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ORIGINAL RESEARCH

Handling of Simultaneous Morphology of Sign Languages: Concerns for Cross-modal Machine Translation of Marathi to Indian Sign Language

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Abstract

Effective communication can be challenging when individuals are unfamiliar with each other's spoken language. This problem becomes more complex when the languages involved differ in modality such as spoken language and sign language. Machine translation has emerged as a valuable tool for bridging this communication gap in various scenarios. This research addresses the unique challenges presented by cross-modal machine translation systems, specifically in translating from spoken language to sign language. While spoken languages typically exhibit linear linguistic characteristics, sign languages employ simultaneous expressions through manual, non-manual, and spatial features. This divergence in delivery mechanisms necessitates careful consideration in the development of a translation system. The primary objective of this research is to develop a framework that translates simple Marathi sentences into Indian sign language, incorporating computational techniques to account for the simultaneous nature of sign language grammar. A comprehensive linguistic analysis is conducted to identify the specific divergences between Marathi and Indian sign language. The system is evaluated using a database comprising vocabulary relevant to daily communication. This paper provides a detailed account of the system architecture, experimental setup, results, and evaluation. The development of a cross-modal translation system holds significant potential in bridging the communication gap between individuals using spoken languages and those who rely on sign languages as their primary means of communication. The system-generated ISL can facilitate communication for hearing-impaired persons and, thus, it contributes to the inclusivity of hearing-impaired communities in the mainstream.

Keywords Cross-modal machine translation · Marathi · Indian sign language · Simultaneous morphology · Phrase-based machine translation · Inclusion of hearing-impaired people

Introduction

Linguistic diversity is an imminent feature of India. The languages spoken in India belong to different language families, yet the majority of them belong to the Indo-Aryan language family. Marathi is one of the spoken languages that belong to this family. It is the official language of Maharashtra state (India) and is the 3rd most spoken language in India. On the other hand, Indian sign language (ISL) is used by the hearing-impaired community all over India with some regional dialects. It has a formal grammatical structure.

Though there are ample natural language processing (NLP) applications available, the languages they can process is still a subset of existing (spoken as well as sign) languages used worldwide. Many languages are still in need of NLP tools and computationally feasible resources that can be utilized by existing NLP approaches and applications.

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Marathi and Indian sign language are both among them. This language pair deficit a compatibly large bilingual corpus that is sufficient to develop a data-driven or knowledge-based translation system. Thus, a rule-based machine translation system for translation from Marathi to ISL can be a stepping stone to enhance these circumstances.

According to the 2011 Indian census, there are 1.3 million people with "hearing impairment." The World Health Organization (WHO) data cite around 63 million people suffering from significant auditory loss. Still, there was always a bias in India about the use of sign language. But circumstances started improving after India signed the 'UNCRPD's Rights of Persons with Disability Act,' in 2016. The awareness about the use of ISL is rapidly increasing since the last decade.

Currently, sincere efforts are being taken by the Indian Government, special schools, and numerous NGOs to use ISL. Indian Government has released a video-based dictionary of ISL signs in three volumes. But most of the resources use pre-recorded videos that are not dynamic and cannot be used for run-time translation of a spoken language to sign language. This justifies the need for a computer-aided system for translating a spoken language to sign language. Such a system can help hearing people communicate with hard hearing effectively.

In the field of machine translation, both kinds of translation systems, spoken language to sign language and sign language to spoken language, are noted. Such systems are termed cross-modal translation systems as the source, and target languages use different communication modes. The utterance, perception, and (specifically morphological) grammatical features of spoken languages are 'linear.' But, in the case of sign language, grammar, facial expressions, and the use of signing space add extra dimensions to the signing sequence. In sign languages, many important linguistic and grammatical features are simultaneous. This key difference between source and target language creates exciting challenges for machine translation.

We are making efforts to translate simple Marathi sentences to equivalent ISL representations. Our foundational work for the development of a phrase-based translation from Marathi to ISL is presented in [1]. It presents the essential morphological and syntactical features of Marathi and ISL in a contrasting way. The system architecture and distinguished results are also illustrated.

During the exhaustive linguistic study of ISL, it is noted that 'simultaneous morphology' is a distinguished feature of ISL. It is imperative to uphold the same during its generation for any NLP application. The article reports an extension to earlier work where we have focused on the processing of simultaneous morphological features of ISL during the generation phase. It is arranged as follows. A literature review on spoken sign language machine translation systems is in Section "Literature Survey". Section "Sign Formation and Computational Representation" introduces phonetic details about sign formation and its computational representation. The instances of simultaneous morphology (specifically in ISL) are described in Section "Instances of Simultaneous Morphology in Indian Sign Language" in detail with appropriate examples. Section "System Architecture" describes system architecture. In Section "Results and Illustrative Examples", the results of the framework are discussed using appropriate illustrations. The details about the underlying database and experimentation are inscribed in Section "Experimentation". Section "Evaluation" encodes the evaluation of the framework. A comparative analysis of our efforts with existing and notable systems is performed in Section "Comparative Analysis of proposed system and existing systems" followed by concluding remarks in Section "Conclusion".

Literature Survey

As already stated, the grammatical study of the source and target language has been an essential part of this work. The roots of Marathi can be found in 1000AD [2]. Several grammarians and linguists have documented their history research. Several books and research materials are available for the study of the Marathi grammar framework. Most of the study for this work has been done from [3] and [4].

Concerning Indian sign language, the research work and field work done by Dr. Madan Vasishta [5] followed by Ulrik Zeshan [6] is the pioneer. The grammar analysis of Indian sign language done by Dr. Samar Sinha [7] has helped us to get detailed insights into the target language of our system.

A variety of efforts for spoken-to-sign language translation are noted in the last few decades. Researchers have also made efforts the development of sign language interpreting tools. Some of the imminent systems are discussed in this section. A special note of systems dealing with ISL is made at the end of the section.

The initial systems for spoken-to-sign language translation were rule based. The translation was done either direct, syntactic, or at the semantic level. In 2000, the Zardoz System [8] was developed using PATR-based unification grammar and an *interlingua approach* for English to American sign language translation [9] employed the TEAM system using a *syntactic transfer-based* approach. It was initially proposed for English to American sign language; later on, also implemented for South African sign language. Synchronous tree-adjoining grammars (STAGs) are used to create source and target language parse trees. Human modeling and simulation technology is used to generate animation using a 3D graphical avatar. Ian Marshall and Eva S'afar have utilized a *semantic transfer-based* approach for the translation of English text to British sign language in the visual sign language broadcasting system (ViSiCast) [10].

Probabilistic machine translation techniques require an aligned corpus. [11] has taken efforts for the creation of corpus based on the Airport domain. [12] is an important effort using *example-based and statistical machine translation* for English to American sign language translation using aligned sentences and chunks. An automatic evaluation was done for annotations or GLOSS. A manual evaluation was done for animation, considering the characteristics like understandability, fidelity, naturalness, etc.

Some systems based on *neural machine translation* are enlisted in Table 4 and compared with our system.

In the case of Indian sign language, all the noted systems have used a *rule-based approach*. INGIT [13] has been the very first attempt at the translation of Hindi strings to ISL strings. The domain of the system is based on the communication between a railway reservation clerk and a passenger.

[14] developed a dictionary tool for the conversion of Hindi/Bengali/English to ISL. This tool can be used to associate signs with the words, phrases, or sentences of a spoken language text. The sign associated with each word is composed of its related part-of-speech and semantic senses. In the later phase of this venture, a prototype for English to ISL translation is employed. The system can handle morphological functionalities like discourse, direction, and classifier predicates minimally. Only simple sentences in English can be utilized as input.

[15] has made an admirable attempt for sign language generation system based on ISL grammar. The system is publicly available for translation of English to ISL in the form of a web interface and mobile application. The system uses the Stanford parser to analyze the linguistic structure of input English sentences. This linguistic information is utilized, and then sign language gloss is translated using ISL grammar rules.

Apart from this, the Gurumukhi script to ISL translation system is developed by [16, 17] developed a system that pre-processes Hindi text and translates it into ISL grammar using a dependency parser and WordNet 6.

It is observed from the literature survey that sign language machine translation systems mainly use a rule-based approach may be due to the unavailability of linguistic resources. Very few systems have used a statistical approach using a small corpus. HamNoSys and SiGML are used by most of the systems to generate animation for the interpretation of sign language. Very few attempts are made for the translation of Indian regional languages to ISL out of which most of the systems are domain bounded. We have reported a prototype for Marathi to Indian sign language using phrase-level rule-based approach in [1]. Also, up to the best of our knowledge, none of the machine translation systems generating Indian sign language has reported any dynamic processing for incorporating simultaneous morphological features during the generation phase.

Sign Formation and Computational Representation

Sign languages are gesture-based natural languages. It uses body parts like hands, fingers, shoulders, and face movements for articulation. They have evolved over a while and have a formal linguistic and grammatical structure like spoken languages. A 'sign' in sign language is a meaningful combination of the following phonetic parameters. A significant change in one of these aspects may alter the sign's meaning or result in a completely different sign.

1. Manual Features:
    - Hand-shape: the shape of the hand used in the sign
    - Orientation: the direction of the palm and fingers
    - Location: the position of the hand in the signing space
    - Movement: the way the hand(s) move through space
2. Non-manual Features (NMF): Facial expression, eye gaze, movements of the head and body

It is essential to note that sign languages use both manual and non-manual features simultaneously to convey the message. In many cases, the articulation of a sign is done at a specific location in the signing space. The visual signal created by these gestures is multi-dimensional. The visual perception system used in sign language, i.e., the eye, can receive and process this multi-dimensional signal.

Though sign language produces a visual signal, it can be encoded textually. 'Gloss' is used for the same. 'Glossing' means to describe something briefly and misleadingly. It is a kind of annotation used to write brief one or two-word translations in one language for a word or morpheme in another language. It can encode morpho-syntactical information in sentences.

In sign language linguistics, 'gloss' plays an important role [18]. It is sign-language-independent and does not have any universal rules. Linguists can use conventions as per their comfort. It is mainly used to represent 'signing sequence' along with grammatical, spatial, and non-manual features. Any spoken language script can be used to write a Gloss of sign language. This paper uses a capitalized Roman script for writing Gloss. For example, 'I SCHOOL GO' means the sign 'I' is followed by the sign of SCHOOL, and then the sign of 'GO.'

As discussed in the introduction, to encode manual, non-manual, and spatial features concurrently, a three-dimensional gloss structure is devised. Each sign is represented using a triplet (MA, NM, SP) where MA, NM, and SP are manual, non-manual, and spatial features, respectively. The symbol,'–' is used in the absence of any specific value of the corresponding feature. Following are some examples with explanations.

- (SCHOOL, –, –): Only manual articulation for the sign of 'SCHOOL' without any specific non-manual and spatial features.
- (EAT, YN, –): Manual articulation for the sign of 'EAT' along with facial expressions for closed (Yes–No) questions. No specific spatial feature is used.
- (TABLE, –, IPSL): Manual articulation for the sign of 'TABLE' and it is articulated at the ipsilateral side (IPSL) of the signer to assign that location to the object (i.e., a 'table' in this case). No special non-manual feature is used.
- (GIVE, YN, 1–3): Manual articulation for the sign of 'GIVE,' with non-manual expression for a closed question. The '1–3' spatial feature suggests the location for beginning and ending locations for the respective verb sign. As gloss is a textual representation of sign language, it does not tell what signing will look like. i.e., gloss is not able to encode the phonetic parameters of manual features.

For the generation of animation, we have used HamNoSys codes [10]. They encode phonetic particulars of signs. Later, these codes can be converted to sign gesture markup language and animation can be rendered using SiGML player [19]. Figure 1 illustrates this process.

Instances of Simultaneous Morphology in Indian Sign Language

A 'sign' in sign language is the smallest meaning full unit, just like a 'morpheme' in a spoken language. In spoken language linguistics, the morphemes are distinguished as free morphemes (having stand-alone meaning) and bound morphemes (appearing as part of a bigger expression). In turn, bound morphemes are functionally classified as derivational and inflectional morphemes. The bound morphemes are formed using affixation. It is important to note that, in the case of spoken languages, morphemes are usually combined sequentially (either as prefixes or suffixes). E.g., un-believe-able, fruit-full, etc. Certainly, a' sign' can be modified for morphological purposes. A sign can be modified in different ways, sequentially or simultaneously.

1. Morphological Reduplication: One sign is duplicated to show repetition of action or pluralization of a noun, e.g., GIVE + + +, BOOK + + +

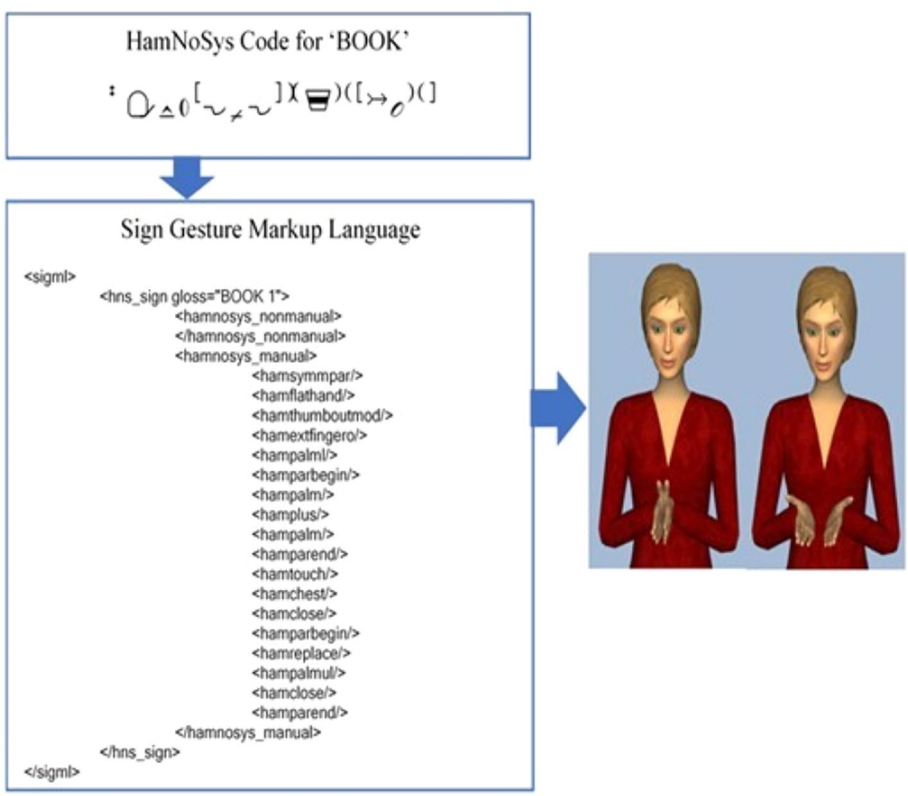


Fig. 1 Sign language representation using animation generated by HamNoSys codes and SiGML

2. Compounding of signs: Two or more signs are concatenated together to form a compound sign.

   e.g., BEAUTIFUL = FACE + NICE,
   KITCHEN = COOK+EAT+HOME

3. Stem Internal Change: One or more phonetic parameters of root signs are changed.
4. Addition of Non-manual and Spatial Features: Facial expressions are added to the sign to express some grammatical property. Also, the locations of articulation are changed to exhibit grammar properties.

The reduplication and concatenation of signs are a sequential type of change. They are evident and easy to handle computationally. But ’stem internal changes’ and simultaneous addition of non-manual and spatial features make computational processing of sign language interestingly challenging. This section discusses some of such circumstances where one needs to perform such morphological changes in a ’sign.’

The following subsections discuss important, distinguished features of ISL where a ’sign’ is modified for morphological purposes [7]. Representative examples using a Marathi sentence and corresponding gloss are also explained.

Numeral Incorporation

In the process of’ Incorporation,’ a phonetic parameter of one sign is replaced by that of another sign. It results in a complex sign. In ISL, a numerical quantifier is incorporated in time units (like day, week, and year). In this process, the time unit is articulated using numerals’ hand-shape instead of the original hand-shape. The resultant sign creates an adverbial time reference, and it is signed at the beginning of the sentence. Only numbers up to 4 are incorporated into signs of time units. Figure 2 shows phonetic details of the root sign of ‘day’ and ‘week’ using HamNoSys codes and animation frames. It also shows the simultaneous morphological change in root signs due to numeral incorporation.

The highlighted portion in the HamNoSys code in Fig. 2 shows how the hand-shape needs to be changed to perform numeral incorporation.

Syntactically, in a Marathi sentence, a quantifier followed by a time unit acts as a temporal adverb. It occurs pre-verbal or even at the beginning of the sentence. In ISL, such a phrase is signed along with a tense phrase at the beginning of the sentence. Some examples are given as follows. Note that ‘ = ’ in ISL gloss is used for representing the ‘incorporation’ of two signs.

Example 1 Marathi Sentence: मी दोन दिवसांपूर्वी पुस्तक वाचले. [Mī dōna divasāmpūrvī pustaka vācalē.]

Meaning in English: I read the book two days ago.

ISL Gloss: ((TWO=DAY, -, -) (I, -, -) (BOOK, -, -) (READ, -, -))

Remark: The original hand-shape in ’sign of day’ is replaced by the hand-shape of ’TWO.’

Ad-position Incorporation

This kind of ’incorporation’ is applied where an ad-position follows a noun. Ad-positions like in, inside, under, above, and below are incorporated into nouns. But ad-positions like near, with, etc., do not undergo incorporation. In the case of ad-position incorporation, one hand articulates the noun sign, and the other articulates the ad-position. Figure 3 shows a classic example of ad-position incorporation with its HamNoSys codes and animation frames. The highlighted portion in the HamNoSys code in Fig. 3 shows how the orientation of hands needs to be changed to perform Ad-position incorporation.

In the Marathi language, a locative ad-position follows a common noun. Usually, such a phrase functions as a locative adverb. According to ISL grammar, it appears at the beginning of the sentence. Some examples are given as follows.

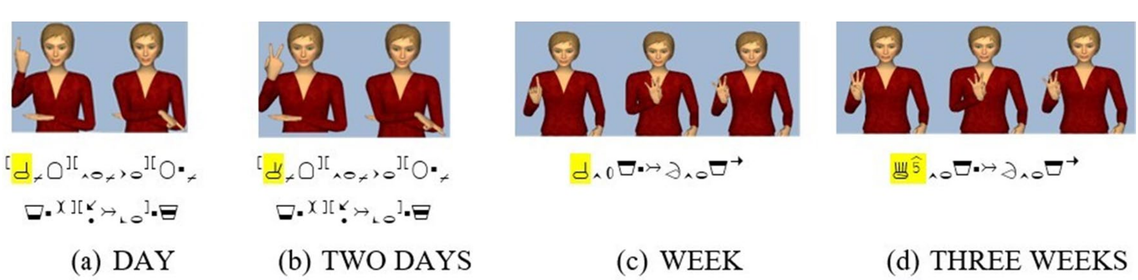


Fig. 2 Examples of numeral incorporation

Example 2 Marathi Sentence: पक्षी घराच्या आत बसतो.[Pakṣī jhāḍācyā Āta basatō].

Meaning in English: The bird sits in the house.

ISL Gloss: ((HOUSE=IN, –, –) (BIRD, –, –) (SIT, –, –))
Remark: Because of ad-position incorporation, the non-dominant hand articulates 'HOUSE', and 'ON' is articulated by the dominant hand on the non-dominant hand.

Classifier Incorporation

In sign language literature, the phonetic parameter 'hand-shape' is used to categorize lexical items into semantic classes. This categorization is based on characteristics like shape, size, and qualities of the object. There are fourteen classifier hand-shapes defined in ISL. Table 1 lists some representative examples of the classifier (hand-shapes).

In 'classifier incorporation,' the 'verb sign' is articulated with a hand-shape specified by the classifier. It is important to note that classifier incorporation is performed only with locomotive verbs (e.g., give, bring, put, pick, etc.). The process of classifier incorporation gives a visual effect as if the signer is carrying the object in the hands. Representative examples of classifier incorporation (for noun books and mugs) are given in Fig. 4. The highlighted portion in the HamNoSys code in Fig. 4 shows how the hand-shape needs to be changed to perform classifier incorporation.

Computationally a locomotive verb having a non-abstract argument is needed for classifier incorporation. The classifier for the argument is incorporated in the verb sign. Following are some examples of classifier incorporation phrases in a Marathi sentence and corresponding ISL Gloss.

Example 3 Marathi Sentence: मी चेंडू ठेवतो. [Mī cēṇḍū ṭhēvatō].

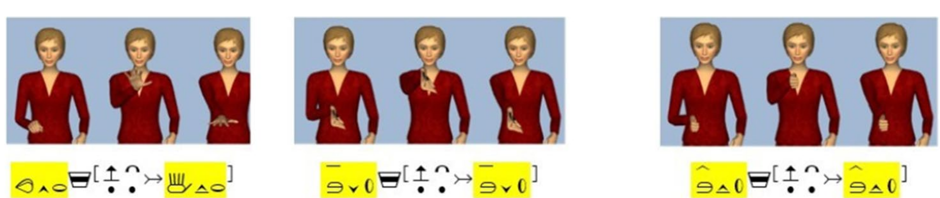
Meaning in English: I put the ball.

(a) HOUSE (b) IN (c) IN THE HOUSE

Fig. 3 Examples of ad-position incorporation

Table 1 Examples of classifier hand-shapes in ISL

Handshape	Classifier	HamNoSys	Semantics	Object
	SMALL ROUNDISH	[illegible]	Smallness	ORANGE, OWL, PLUG, LEMON, POTATO,
	CYLINDRICAL	[illegible]	Cylindrical, Handle-less shape	GLASS, BOTTLE, VASE, CAN
	HANDLE	[illegible]	Container with handle	REFRIGERATOR, BAG, JUG, MUG, BUCKET,
	FLAT THICK	[illegible]	Flatness and Thickness	BOOK, CARDBOARD BOX, PACKET



(a) PUT (b) PUT (while putting a book) (c) PUT (while putting a mug)

Fig. 4 Examples of classifier incorporation in ISL

ISL Gloss: ((I, –, –) (BALL, –, –) (CL:BALL=PUT, –, –))
Remark: The classifier hand-shape of ‘BALL’ replaces the original hand-shape used in ‘PUT.’

Non-manual Feature Incorporation

In ISL, there are some instances where Non-Manual Expressions are used to exhibit ’mood’ features. A specific ’non-manual feature’ is used along with a ’verb sign’ to distinguish the ’mood’ of a sentence. The ’raised eyebrows, nodded head,’ are expressed on the face for yes/no questions. Conditional sentences are also represented using distinguished NMF. The last sign of a conditional clause is accompanied by ’raised brow and head forward’ followed by a brief pause before the main clause. Figure 5 represents the visual distinction between a declarative sentence and a closed question. The phonetic details are shown using corresponding highlighted HamNoSys codes.

In Marathi, a question mark at the end of a declarative sentence optionally preceding by 'का' [ka] or 'ना' [na]is used to represent the closed interrogative form of a verb phrase. The following examples show a Marathi sentence and ISL gloss, distinguishing a declarative sentence from the yes–no question.

Example 4 Marathi Sentence: तू आंबा खातो. [Tū āmbā khātō].

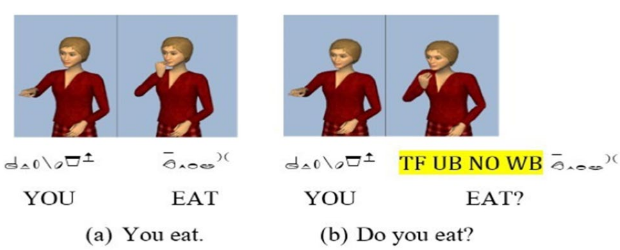


Fig. 5 Distinction between a declarative sentence and a closed question using non-manual features

Meaning in English: You eat a mango.

ISL Gloss: ((YOU, –, –) (MANGO, –, –) (EAT, –, –))
Remark: This is a declarative sentence. There is no specific NMF.

Use of Signing Space for Verb Agreement

In ISL, the verb does not agree with the gender and ‘number feature’ of its arguments. But directional verbs (ask, talk, help, give, advise, bring, give, invite, etc.) and spatial verbs (go, walk, run) show agreement with the person feature of arguments. Specific locations in the signing space are utilized for this purpose. It is achieved as follows.

The space in front of the signer where the articulation of hands is performed is known as the signing space. Particular locations in the space are of grammatical importance. The signing space is also used for the localization of non-present participants (third person). They are generally localized at the ipsilateral and contralateral sides of the sign. Figure 6a shows specific locations in the signing space corresponding to person features (1): First-person, (2): Second-person, 3A/3B: Third-person). The onset (a location where a sign’s movement begins) and offset (a location where a sign’s movement ends) agree with the locations (and ultimately with the ‘person feature’) of its arguments. Figure 6 also shows a pictorial example for various forms of the sign verb’GIVE’ according to the ‘person features’ of its arguments. The highlighted portion in the HamNoSys code in Fig. 6 shows how the location of the sign needs to be changed for verb agreement.

The spatial feature in Gloss is used to encode the onset and offset of the verb. The default onset and offset of verb signs are from first-person to second-person locations. For subjects and/or objects belonging to the third person category, their locations are marked by ’upper body tilt,’ ’finger-pointing,’ or ’eye gaze’ towards corresponding locations. Following are some examples of verb agreement in Marathi and ISL.

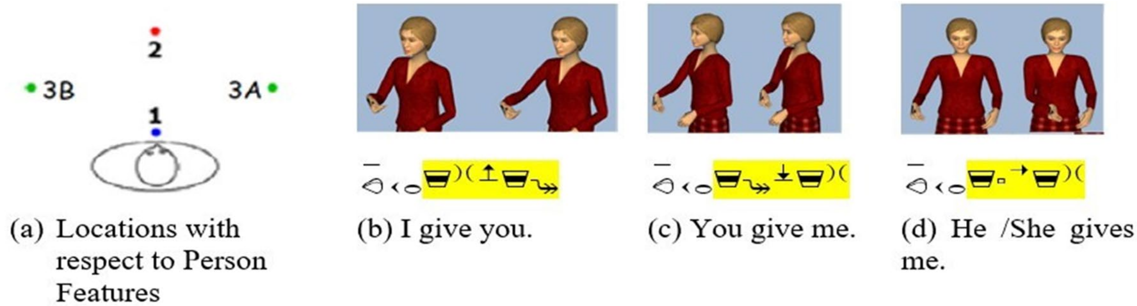


Fig. 6 Verb agreement in ISL using change in onset and offset

Example 5 Marathi Sentence: मी त्याला पाठिंबा देते. [Mī tyālā pāṭhimbā dētē].

Meaning in English: I support him.

ISL Gloss: ((I, -, -) (HE, -, 3A) (SUPPORT, -, 1-3A))
Remark: 'HE' is localized at the 3A. The onset and offset of 'SUPPORT' are locations 1 and 3A, respectively.

Thus, this section has discussed some prominent features of ISL. The incorporation (of classifier, numeral, and ad-position) and verb agreement using signing space is performed by 'stem-internal change.' At the same time, the addition of non-manual features and spatial features add one dimension each to the gloss. Section "Instances of Simultaneous Morphology in Indian Sign Language" discusses the system architecture of the framework designed to translate 'Simple Marathi sentence to Indian Sign Language.' It also mentions how the system tackles the ISL features discussed in this section.

System Architecture

To decide the design strategy of this system, we have done an exhaustive morpho-syntactic analysis of Marathi and Indian Sign Language. This study is described in our work [1] contrastively. This study concludes that the word order of main constituents in Marathi and ISL sentences is the same, i.e., SUBJECT–OBJECT–VERB. But the relative order of other components like adjectival phrases, adverbial phrases, negation phases, and WH question markers is dissimilar. So, we did not find any need for deep parsing of the whole input sentence. The study led us to follow the translation process at the phrase level. The morpho-syntactic analysis has also helped us decide the structure of phrases (to be utilized by translation rules) and formulate translation rules.

At the next level of research, we are now incorporating the processing of various morphological features of ISL (discussed in Section "Sign Formation and Computational Representation") in the existing translation framework. Accordingly, four modules are designed. The database management module has a Marathi Vs. ISL bilingual dictionary based on the vocabulary needed for daily communication. The 'root form' of each ISL sign is stored using HamNoSys code and the corresponding SiGML file parallelly.

The pre-processing module initially tokenizes the input Marathi sentence. The PoS categories of all tokens are derived. The vital phrases are then identified using regular expressions. These phrases are utilized by the morpho-syntactic knowledge extractor. Various GNPC features specific to particular phrases are extracted and noted for further processing. Sentence level knowledge like TAM features and sentence structure, sentence type is extracted from the verb phrase. Feature structure is used to encode this information. Refer to Fig. 7.

Translation rules then utilize the phrases and the morpho-syntactic knowledge. The identified phrases are processed to generate an ISL gloss based on ISL grammar. The three-dimensional gloss encodes the signing sequence in terms of manual, non-manual, and spatial features.

The existing SiGML files define the root signs. The 'dynamic sign modifier' checks if there is any need to make changes in the root sign. Accordingly, it performs various operations like the addition of non-manual features, change in spatial features, incorporation of two signs, etc. The modified sign is then used to generate the Master-SiGML file; the animation player will play it.

NLTK Toolkit is used for pre-processing input Marathi sentences. The 'LXML' library is used to handle SiGML file modifications at run-time.

Results and Illustrative Examples

This section discusses the illustrations depicting how the system upholds the simultaneous morphological nature of ISL. The dynamic changes in root signs are done at run-time during the generation phase of machine translation. Table 2 illustrates some input sentences and intermediate results.

Experimentation

The system is implemented using the vocabulary needed for daily communication. Currently, the system collectively has more than 1000 words of various PoS categories. Table 3 shows the frequency of words based on their morphological classification. This PoS categorization is done from the prospect of spoken language, i.e., Marathi in this case. But for the processing of morphological inflections in root signs, we needed to classify some PoS categories further according to ISL grammar features.

For the numeral incorporation, the adverbs are further categorized in calendric units as दिवस (Divasa, day), आठवडा (āṭhavaḍā, week), महिना (mahinā, month), वषर् (varṣa, year). The system can successfully identify phrases like दोन महिन्यांनी (Dōna mahin'yānnī, after two months), चार आठवड्यांपूर्वी (cāra āṭhavaḍyāmpūrvī, before four months), etc., and process them successfully for simultaneous morphological inflections. In the case of ad-position incorporation, the system can process various Marathi phrases headed by common nouns and followed by ad-positions like च्या वर (Vara, above, खाली (khālī, under), मागे (māgē, behind), पुढे (puḍhē, in front of), जवळ (javaḷa, near), लांब (lāmba, far).

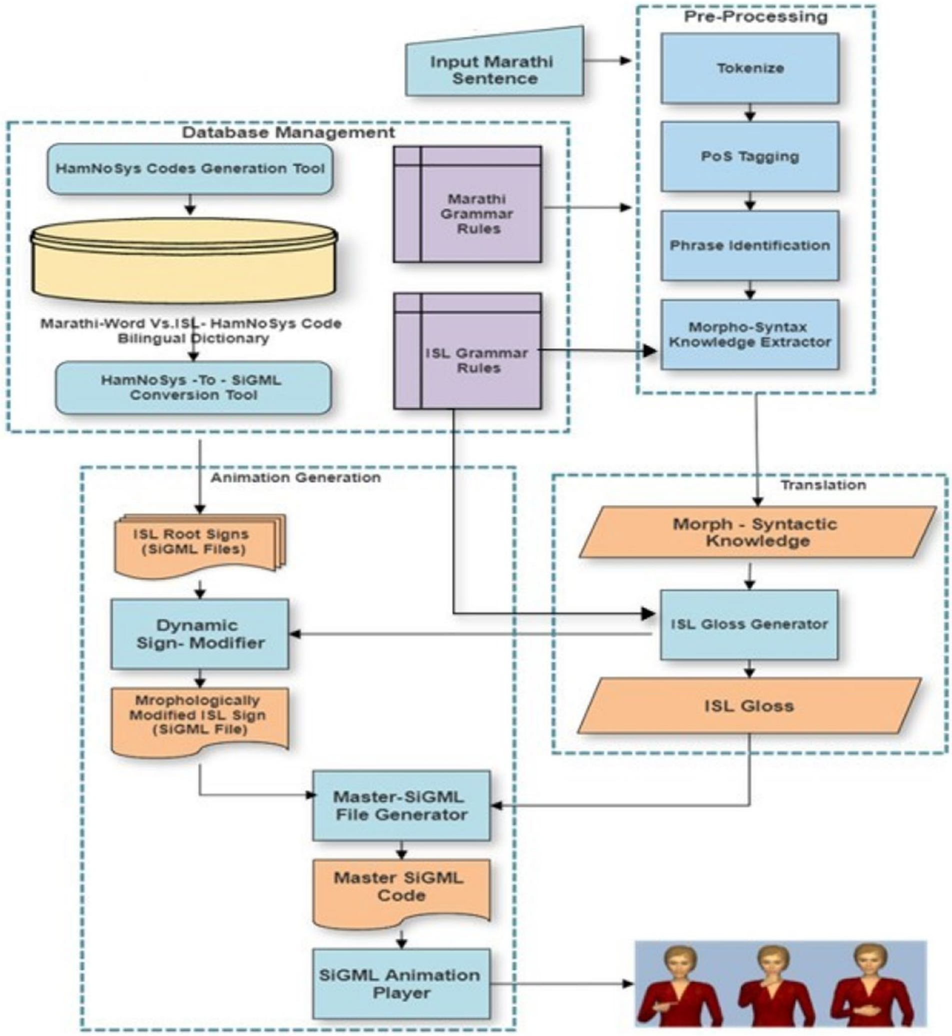


Fig. 7 System architecture

For classifier hand-shapes incorporation, the common nouns are again classified as per their respective classifier hand-shapes. As classifier incorporation is performed only with a specific set of verbs, the main verbs are further classified into plain verbs, directional verbs, and locomotive verbs as per their semantic nuance. The classifier hand-shape incorporation is tested successfully with locomotive verbs like ठेवणे (Ṭhēvaṇē, to put), उचलणे (ucalaṇē, to pick), आणणे (āṇaṇē, to bring) and directional verbs like सांगणे (sāṅgaṇē,), विचारणे (Vicāraṇē, to ask), उत्तर देणे (Uttara dēṇē, to answer), जाणे (jāṇē, to go). The directional verbs are also successfully exhausted for the inflection due to personal feature agreement with the subject and object.

Various types of Marathi sentences (like assertive, negative, imperative, and interrogative) are designed using the phrases that map to these instances of simultaneous morphology of ISL. The system can successfully identify and process them for the generation of ISL.

Evaluation

There are various evaluation matrices available in the literature. But adequacy and fluency are the most common evaluation matrices suggested for a rule-based translation system. Adequacy represents how much the translation in the target language conveys the original meaning in the source language. In comparison, fluency is related to grammatical correctness and word choice for the translation. The evaluation of the reported system has been done manually at two levels. The ISL gloss is evaluated for adequacy and fluency. The rendered animation is assessed for understandability and fidelity. Understandability is used in concern with the articulation of hands and non-manual expressions.

The evaluation of the system was carried out using the expertise of government-authorized ISL interpreters, and special education teachers in Hearing-Impaired schools. Two ISL interpreters and five special education teachers have contributed through their expertise for evaluation. The

Table 2 Illustrative example and intermediate output

Marathi Sentence /IPA/ English Meaning	Intermediate Output- ISL Gloss	ISL Gloss	Comment about Dynamic Sign Modifier output
Illustration 1 (Numeral Incorporation)			
तो दोन आठवड्यांपूर्वी आला. [Tō dōna āṭhavaḍyāmpūrvī ālā] He arrived two weeks ago.	(S तो/PRP (NINC दोन/QTY आठवड्यांपूर्वी /RBT) (VP येईल/VFM) ./FT	[('NUM:TWO=WEEK', -, -), ('PAST', -, -), ('HE', -, -), ('COME', -, -)]	In the sign of 'WEEK', ([illegible]), the dominant hand's original handshape ([illegible]) gets replaced by ([illegible]), and the resultant sign of 'TWO=WEEK' ([illegible]) is produced.
Illustration 2 (Classifier Incorporation)			
मी पुस्तक ठेवते. [Mī pustaka ṭhēvatē] I put the book.	(S मी/PRP (NP पुस्तक /NNC) (VP ठे वते /VFM)./FT)	[('I', -, -), ('BOOK', -, -), ('CLF:BOOK=PUT', -, -)]	In the sign of 'PUT' ([illegible]), the original hand-shapes ([illegible] and [illegible]) get replaced by the classifier hand-shape ([illegible]) of the book, and the resultant sign of 'BOOK=PUT' ([illegible]) is produced.
Illustration 3 (Closed Interrogative)			
तू पुस्तक वाचते? [Tū pustaka vācatē?] Do you read a book?	(S तू /PRP (NP पुस्तक/NNC) (VPवाचते/VFM) ?/QM)	[('YOU', -, -), ('BOOK', -, -), ('READ', YN, -)]	The yes-no question is marked on a verb using a specific facial expression. The Dynamic Sign Modifier will insert required tags (TF NO WB) to the root sign of 'read' ([illegible]) under the non-manual node.
Illustration 4 (Verb Agreement using Spatial Features)			
ती मला मदत करते. [Tī malā madata karatē] She helps me.	(S ती/PRP मला /PRP (VP मदत/NNA करते/VFM) ./FT)	[('SHE', -, -), ('ME', -, -), ('HELP', -, 3-1)]	This unit identifies an appropriate SiGML code version for the verb phrase according to the person feature of the subject and object.
Illustration 5 (Ad-position Incorporation)			
पुस्तक टेबलाच्या वर आहे. [Pustaka ṭēbalācyā vara āhē.] The book is on the table.	(S (NP पुस्तक/NNC) (NNP टेबलाच्या/NNC वर/PSP) (VP आहे/VAUX) ./FT)	[('TABLE', -, -), ('ON', -, -), ('BOOK', -, -)]	As per the discussion with local ISL experts, we find the need to 'sign' the ad positions to maintain the adequacy of the translation. So, they are signed separately after the head noun.

Table 3 Word frequency in database

PoS Category	No. of Words
Common nouns (NNC)	377
Temporal adverb (RBT)	27
Proper nouns (NNP)	40
Verb (VM)	115
Abstract nouns (NNA)	95
Assertive auxiliary verb (VAUX)	33
Personal pronouns (PRP)	30
Negative auxiliary verb forms (NEG)	34
Adjectives (JJ)	130
WH-word (WH)	27
Adverbs of manner (RBM)	10
Conjunction (CC)	5
Locative adverb (RBL)	8
Post positions (PSP)	28

evaluators have reported their scores on a 5-point scale. Table 4 enumerates the average of the scores reported.

Comparative Analysis of Proposed System and Existing Systems

We have performed a comparative analysis of our efforts with existing systems based on various parameters. Table 4 shows the outcome. As discussed in the literature survey very few systems have used probabilistic machine translation approach. As we are working with low-resource languages, we have used a rule-based approach because of the lack of sufficient-sized bilingual parallel corpora. As denoted in Table 5, many of the systems have not deliberated the key feature of simultaneous morphology or it has been minimally taken care of. So, the main objective of our work was to develop a module to handle simultaneous morphology for Marathi to ISL machine translation in an inexpensive way. The module design is robust and can be generalized for other language pairs. As per the feedback from evaluators, our results are encouraging.

Conclusion

Simultaneous morphology is a distinguished feature of sign languages. Our thorough study of ISL revealed that it is significant to embody these features while generating them for any NLP application. We have studied such instances from available ISL literature from a computational perspective.

Our study has led to the design and development of a module that can dynamically make simultaneous morphological inflections to ISL root signs (represented using HamNoSys codes and SiGML). This module is being used in the phrase-based machine translation framework for translating simple Marathi sentences to equivalent ISL representation. The results are promising and prove that the morphologically simultaneous nature of sign languages can be preserved to a large extent while generating dynamic ISL.

The framework is tested using a database based on the vocabulary needed for daily communication. The evaluation of the system is performed manually by ISL experts. There is improvement in the fluency of the machine translation process because of the incorporation of the simultaneous morphological nature of ISL during the generation phase.

Based on the linguistic study as well as efforts taken for Marathi to Indian sign language machine translation, we can affirm that this approach and system architecture can be extended for translation using another source and target language pair using minimum updates. We are also working on the automatic development of bilingual corpora of Marathi to Indian sign language gloss using the developed system. The statistical and knowledge-based approaches can be exhausted using such a corpus.

Table 4 Evaluation matrices and score

Output	Evaluation criteria	Comments by experts	Average score (on a 5-point scale)
ISL Gloss	Adequacy	The system can convey the meaning of the input Marathi sentence to ISL impartially	4.3
	Fluency (without handling the ISL simultaneous morphology}	The generated ISL GLOSS is grammatically correct, but improvement is needed	4.2
	Fluency (after processing of ISL simultaneous morphology)	The generated ISL GLOSS is grammatically more correct and truthful to the ISL features	4.6
Animation	Understandability	Articulation by hand is fairly understandable	4.4
	Fidelity	The ISL sign expressed is regularly authentic	4.8

Table 5 Comparative analysis of proposed system and existing systems

Project	Source–target language	Sign representation	MT approach	Remark concerning simultaneous morphology handling	Evaluation
ZARDOZ system (1994)	English–American, Japanese Irish SL	Doll control language, graphical display	Knowledge-based interlingua	Spatial features and non-manual features are handled	Not mentioned
TEAM project (2000)	English–American sign language	GLOSS, 3D human modeling and simulation	Syntax level transfer based	STAG trees are used to embed non-manual features in gloss	Not mentioned
ViSiCAST (2002)	English–British sign language	HamNoSys/SiGML 2D animation	Semantic level transfer based	Simultaneous morphological features are handled using manual intervention	Not mentioned
Multipath (2004)	English–American sign language	3D virtual reality Avatar (NLI) software	Hybrid: interlingua, direct and transfer	Non-manual features are handled	Not mentioned
RWTH statistical translation (2007)	German–German sign language (DGS)	HamNoSys/SiGML 2D animation	Phrase-based statistical translation	Non-manual features and repetition of signs handled	80% accuracy
Web-sign roject (2006)	English–American and French sign language	Text adapted sign modeling language	Statistical translation	Non-manual features are generated using time place, subject, and action	Not mentioned
MaTrEx (2008)	English–Dutch sign language	HamNoSys/SiGML 2D animation	The hybrid of SMT and EBMT	Not reported	Manual evaluation
Japanese to JSL using pre-trained model (2020)	Japanese to Japanese sign language	Gloss	Neural machine translation	Nodding, pointing, classifiers inscribed in Gloss	BLEU Score 24.24
Sign production using GAN (2020)	English to British sign language	Gloss, generative adversarial networks for video generation	Neural machine translation	Non-manual features are generated using motion graph technology	a BLEU-4 score of 16.34/15.26
INGIT (2008)	Hindi-Indian sign language	HamNoSys, SiGML 2D animation	Rule-based	Simultaneous morphological features are not handled graphically	Not reported
Dictionary-based prototype system (2008)	English–Indian sign language	HamNoSys/SiGML2D animation	Rule-based	Morphological functionalities are handled minimally	Not reported
Indian sign language from text (2016)	Hindi, English– Indian sign language	HamNoSys/SiGML 2D animation	Stanford parser, rule-based	Not reported	BLEU 0.95
Proposed system	Marathi–Indian sign language	HamNoSys/SiGML 2D animation	Shallow parsing, phrase level rule-based approach	Dynamic simultaneous morphology handling	Adequacy—4.3 Fluency—4.2 Understandability—4.4 Fidelity—4.8

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Declarations

Conflict of Interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

Ethical Approval This article does not contain any studies with human participants or animals performed by any of the authors.

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