English to ASL by Machine (TEAM). TEAM was the first translation system for English to 3D animated ASL that not only considered linguistic but also visual and spatial information associated with ASL. The translation system uses gloss notation and Synchronous Tree-Adjoining Grammar (STAG) [6] for intermediate representation of English text. Further, a sign synthesizer is employed for Parallel Transition Networks (PaT-Nets) [7] to achieve the smooth transitions between signs.

Kar et al. [2] developed the INGIT system for translation of Hindi text to ISL. The system uses Fluid Construction Grammar (FCG) [2], ellipsis resolution, and the HamNoSys converter for ISL generation from text. It uses a graphical simulator without facial expressions for playing signs of ISL. Moreover, use of the proposed system is restricted to the railway domain, where it is used for making reservations, and hence it has a limited vocabulary of 90 words [2]. Dasgupta et al. [1] introduced an English text to ISL generation system. The system uses Lexical Functional Grammar (LFG) [1] and transfers grammar rules for representation of a sentence in ISL syntax. It has a corpus of 208 sentences and generates signs with an accuracy of 90%, as reported in the literature [1].

Halawani and Zaitun [8] developed a system for translating Arabic speech to Arabic Sign Language (ArSL) using the Microsoft speech recognition engine. This avatar-based translation system uses ArSL grammar. Faraz et al. [9] proposed a translation model for English text to ISL that uses direct mapping between English words and corpus entries. The system handles inquiries related to railway reservations. Moreover, the proposed model's implementation does not follow ISL grammar rules.

Porta et al. [10] developed a translation system for Spanish text to Spanish SL glosses. The system uses a rule-based approach for translation. The transfer-based architecture was implemented from syntactic functions of dependency analyses. The performance of the system was evaluated with an open domain test bed, and the test results reported a 42% Translation Error Rate (TER) and a 0.30 BiLingual Evaluation Understudy (BLEU) score [10]. Mishra et al. [11] introduced a transfer-based system that translates English text to ISL specifically for endocrinologists, in which a doctor types text that is then parsed and forms a parse tree. This tree is then converted into an ISL parse tree according to Subject-Object-Verb (SOV) order. Finally, it generates an ISL that is displayed to patients with hearing loss on a screen [11]. Kaur and Kumar [12] developed a graphical user interface to generate HamNoSys by selecting various symbols. The tool is used for avatar animation of 200 ISL signs. Joy and Balakrishnan [13] developed a prototype for Malayalam to ISL, which takes Malayalam text as input. It translates the input using POS tagger that performs morphological analysis and optimization on sentences.

Kaur and Singh [14] developed the HamNoSys of words based on ISL signs. It uses the JA Signing Gesture Mark-up Language (SiGML) Player app for avatar animation of ISL signs and has a corpus size of 100 words. Verma and Kaur [15] extended this system for the Punjabi language, which generates HamNoSys for Punjabi words. This system has been tested on a corpus of 235 words using the JA SiGML Player app. Vij and Bhatia [16] developed a system that pre-processes Hindi text and translates it into ISL grammar using a dependency parser and WordNet.[6] It uses HamNoSys and SiGML for 3D animation. Goyal and Goyal [17] implemented an ISL video dictionary using synthetic animation, which converts written or spoken English sentences into ISL animation. The system has a dictionary of 1,818 commonly used words. It uses HamNoSys and SiGML for avatar animation.

[6] http://www.cfilt.iitb.ac.in/wordnet/webhwn.

After performing the literature review, it was observed that very few systems have features such as 3D animation, multilingual SL generation, and speech to sign. Most of these systems are limited to a particular domain. However, no real-time system is available online that can be used by the masses over the Internet. Moreover, no mobile app is available to translate the English language into ISL, which provides us with the motivation to develop a system for generation of SL on the basis of ISL grammar. The ISL grammar and its major features are discussed in the next section.

3 ISL GRAMMAR

ISL has its own grammar that is similar to other spoken languages. The whole grammaticalization process used by ISL uses a layered approach. ISL uses different *word orders* depending on its structure. Generally, the basic structure of ISL is Time-SOV. Zeshan [18] stated that ISL follows its own ISL grammar rules. Later, Sinha [19] highlighted various structures and use of ISL grammar. The linguistic study of ISL indicates that ISL grammar follows the same rules all over India [1].

Each sign in ISL is either coinage or finger spelled. ISL neither uses verbs (which show action or a state of being e.g., *is, am, are*) nor uses articles (e.g., *a, an, the*). The finger spelling is used to introduce acronyms, abbreviations, clippings, and words of a spoken language for which there is no sign. ISL does not use any inflections (gerunds, suffixes, or other forms); it uses only root words. Additionally, no conjunctions, articles, or helping verbs are used in ISL. It has some specific spatial indices of time to represent the tense. Past and future tense has an orientation of the back toward the signer and the front toward the line of bilateral symmetry. Most of the ISL lexicon is made up of compounds [1].

The various characteristics of ISL grammar are explained as follows:

(i) *Representation of person:* The first person is always addressed as a speaker and the second person as the addressee. ISL handles the orientation of the signer corresponding to time and place. The pronoun (whose index is R-expression) and anaphora do not exist in ISL. Signs for personal names are based either on a spoken language word or an individual's physical appearance [19].

(ii) *Representation of number*: The numbers are categorized as singular or plural. In ISL, singular is unmarked morphologically and plural is carried out through different strategies in ISL. Reduplication is the common strategy employed for pluralization. In the case of an indefinite plural of a noun, a noun sign is reduplicated three times with change of location [1].

(iii) *Representation of gender*: Gender in ISL is represented by a sign pointing on the side of the face [19]. To express the sign for *male*, it is articulated by a sign marked above the lip level. Similarly, a fingertip on the nose represents *female*.

(iv) *Representation of tenses:* In ISL, all three tenses can be visualized using signs. A spatial time line is used to represent the past, present, and future tense [18]. Figure 2 depicts the time line used in ISL. The present tense in ISL is unmarked, whereas for representing the future or past tense of sentences, a spatial time line representation is used, as shown in Figure 3.

(v) *Representation of aspects:* ISL also accommodates different aspects of a sentence through signs such as formational parameters of the verb, namely movement in terms of tense, dynamics, shape, and size. The continuative aspect usually represents an event continuity without any interruption over a period of time. In the context of ISL, it is expressed by lengthening the verb movement either by triplication or by a verb with no other formational changes [19].

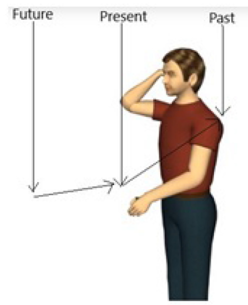
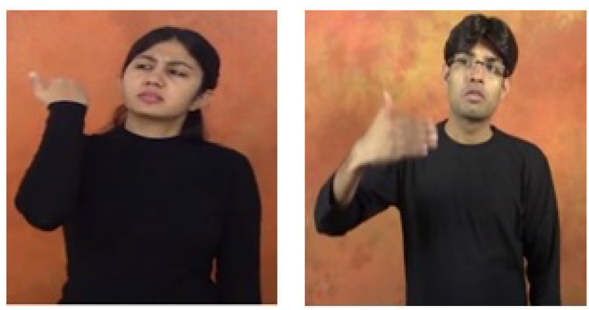


Fig. 2. Time line used in ISL.



(a) (b)

Fig. 3. ISL sign for *past* (a) and *future* (b).

For representing the perfect aspect of a sentence, it uses the grammatical form of *finish*, which can be attached after projecting the sign for verbs such as drink and eat. [19]. The perfect aspect is used to show that an event was completed recently, and this could be done using either a single or double hand.

To represent the recurring (repetitive) nature of any verb or an action in a sentence, there is usually an assignment of aspect to it, which could be a frequentative or iterative aspect. A frequentative aspect is one in which the verb occurs for a prolonged period of time, whereas an iterative aspect is one in which the verb recurs, although for some fixed and definite time period [19]. For articulating the frequentative aspect, the verb is slowly showcased with a lengthening triplicate movement followed by a rounding thrust, whereas the iterative aspect in ISL is represented by the sign for *again*.

The inchoative aspect indicates the state where someone is about to do something. To represent the inchoative aspect, complete articulation of the verb is reduced to an abrupt form [1]. Figure 4(a) depicts that the action of break is initiated and is about to complete, whereas Figure 4(b) shows the complete closure action for break.

(vi) *Representation of relations*: To represent relationships such as *bhai* (brother), *beta* (son), *patni* (wife), and other distinct relations in ISL, a combination of two or more words are used [1]. For example, *bhai* is expressed as *man* followed by the sign for *sibling* (i.e., brother). Similarly, *beta* is expressed as *man* followed by *child*, whereas *patni* is expressed as *woman* and *married*.

(vii) *Representation of questions*: To represent questions, facial expressions and body gestures are also used with hand gestures. To express questions sentences, eyebrows are raised

(a) (b)

Fig. 4. ISL sign for *break*: inchoative aspect (a) and non-inchoative sign (b).

Fig. 5. Types of hand shapes.

[17]. Interrogative terms such as *when*, *what*, and *how* are always placed at the end of a sentence in ISL [20].

(viii) *Representation of negation:* Non-manual signs like facial expressions and head movements are used to denote negation in negative sentences (e.g., shaking of the head). Negation in ISL is represented with the sign for not, which is always placed at the end of sentence [17].

These aspects of ISL grammar have been taken into consideration by the proposed system for generation of ISL sentences. The proposed system uses techniques such as HamNoSys, SiGML, and avatar animation for generation of SL. A description of these techniques is described in the next section.

4 TECHNIQUES USED FOR GENERATION OF SL

In this proposed system, HamNoSys is used for sign representation, SiGML for its conversion to an XML file, and an avatar for generation of signs. A description of these components is provided next.

4.1 HamNoSys

HamNoSys notation was developed by Siegmund Prillwitz in 1984 [3]. It is a standard transcription that has approximately 200 characters and could be used to represent SL in any region. It includes manual and non-manual components. HamNoSys is a phonetic notation that consists of different parameters such as the configuration of hand, movement, location, head, and body gestures. These parameters are named as hand shape, hand orientation, location, and movement, among others. For representing a sign, there are various hand shape symbols available in HamNoSys [21]. Figure 5 shows some of the various hand shapes and finger positions used in HamNoSys.

(a) (b)

Fig. 6. ISL sign for *alone* (a) and its HamNoSys (b).

The hand orientation includes the direction of the fingers and palm. It can be left, right, upward, inward, downward, or outward depending on the position of the signer/body. The location of a sign can be defined using location symbols such as above the head, shoulders, forehead, head, nose, mouth, lips, cheek, ears, neck, chest, stomach, or below the stomach. It also defines the movement of a hand from the initial location to the destination. HamNoSys includes symbols used for representing two-handed signs. Figure 6 depicts the ISL sign for the word *alone* and its HamNoSys.

4.2 SiGML

SiGML [22] was developed at the University of East Anglia for specifying signing sequences. It is an XML form of various tags for representing each symbol of HamNoSys in the particular sign [21]. It starts from the *<sigml>* tag and ends with a closing tag (i.e., *</sigml>*). Thereafter, a gloss attribute is defined that usually refers to the word name for which its SiGML is generated. The non-manual features are defined with their corresponding tags between *<hamnosys_nonmanual>* and *</hamnosys_nonmanual>* tags. For manual features of a sign, the tags are defined within *<hamnosys_manual>* and *</hamnosys_manual>* tag. Figure 7 shows SiGML for the word *alone*.

4.3 Avatar

The avatar, also known as a virtual human, was developed by Elliott et al. [22] at the University of East Anglia. It takes SiGML as input that is generated from HamNoSys notation and produces the animation frames. When played, these frames generate 3D avatar animation. Figure 8 shows avatar animation for the word *alone*.[7]

5 FEATURES OF PROPOSED SYSTEM

The proposed system has various features that make it more compatible, flexible, and easily accessible to users, such as the following:

- The proposed system has both a web interface and a mobile app. Figure 9 depicts the web interface of *www.islfromtext.in* through which a user can give input in English language and the ISL output is generated using 3D avatar animation.
- The mobile application *Sanket* is available in Google Play Store at https://play.google.com/store/apps/details?id=in.dsingh.sanket&hl=en_IN.

[7] http://vhg.cmp.uea.ac.uk/tech/jas/vhg2017/WebGLAv.html.

```
<sigml>
<hns_sign gloss="alone">
   <hamnosys_nonmanual>
     <hnm_mouthpicture picture="L19"/>
   </hamnosys_nonmanual>
   <hamnosys_manual>
    <hamfinger2/>
    <hamthumbacrossmod/>
    <hamextfingeru/>
    <hampalmu/>
    <hamshouldertop/>
    <hamlrat/>
    <hamcircleu/>
    <hammoveo/>
    <hamsmallmod/>
  </hamnosys_manual>
</hns_sign>
</sigml>
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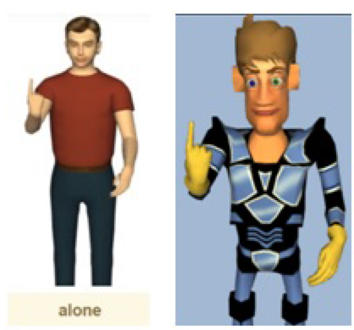
Fig. 7. SiGML for *alone*.



(a) (b)

Fig. 8. Avatar animation of the word *alone* using Humanoid (a) and Cartoon character (b).[7]

- The mobile application *Sanket* has the feature of speech to text conversion. The user can also control the avatar animation speed (i.e., he can increase/decrease the speed). The same is depicted in Figure 10.
- It uses real-time HamNoSys for representing gestures instead of pre-recorded videos, which provides flexibility in terms of generation of signs.
- It has a special keyboard for creating signs and a module for automatic conversion of HamNoSys to SiGML.
- It has the corpus of 2,950 words and 1,000 sentences. There are many filters provided by the system that the administrator can easily use to search a specific word in the corpus.
- The system uses WebGL for fast 3D avatar animation and makes it compatible with all browsers.
- The Avatar Application Programming Interface (API) is also developed, which provides various functionalities of avatar animation such as playing animation of a word or sentence, speeding up/down animation, fetching current animation speed, replaying last animation, releasing lock of avatar, and checking for error for its integration with other applications.

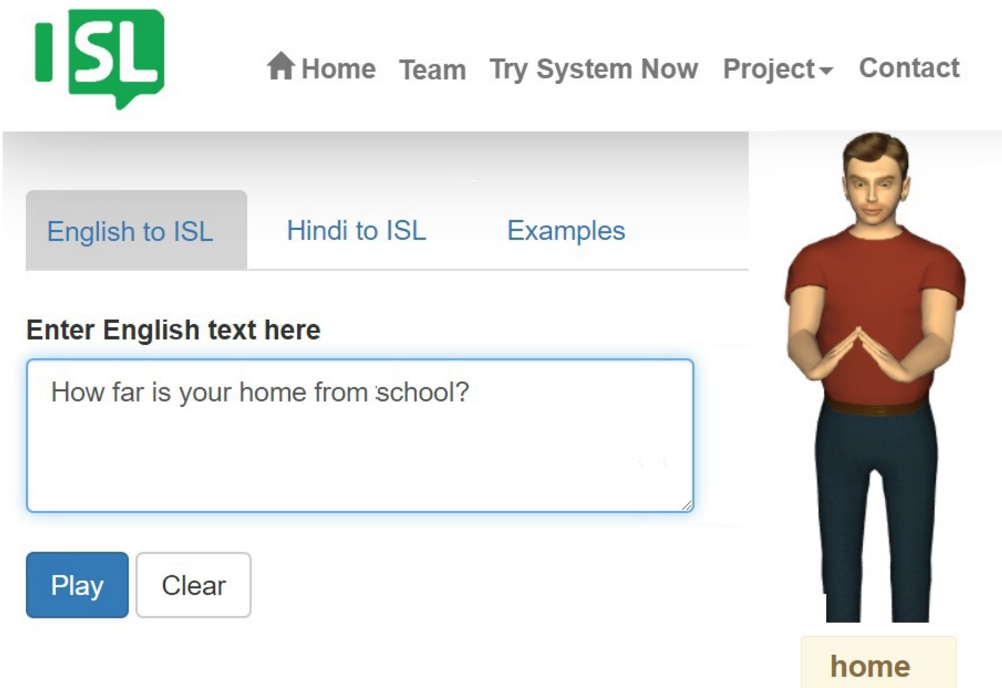


Fig. 9. Web interface of *www.islfromtext.in*.

- There can be two types of users for the proposed system: admin or ISL user.
- The system has a admin panel for handling the database through which the administrator can add, delete, search, and modify the words using various filters. Using this interface, ISL signs can be easily created, deleted, or updated.
- By using the proposed system, an English textbook from the Punjab School Education Board (PSEB) has been reproduced in ISL. This would be very effective in the education of students with hearing loss.

6 HAMNOSYS-BASED ISL CORPUS

The major task for the development of the proposed system was the creation of the HamNoSys-based ISL dictionary. To fulfill this, an online ISL corpus was developed using HamNoSys notation.

This corpus consists of 2,950 various commonly used English words. For each word, HamNoSys experts watch ISL videos developed by the Indian Sign Language Research and Training Centre (ISLRTC), and based on the visual representation of a symbol in the video, its corresponding HamNoSys representation is created, which is stored in the database. Further, SiGML files are created for each of these HamNoSys representations of English words as the system supports automatic HamNoSys to SiGML conversion [21]. Hence, the online database stores English words with their SiGML representations. Moreover, the corpus can also be handled through the admin panel for addition, deletion, and modification of a word and its corresponding HamNoSys for ISL signs.

Details of the corpus on the basis of each category, such as alphabets, numbers, weekdays, animals, countries, jobs, technical, academic, medical, and legal terms, among others, are depicted in Table 1.

In Table 2, information about the ISL corpus on the basis of morphological detail or chunks is shown. The analysis of each word category on the basis of its appearance in 1,000 sentences is

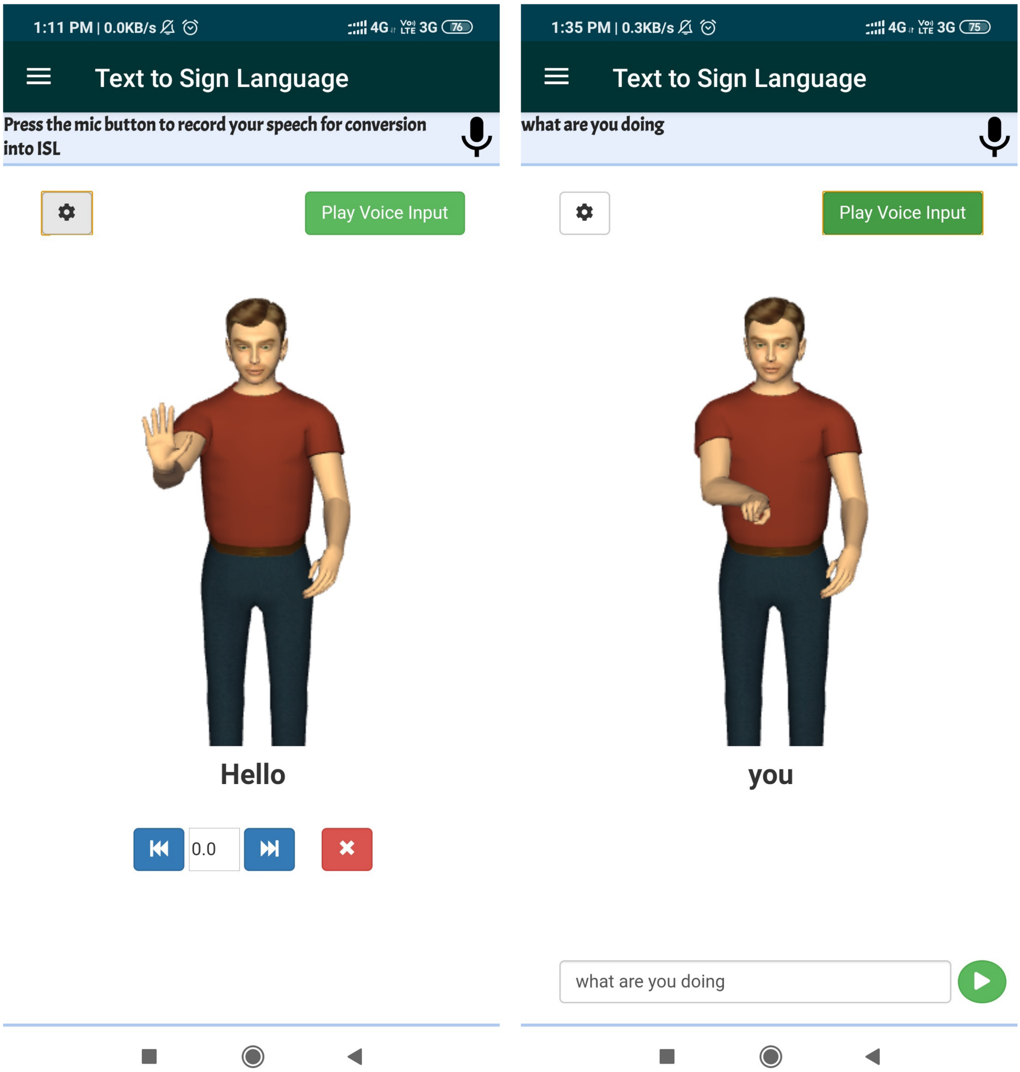


Fig. 10. Mobile interface of the *Sanket* app.

depicted in Figure 11. It consists of various type of sentences, including declarative, interrogative, imperative, exclamatory, and negative sentences. The average length of these 1000 sentences is between 9 to 11 words.

7 SYSTEM ARCHITECTURE

The proposed system generates ISL sentences from English text using ISL grammar as depicted in Figure 12. It takes English words or sentences as an input, which may even consist of numbers. The input is then parsed using the parser, which performs a morphological and syntactical analysis. This results in the formation of root words with their respective morphological information. Through this information, ISL rules are implemented for each of the input sentences. Using these rules of ISL grammar, an output is generated and the word order is fetched. For each fetched root words, the corresponding HamNoSys is obtained from the database. Further, the implicit tool for

Table 1. Categories of ISL Corpus

S. No.	Category	HamNoSys-Based Corpus
1	Alphabets	26
2	Numbers	46
3	Animals, Birds, and Insects	56
4	Basic phrases	9
5	Body parts	17
6	Colors	15
7	Countries, States, and Cities	84
8	Family and Relationship terms	41
9	Festivals and Holidays	26
10	Fruits	18
11	Jobs, Professions, and Trades	91
12	Months	12
13	Places, Buildings, and Institutions	24
14	Vegetables	18
15	Weekdays	14
16	Deaf studies	23
17	Maths	45
18	Science	60
19	Technical terms	330
20	Legal terms	21
21	Academic terms	188
22	Medical terms	150
23	Others (from books and other sources)	1,636
	Total	**2,950**

Table 2. Word Frequency in Corpus

S. No	Category	No. of Words
1	Noun (NN)	2,270
2	Adjective (JJ)	216
3	Noun plural (NNS)	107
4	Adverb (RB)	91
5	Verb (VB)	82
6	Verb gerund/Present participle (VBG)	61
7	Personal pronoun (PRP)	32
8	Coordinating conjunction (CC)	29
9	Preposition (IN)	15
10	Wh-adverb (WRB)	23
11	Others	17
	Total	**2,950**

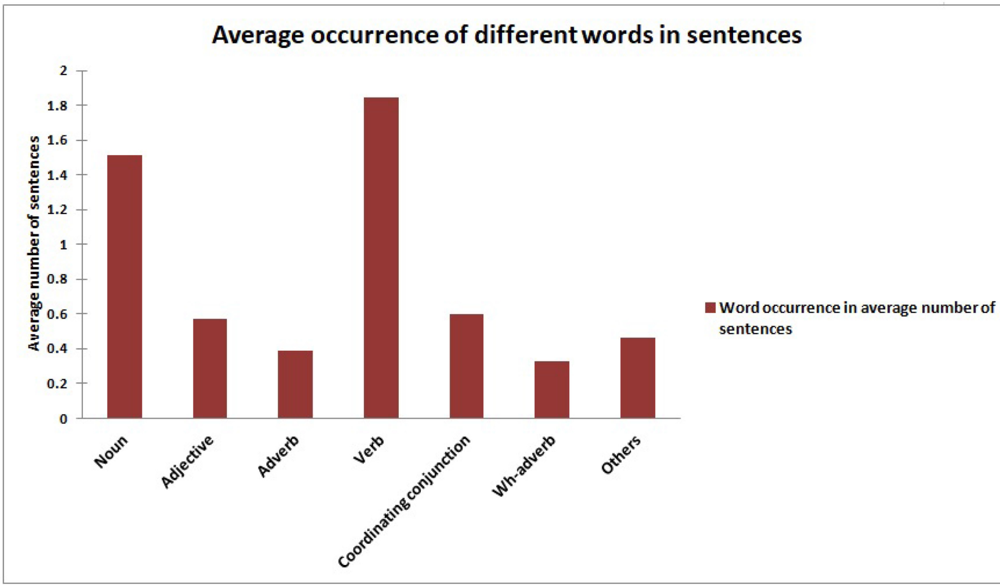


Fig. 11. Average occurrence of different words in sentences.

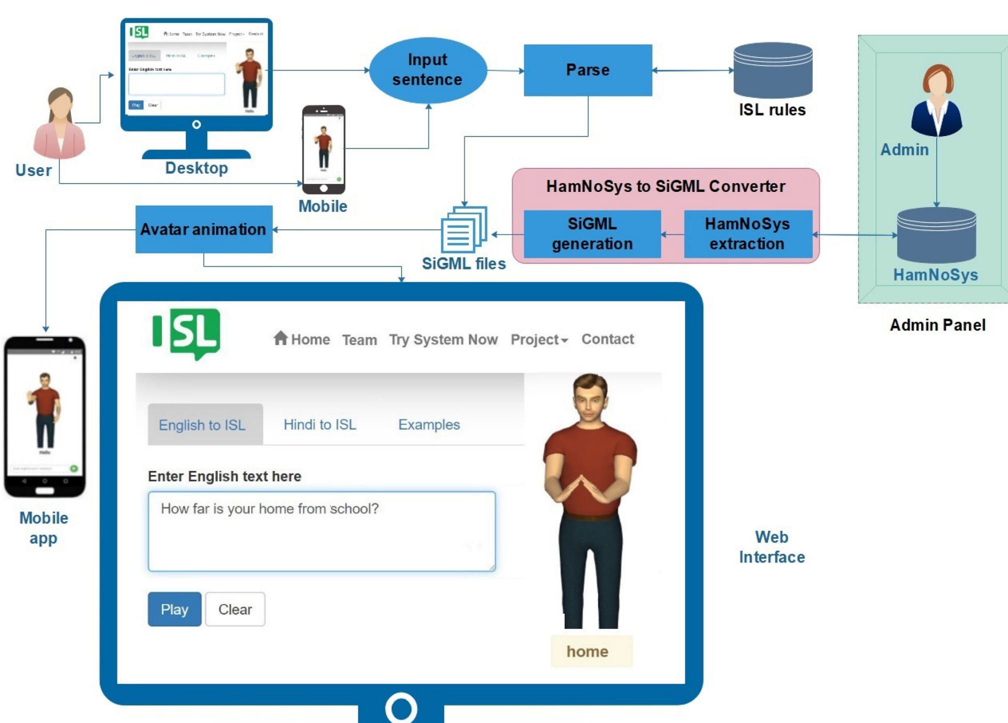
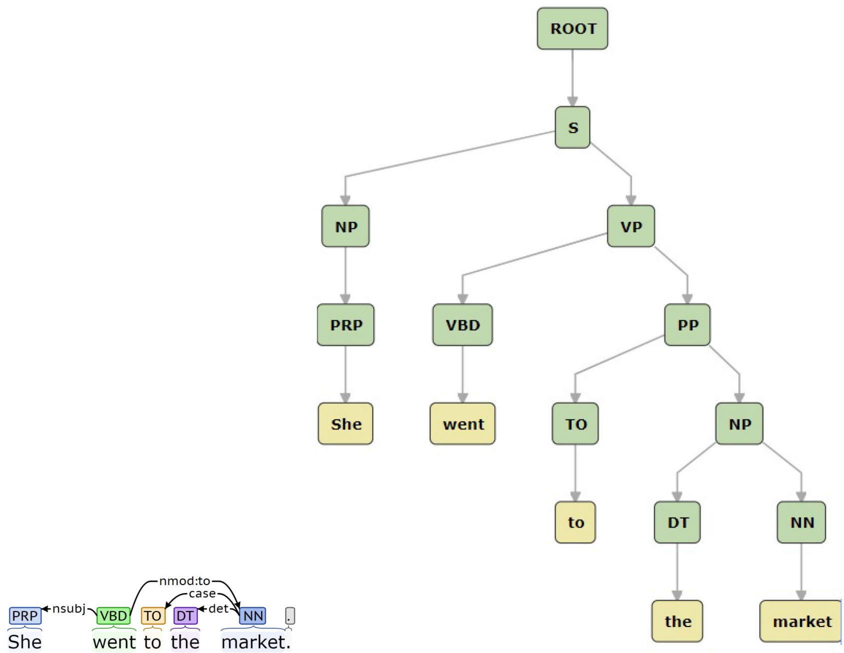


Fig. 12. System architecture of ISL generation from text.



(a) (b)

Fig. 13. Morphological information (a) and phrase tree structure (b) of the example sentence (1).

converting HamNoSys code to a SiGML file is used to obtain the file. This file is stored with the SiGML file of other words. It is then fed to the animation server whenever some word is queried. Depending on the tags used in the SiGML file, animation frames are generated, which are played together to animate the 3D avatar. Figure 12 also depicts the web interface for input of English sentences and shows the generation of ISL animation by the avatar.

Details of each component for the proposed system are described next.

7.1 Implementation of the ISL Parser

The user inputs the English word or sentence through a web interface or mobile app. This input is parsed using the parser. In this system, the *Stanford parser*[8] is used to process the input sentences. The parser analyzes the linguistic structure of that sentence and rearranges words together as phrases on the basis of information such as, subject, object, and verb. It defines the dependency level of words. The parser uses a Part-of-Speech (POS) tag to represent its morphological information. Based on this information, punctuation is removed through the filter and chunks are created for further processing. The words are stemmed and lemmatized using the *Skyeng Php-lemmatizer* to extract the list of root words.

To understand the workings of the proposed system, let us consider the example sentence given in (1):

$$\textit{She went to the market}. \tag{1}$$

The Stanford parser used in the system divides the sentence into the chunks with their morphological information as shown in Figure 13(a), and its phrase structure tree is also depicted in

[8] http://nlp.stanford.edu:8080/corenlp/process.

Sentences

Sentence #1

Tokens

Id	Word	Lemma	Char begin	Char end	POS	NER	Normalized NER	Speaker	Sentiment
1	She	she	0	3	PRP	O		PER0	
2	went	go	4	8	VBD	O		PER0	
3	to	to	9	11	TO	O		PER0	
4	the	the	12	15	DT	O		PER0	
5	market	market	16	22	NN	O		PER0	
6	.	.	22	23	.	O		PER0	

Parse tree

(ROOT (S (NP (PRP She)) (VP (VBD went) (PP (TO to) (NP (DT the) (NN market)))) (. .)))

Uncollapsed dependencies

- root (ROOT-0 , went-2)
- nsubj (went-2 , She-1)
- case (market-5 , to-3)
- det (market-5 , the-4)
- nmod (went-2 , market-5)

Enhanced dependencies

- root (ROOT-0 , went-2)
- nsubj (went-2 , She-1)
- case (market-5 , to-3)
- det (market-5 , the-4)
- nmod:to (went-2 , market-5)

Fig. 14. Dependency-level information of the example sentence (1).

Figure 13(b). Moreover, the dependency information generated by the parser is shown in Figure 14. It also includes lemmatized words of the input sentence given in (1).

After fetching the list of root words, ISL grammar rules are applied for reordering the words in SOV order as English follows Subject-Verb-Object (SVO) order. As discussed in Section 3, ISL has its own grammar and syntax. For the development of the ISL parser, a rule-based system has been framed to handle all aspects of ISL grammar, including person, numbers, gender, questions, and tense, among others. These rules are described with the help of a flow chart, as shown in Figure 15.

As shown in the flow chart, first the user inputs the English word or sentence. The system then parses the input and applies filters over it. As a result, the list of root words is obtained using this information. Thereafter, the system compares the morphological information of obtained root words with existing ISL grammar rules that are pre-stored in the database. When a named entity appears or the word is not present in the dictionary, its finger-spell is played. To represent present participle, its sign is repeated three times. Similarly, possessive pronouns are converted into personal pronouns, and plural is represented by repeating the sign twice or more. Tense in ISL is represented using a spatial time line, and gender is denoted with *he* or *she*. Thereafter, these root

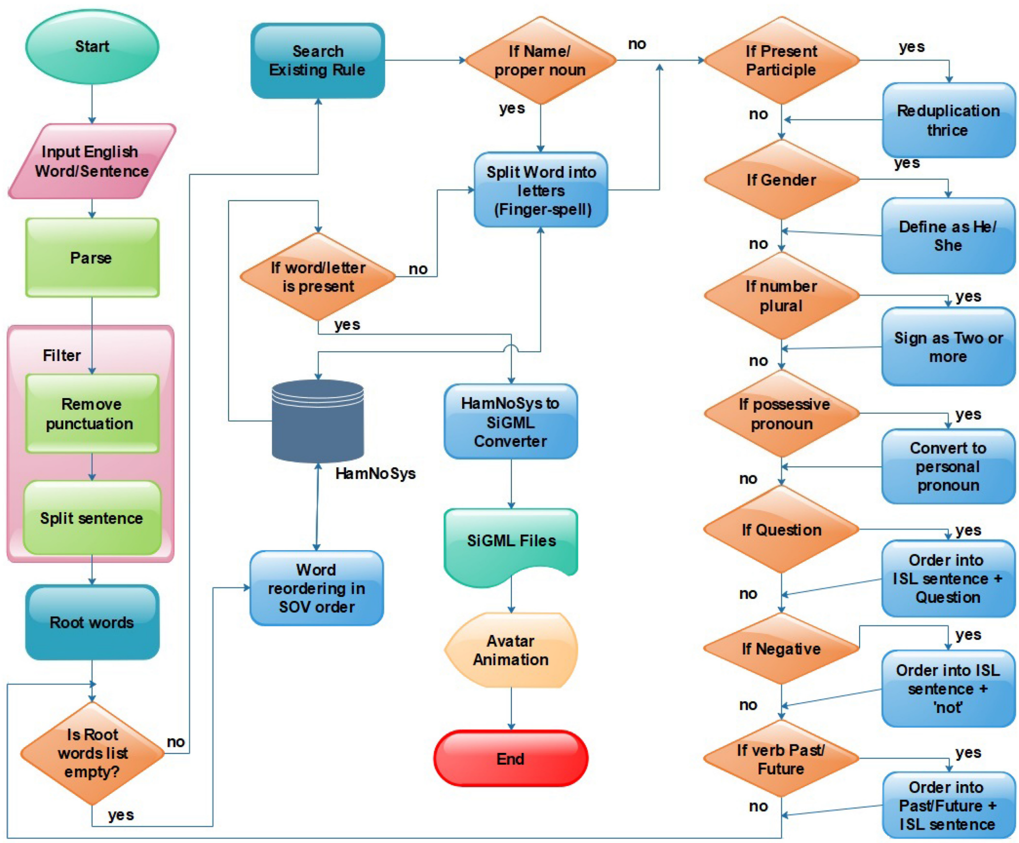


Fig. 15. Flow chart of the system.

words are reordered in SOV order. In case the rule for a particular input is not found, its root words are extracted and its SiGML files are fetched, and it generates ISL signs using avatar animation.

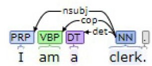
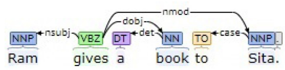
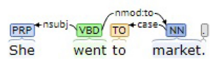
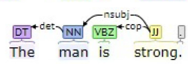
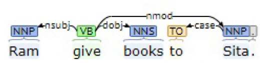
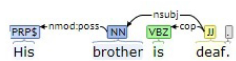
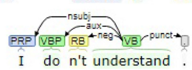
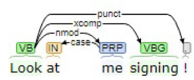
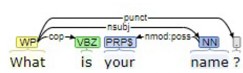
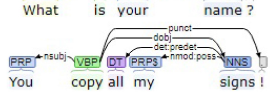
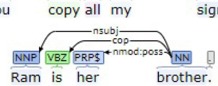
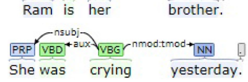
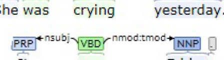
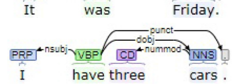
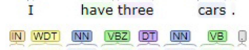
Let us consider the example sentence given in (1); after parsing the input sentence, its morphological information is extracted and punctuation marks are removed. The input is then divided into chunks such as *She, went, to, the, market*. Thereafter, its root words (*She, go, to, the, market*) are fetched, and on the basis of its grammatical aspect, the corresponding rule is mapped. After applying ISL grammar rules, the ISL sentence for the input sentence (1) is generated by removing the preposition (*to*) and article (*the*), followed by reordering of words (i.e., *She market go*).

The ISL rules are framed for each category of English sentences. It includes various aspects of ISL grammar that are depicted with a set of example sentences given in Table 3.

7.2 Generation of Sign Animation

For each root word in the ISL sentence, the system extracts its HamNoSys from the database as shown in Figure 15. Thereafter, the proposed system automatically generates SiGML files from its HamNoSys. Each SiGML file represents the sign for a word. It consists of different tags used for sign animation. The SiGML file generated from HamNoSys is taken as input for further processing. It is accessed by the animation server for generating animation frames. Further, these frames are used to define the pose of an avatar. Finally, the ISL sign is played through these frames in the form of 3D avatar animation that is displayed to the user as an output of the proposed system.

Table 3. Translation from English to an ISL Sentence Based on ISL Rules

S. No.	English Sentence	Dependency Tree	Output Tag	Type	General ISL Sentence
1	I am a clerk.		PRP, NN	Person	I clerk.
2	Ram gives a book to Sita.		NNP, NNP, NN, VB	Person	RAM SITA book give.
3	She went to market.		PRP, NN, VB	Gender	She market go.
4	The man is strong.		NN, JJ	Gender	Man strong.
5	Ram give books to Sita.		NNP, NNP, NN, NN, VB	Plural Noun	Ram Sita book book give.
6	His brother is deaf.		(PRP), NN, JJ	Possessive pronoun	He brother deaf.
7	I don't understand.		PRP, VB, RB	Negative	I understand not.
8	Look at me signing!		(PRP), VB, VB, PRP	Possessive pronoun	I sign look me!
9	What is your name?		PRP, NN, WP	Question	Your name what?
10	You copy all my signs!		PRP, NN, DT, PRP, VBP	Possessive pronoun	My sign all you copy.
11	Ram is her brother.		NNP, PRP$, NN	Relation	RAM her (Man + sibling).
12	She was crying yesterday.		NN, PRP, VB, VB, VB	Gender, Present participle	Yesterday she cry cry cry.
13	It was Friday.		(VBD), NNP	Tense	Past Friday.
14	I have three cars.		PRP, NN, CD	Plural	I car three/(two or more).
15	At what time does the shop open?		NN, VB, NN, WDT	Question	Shop open time what?

For the example sentence given in (1), HamNoSys of the ISL sentence is fetched from the database—that is, HamNoSys of the root words *she*, *market*, and *go* is extracted as depicted in Figure 16. Thereafter, SiGML is generated using the HamNoSys to SiGML converter, and the avatar animation server processes it for ISL generation. The avatar animation of the example sentence given in (1) is depicted in Figure 16.

A detailed algorithm for rule-based ISL generation that explains the workings of proposed system is given in Algorithm. The notations used for ISL generation in Algorithm 1 are depicted in Table 4.

8 RESULTS

The proposed system has been tested on a corpus of 1,000 commonly used sentences, for which SL experts manually generate its ISL output based on ISL grammar. To assess the proposed system, the BLEU score is used, which compares the output generated by SL experts with the output generated

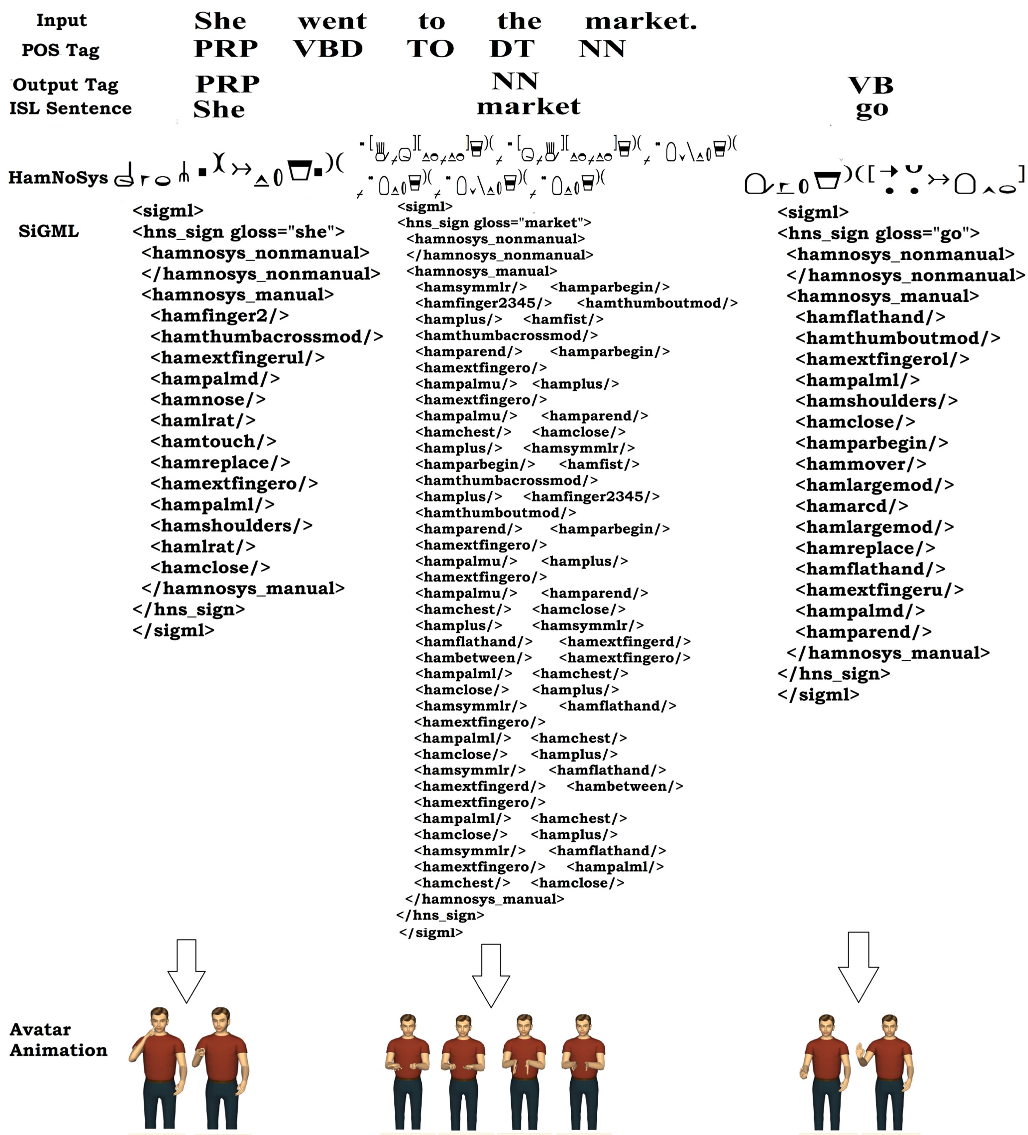


Fig. 16. ISL generation of a sentence (1).

by the proposed system. Based on the resemblance of system output with the manual output of SL experts, the BLEU score is measured. The BLEU score always lies between 0 and 1 [10]. It depicts the similarity between translated and expected output, where a value near 1 means that both sentences are similar, and a value near 0 means that both sentences are not similar. Henceforth, the BLEU score as shown in (2) is calculated for each of the translated sentences, by comparing each of them with reference sentences (i.e., generated by experts). Thereafter, an average of these scores is calculated to estimate the overall translation quality of the system.

$$BLEU = BP * exp\left(\sum_{n=1}^{N} w_n * logp_n\right), \tag{2}$$

Table 4. Notations Used for the ISL Generation Algorithm

Notations	Description
S	Input sentence list
ISL	Final ISL sentence
s	Input sentence in list S
w	List of words in the ISL sentence
W	List of root words fetched from the parser for sentence s
M	List of morphological information for sentence s
B	List of stop words
MS	String containing morphological information of root words
MI	Rules stored in the rule database
N	Stores the indexing of word order corresponding to rule MI
RW	List of root words after reordering
HAM	HamNoSys of a word
H	List of HamNoSys for root words
l	Literals of the word
HAM_LIT	HamNoSys of a literal
$hamnosys$	HamNoSys stored in the H list
SIGML	SiGML file of HamNoSys
SIG	List of SiGML files
$sigml$	SiGML stored in the SIG list
RDB	Rule database for ISL generation
HDB	HamNoSys database
GRW(sentence)	Get root words from the parser of the sentence
GET_MI(sentence)	Get morphological information of from the parser for sentence s
COMPARE(morphological_info,rule)	Match the morphological information of the sentence with rules stored in the RDB database
FILTER(sentence,rootWords, morphologicalInfo,stopWords)	Remove punctuation and apply filters
CONCAT(morphologicalInfoList, morphologicalString)	Concat morphological information in a string
INDEX_ORDER(rule)	Extract the indexing of word order corresponding to rule MI
WORD_REORDER(indexOrder, rootWordsList)	Reorder the root words according to the index order
APPEND(rootWords,outputSentence)	Append the root words in the output sentence
IS_HAM(word,HamNoSysDatabase)	Check if HamNoSys of the word is present in the HDB
FETCH_HAM(word,HamNoSysDatabase)	Fetch HamNoSys of the word from the HDB
APPENDHS(string,list)	Append string in the list
HAMSIGML_CONVERTER(hamnosys)	Convert HamNoSys notations into SiGML
PLAY_ANIMATION(sigml)	Play 3D avatar animation of ISL signs from the SiGML file

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

$$BP = \begin{cases} 1, & \text{for } c > r \\ e^{1\text{-r/c}}, & \text{for } c \le r \end{cases} \left. \textit{where c or r is length of translated and reference sentence} \right\}$$

During processing of the BLEU score, the n-gram of both sentences is compared and it counts the number of position-independent matches. Higher matches in n-gram ensure a better quality

ALGORITHM 1: ISL generation from English text

Input: S
Output: ISL

```
Procedure ISL_Generation(S)
Set(ISL, NULL)                          ▷ Set output sentence ISL to NULL
repeat
for each: s ∈ S
    W ← GRW(s)                          ▷ Get the root word from the parser for sentence s
    M ← GET_MI(s)                       ▷ Get the morphological information of words from the parser
    FILTER(s, W, M, B)                  ▷ Remove punctuation and apply filters
    MS ← CONCAT(M, MS)                  ▷ Concat root words morphological information into string MS
    if COMPARE(MS, MI) = TRUE then      ▷ Compare morphological information with the rule stored in database
        N = INDEX_ORDER(MI)             ▷ Get the indexing of word order corresponding to rule MI
        RW = WORD_REORDER(N, W)         ▷ Reorder word order
    else
        RW = W
    end if
    ISL ← APPEND(RW, ISL)               ▷ Append final root words list RW into an ISL sentence
until s! = NULL (Sentence s is not empty)
repeat
for each: w ∈ ISL
    if IS_HAM(w, HDB) = TRUE then       ▷ HamNoSys of a word found in the HamNoSys database
        HAM ← FETCH_HAM(w, HDB)
        H ← APPEND(HAM, H)              ▷ Append Hamnosys in a HamNoSys list
    else
        repeat
for each: l ∈ ⊒                         ▷ Break word into list of literals l
            HAM_LIT ← FETCH_HAM(l, HDB) ▷ Fetch HamNoSys of each literal
            H ← APPENDHS(HAM_LIT, H)
        until l! = NULL (List of literal is not empty)
    end if
until w! = NULL (w is not Null)
repeat
for each: hamnosys ∈ H
    SIGML ← HAMSIGML_CONVERTER(hamnosys)   ▷ Get SiGML file from HamNoSys
    SIG ← APPENDHS(SIGML, SIG)             ▷ Append SiGML file in list SIG
until hamnosys! = NULL (HamNoSys list is not empty)
repeat
for each: sigml ∈ SIG
    PLAY_ANIMATION(sigml)               ▷ Play avatar animation of ISL sign using SiGML
until sigml! = NULL (SIGML list is not empty)
End Procedure
```

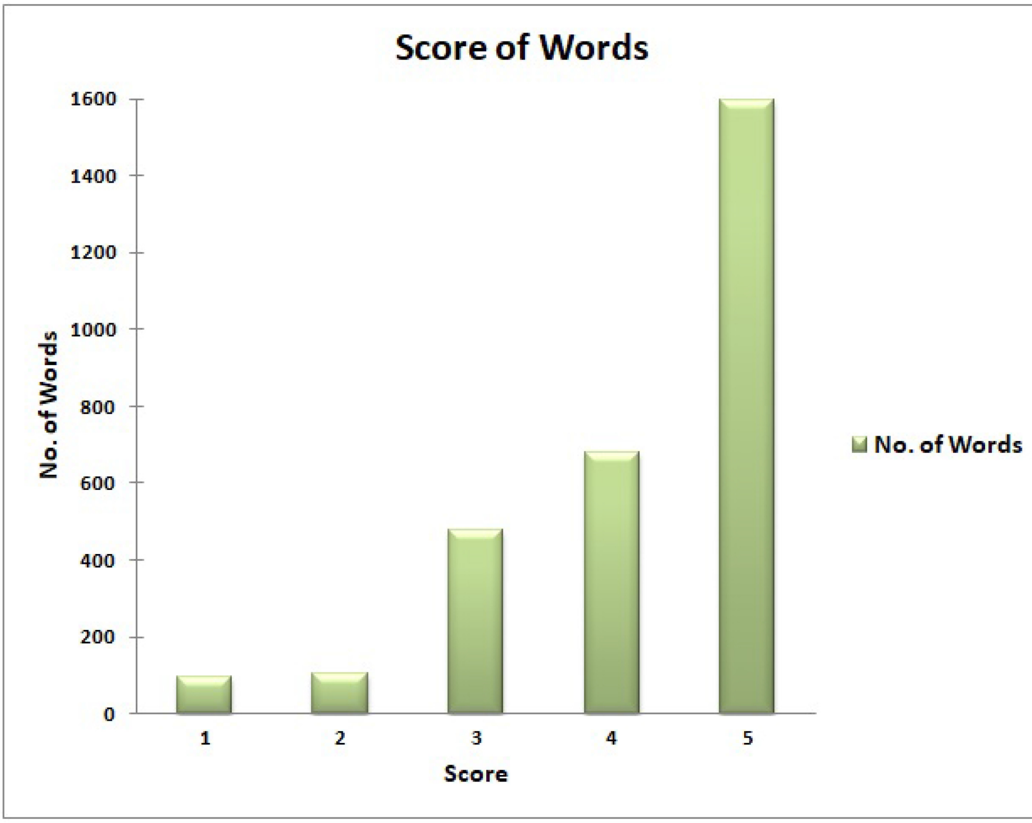


Fig. 17. Score of words.

of translated sentences. The proposed system has achieved a BLEU score of 0.95 for a corpus of 1,000 sentences.

To evaluate the quality of signs, a manual evaluation is also performed in which 2,950 words had been tested by six SL experts. During manual testing, an avatar animation is played for each of the words from this corpus, and based on their accuracy or resemblance with the real sign, ISL experts assigned the score to them [23]. This evaluation is performed on a scale from 1 to 5, where 1 denotes very poor performance, 2 refers to poor, 3 is average, 4 denotes good, and 5 is the best performance. As depicted in Figure 17, the maximum number of words (i.e., 1,594) was awarded the highest score, and only 200 words were assigned with a low score of 1 or 2.

Apart from words, the proposed system has also been evaluated for testing the accuracy of sentences. About 1,000 sentences were manually tested based on their output generated by the system. As shown in Figure 18, there are 694 sentences that can be considered as accurately generated, as their score lies between 4 and 5 (i.e., good and excellent performance). The weighted mean as given in (3) is also measured for the scores of words and sentences. From the result as depicted in Figure 19, the weighted mean for the score of words is 4.2, whereas the weighted mean for sentences is 3.8.

$$\overline{x} = \sum_{i=1}^{n} \frac{w_i * x_i}{w_i} \qquad (where\ n = 5), \tag{3}$$

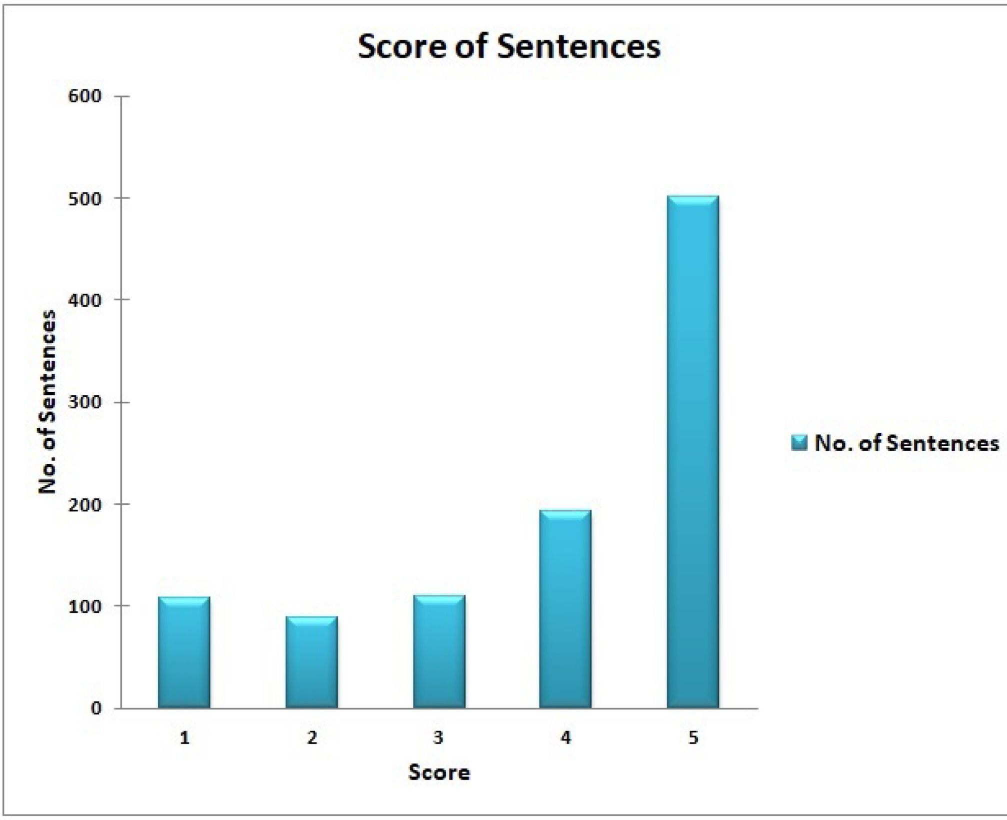


Fig. 18. Scores of sentences.

where $\overline{x}$ is the weighted mean of the score, x_i refers to the score, and w_i refers to the number of words or sentences lying under x_i.

The results of the proposed system are very encouraging, and the proposed system has potential for use in areas such as education, railway reservations, banking systems, and airports.

9 ERROR ANALYSIS

It has been observed that some signs in ISL are very complex, and to depict these sign via the proposed system, a lot of animation is required. In addition, HamNoSys consists of limited notations. Thus, the proposed system does not showcase a swift animation in the case of complex words and is also devoid of facial expressions that are usually portrayed by human sign interpreters. Another point worth mentioning is the parser dependency of the proposed system. Sometimes the proposed system's parser outputs the wrong morphological information of a sentence, which further leads to wrong mapping with ISL rules, and ultimately the final output is a wrong sentence that does not affirm ISL rules. Presently, the system is not capable of handling complex sentences.

10 COMPARATIVE STUDY OF SL GENERATION SYSTEMS

The comparative analysis on the basis of different parameters has been done between the existing SL generation system and the proposed system as depicted in Table 5.

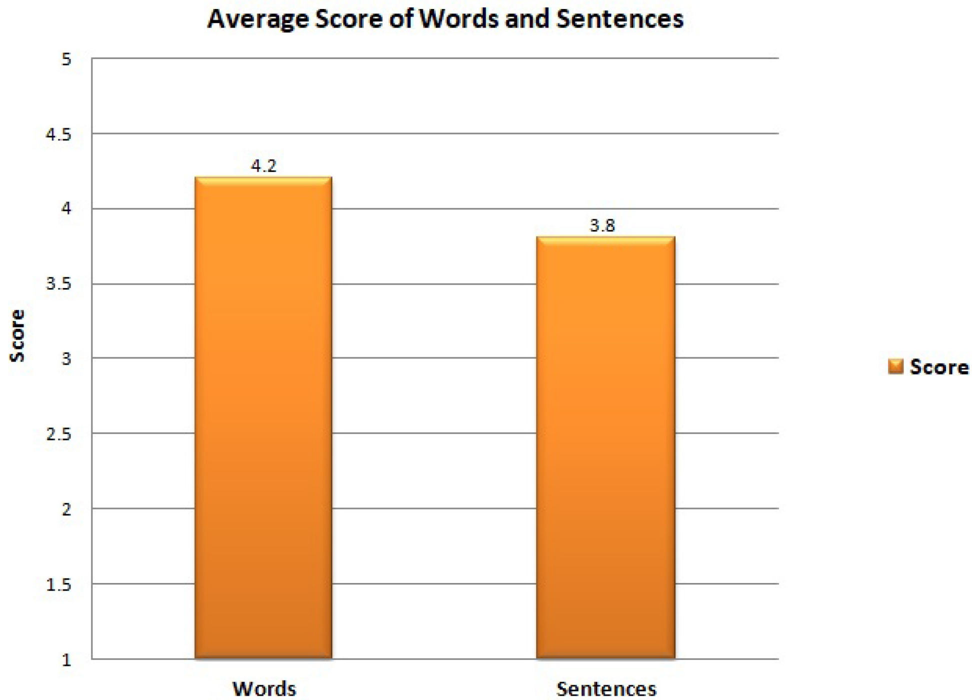


Fig. 19. Average score of words and sentences.

From the analysis, it has been concluded that there is no system available for desktop and mobile devices for real-time communication with people with hearing loss. The existing systems do not have the functionality of the speech to ISL generation system. Moreover, the existing systems have a limited corpus and are bounded to a particular domain only.

To the best of our knowledge, this system is the first of its kind available for ISL generation. The main features of proposed system that make this system unique are a rich vocabulary database, an admin panel to handle the database, a HamNoSys to SiGML conversion module, 3D avatar animation, and speech to ISL. The proposed system has a scalable architecture, and a corresponding API has been developed to extend it to other languages.

11 LIMITATIONS OF THE STUDY

The proposed system has coverage of almost 3,000 words, but some signs are not present in the system. Thus, vocabulary size is one limitation of this system. Therefore, to extend its coverage, continuously building our own HamNoSys database will help. The system supports ISL rules for simple sentences and sometimes for complex sentences, it failed to generate accurate ISL sentences. The proposed system also lacks in representing complex animation and facial expressions of ISL signs, as there are limited facial/body expressions in HamNoSys notation for representing non-manual signs. Moreover, in ISL, there are different criteria for handling directional signs based on its context. Hence, depending on the direction, there can be a change in the position of a sign from beginning to end than its usual sign. The proposed system does not handle indexing of signs based on the context. Currently, the proposed system has the limitation of word-sense disambiguation, which may lead to incorrect word sign animation. There is no standard bench-

Table 5. Comparative Analysis of Existing and Proposed ISL System

S. No.	Name	Year	Corpus Size	Undertaking Technique	Domain	Speech to Text	Access Type	URL	Mobile App	Accuracy
1	ZARDOZ: English to ASL	1994	Not available	Blackboard architecture	General	No	None	Not available	No	Not mentioned
2	TEAM: English to ASL	2000	Not available	Uses ASL grammar rules	General	No	None	Not available	No	Not mentioned
3	INGIT: Hindi to ISL	2007	90 words and 230 sentences	Hybrid-Formulaic grammar approach and Pre-recorded videos	Railway reservations	No	None	Not available	No	80%
4	English to ISL	2008	208 sentences	Transfer Grammar Rule, Lexical Functional Grammar	General	No	None	Not available	No	90%
5	Arabic to ArSL	2012	29 Arabic alphabets and words	Rule-based approach	General	Yes	None	Not available	No	Not mentioned
6	English to ISL	2013	Not available	Corpus-based MT	Railway reservations	No	None	Not available	No	Not mentioned
7	Spanish to LSE	2014	Not available	Rule-based approach	General	No	None	Not available	No	42% TER and 0.30 BLEU
8	Malayalam to ISL	2014	Not available	Morphological Analyzer and Optimizer	General	No	None	Not available	No	Not mentioned
9	English to ISL	2014	Not available	Transfer-based system	Endocrinologists	No	None	Not available	No	Not mentioned
10	Punjabi to ISL	2015	235 words	JA SiGML Player	General	No	None	Not available	No	Not mentioned
11	English to ISL	2016	1,818 words	Probabilistic Context Free Grammar (PCFG), 3D avatar animation	General	No	Private	Not available	No	Not mentioned
12	Proposed System	2018	2,950 words and 1,000 sentences	Probabilistic Context Free Grammar (PCFG) and Dependency parser, Rule-based approach, 3D Avatar animation	General	Yes	Public	http://www.islfromtext.in	Yes	0.95 BLEU

mark available for SL generation system evaluation. Thus, evaluation of the proposed system has been based on the manual review performed by ISL experts and users of the system.

12 CONCLUSION AND FUTURE SCOPE

This article proposes a system that translates English text into its corresponding ISL animation. The system consists of an important component (i.e., an ISL parser) that is being used to parse sentences based on ISL grammar rules. With a corpus of 2,950 English words and 1,000 sentences, the proposed system could be used efficiently for communicating with individuals with hearing loss. The system outputs the ISL representation of a sentence or word using 3D avatar animation in real time rather than using pre-stored pictures or humanoid videos. The system highlighted in the study can be experienced by visiting https://www.islfromtext.in or on the Android app *Sanket*, which is free to download from the Google Play Store, available at https://play.google.com/store/apps/details?id=in.dsingh.sanket&hl=en_IN.

In the future, coverage of the HamNoSys-based dictionary will be extended. To make the system more robust, some additional ISL rules will be added to handle complex sentences. Further, word-sense disambiguation, animation for complex signs, and sign indexing will be included to enrich the systems' functionalities. However, the results and feedback received from ISL users are very positive and encouraging, as the proposed system will help people with hearing loss get in touch with their entourage.

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