Marathi to Indian Sign Language Machine Translation

Marathi to ISL Machine Translation

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Machine translation has been a prominent field of research, contributing significantly to human life enhancement. Sign language machine translation, a subfield, focuses on translating spoken language content into sign language and vice versa, thereby facilitating communication between the normal hearing and hard-of-hearing communities, promoting inclusivity.

This study presents the development of a 'sign language machine translation system' converting simple Marathi sentences into Indian Sign Language (ISL) glosses and animation. Given the low-resource nature of both languages, a phrase-level rule-based approach was employed for the translation. Initial encoding of translation rules relied on basic linguistic knowledge of Marathi and ISL, with subsequent incorporation of rules to address 'simultaneous morphological' features in ISL. These rules were applied during the 'generation phase' of translation to dynamically adjust phonological sign parameters, resulting in improved target sentence fluency.

The paper provides a detailed description of the system architecture, translation rules, and comprehensive experimentation. Rigorous evaluation efforts were undertaken, encompassing various linguistic features, and the findings are discussed herein.

The web-based version of the system serves as an interpreter for brief communications and can support the teaching and learning of sign language and its grammar in schools for hard-of-hearing students.

CCS CONCEPTS • Computing methodologies → Artificial intelligence → Natural language processing→ Machine translation • Human-centered computing →Accessibility → Accessibility systems and tools • Applied Computing → Arts and humanities → Language translation

Additional Keywords and Phrases: Marathi, Indian Sign Language, Phrase-level Translation, Rule-based Translation, Inclusion of specially-abled community, Sign languages' simultaneous morphological features

1 INTRODUCTION

Sign languages, also known as visual-gestural languages, constitute a unique and rich mode of communication primarily utilized by hard-of-hearing individuals around the world. Unlike spoken languages, which rely on auditory stimuli, sign languages employ visual and gestural elements to convey meaning. Each sign language is a distinct linguistic system with its grammar, syntax, and

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lexicon, independent of the spoken languages prevalent in their respective regions. These languages serve as the backbone of communication within hard-of-hearing communities.

In Sign Language, information is conveyed through the meaningful articulation of hands, arms, head, and shoulders. Such an articulation, containing a unique composition of hand shape, palm orientation, location of hands, and movements forms a manual component of a sign. Facial expressions like eye-gaze, raised eyebrows, and puffed cheeks also play an essential role in the expression of grammatical features. They form a non-manual element of a sign. Sign languages exhibit grammatical characteristics at all linguistic levels from phonetics, phonology, morphology, syntax, and semantics to even pragmatics.

With increasing awareness of the needs and human rights of the specially-abled community, there's been a lot more interest and research in sign languages. State-of-the-art tools and technologies in artificial intelligence and natural language processing domains are being used to facilitate communication with and for individuals who use sign languages, contributing to the betterment of mankind. Spoken-to-sign language machine translation is one of such research areas that has been recently exhausted by researchers worldwide to bridge the communication gap between normal-hearing and hard-hearing communities. Various traditional machine translation approaches are being used for spoken-to-sign language translation out of which data-driven and knowledge-based approaches need relevant linguistic resources like parallel corpora of considerable size.

However, some languages, both spoken and signed, don't have as many resources available to help with this. This is where rule-based translation stands out. Instead of needing a huge amount of data, hand-coded rules based on the specific linguistic features of the source and target languages are used for translation. These rules are fairly robust and domain-independent.

In this context, our research endeavors to contribute to this vital area by focusing on the development of a Marathi to ISL Machine Translation system (Figure 1). The system takes input in the form of text, while its output is presented as glosses and an animated video. Marathi, a prominent Indo-Aryan language, holds a rich linguistic heritage as one of the 22 officially recognized languages of India.[1] It is the official language of Maharashtra state and it is the third most spoken language in India. Among the diverse sign languages used globally, ISL holds significant importance, serving as a medium of communication for millions of individuals in India who are deaf or hard of hearing.[2] Due to the relatively low resource nature of Marathi and ISL, we have used a phrase-level rule-based approach to design and develop a prototype that is based on a deep linguistic study of both source and target languages [1].

[1] https://censusindia.gov.in/
[2] https://www.islrtc.nic.in/

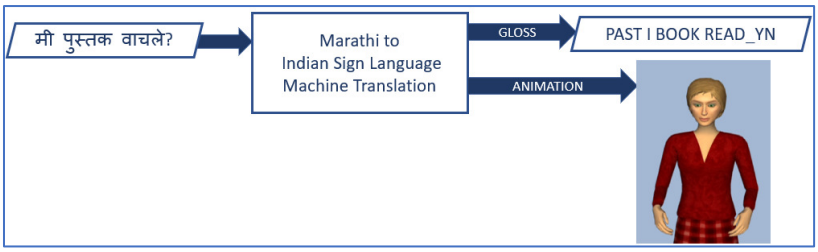

Figure 1 Marathi to ISL translation system's input and output

While assessing the prototype with ISL interpreters and experts, we recognized the importance of including the "simultaneous morphological features" of ISL to improve the fluency generated output. A literature survey has confirmed that there have been minimal efforts taken to deal with such features during spoken-to-sign language machine translation. We studied specific instances of simultaneous morphology confirmed in ISL and integrated a module that actively upholds these characteristics during the generation phase of the rule-based translation process. The study presented in [2] provides a detailed explanation of our approach and philosophy for addressing simultaneous morphological features in translation.

In rule-based machine translation, translation rules play a pivotal role in ensuring accurate and meaningful conversion of content from one language to another. They provide a structured framework that guides the translation process, taking into account the linguistic nuances and specificities of both the source and target languages. In this research paper, we present the translation rules we created, particularly in the context of Marathi to ISL machine translation. We meticulously explain the rules applied in our system, shedding light on how they enable the transformation of grammatically simple Marathi sentences into ISL glosses and animation. By detailing these rules, we aim to provide valuable insights into the methodology and approach.

The rest of this paper is structured as follows: Section 2 covers the literature review and identifies areas where research is lacking. In Section 3, we provide a comparative overview of the significant linguistic features of Marathi and ISL. Section 4 outlines the system architecture and algorithms. Following that, we delve into the results, experimentation, and evaluation in subsequent sections.

2 LITERATURE SURVEY

The field of natural language processing has a rich history and is currently a thriving area of research. Recent advancements in technology and a growing social awareness have spurred researchers to focus on processing sign languages. Efforts to translate spoken languages into sign languages and vice versa have been in progress worldwide [3]. We have examined the efforts for spoken-to-sign language translation and elaborated our findings as well as gap analysis in context with Marathi to ISL translation [4]. Since the proposed system is based on a rule-based approach, here our discussion is focused on notable systems that also employ this methodology.

Spoken-to-spoken language machine translation has a longer history (since the 1950s) and has received substantial attention and development over the years. In contrast, spoken-to-sign language machine translation has had a more recent focus (since the 1990s). This delay can be attributed to several factors. Primarily, sign languages have historically received less attention and research compared to spoken languages. As a result, the development of accurate and reliable sign language

recognition and translation technologies has faced additional challenges due to limited linguistic resources and less established standards. Additionally, sign languages exhibit unique characteristics, including spatial grammar and visual elements, which necessitate specialized approaches and data collection methods. Figure 2 shows historical advancements in spoken-to-sign language machine translation.

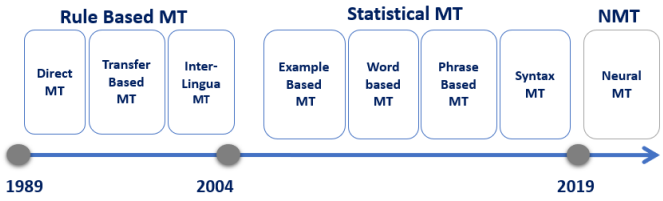

Figure 2 Historical advancements in spoken-to-sign language machine translation efforts

Initially, sign language machine translation systems leaned heavily on rule-based methodologies. Within this approach, translation rules can be applied at various linguistic levels, as described by the Vauquois triangle framework [5]. Pioneering work by [6] laid the foundation using word/direct-level translation efforts. Subsequently, syntax level and semantic level approaches were exhausted by researchers.

As machine translation progressed, statistical methods found their way into the field of spoken-to-sign language translation [7]. This led to the widespread adoption of statistical models, frequently applied to datasets of varying sizes, ranging from small to moderate in scale [8] [9]. Recent progress in translating spoken language to sign language has been driven by advancements in deep learning, particularly through the utilization of neural networks and recurrent neural networks (RNNs) [10] [11].

Rule-based machine translation approaches have been used for spoken to non-Indian sign languages successfully. A comparison of noted efforts is enlisted in Table 1.

In the context of ISL, the initial endeavor to translate from Hindi text was undertaken by INGIT [12] , employing a rule-based machine translation approach to convert Hindi strings into ISL strings. Another notable prototype was developed for English to ISL translation [13]. However, this system has limited capability in handling morphological features like discourse, directionality, and classifier predicates, and it is designed primarily for simple English sentences. Additionally, the system focuses on translating the Gurumukhi script to ISL for word-level translation [14].

A noteworthy accomplishment in the field is the development of a 'Sign language generation system based on ISL grammar' [15]. This system is capable of translating basic English sentences into ISL. It utilizes the Stanford parser to analyze the linguistic structure of the source sentence, followed by the application of ISL grammar rules for translation. Impressively, the system has generated an extensive set of over 2500 Hamburg Notation System (HamNoSys) [16] and Sign Gesture Markup Language (SiGML) for animation production.[3]

Table 2 provides a comparative overview of some prominent rule-based translation efforts taken specifically for Indian sign language.

[3] https://vh.cmp.uea.ac.uk/index.php/SiGML_Tools

Table 1 Comparative overview of some prominent rule-based spoken-to-sign language machine translation systems (for non-Indian sign languages)

Project/Source-Target Language	Translation/ Transfer Level	Highlights	Sign Representation	Comments regarding simultaneous morphology handling
Prominent efforts for spoken to non-Indian sign languages				
Kamata et al. (1989), Japanese-Japanese sign language [6]	Word/ Direct Level	• Simplest direct approach • Word-to-sign mapping	Not noted	Not mentioned
Visual Translation (1992), English- American Sign Language [17]	Syntax level	• Morphological analysis • Phrase structure tree-based translation	Hand motion coding system	Simultaneous morphology not handled
ZARDOZ System (1994), English - American, Japanese, Irish SL [18]	Knowledge-based Interlingua	• Construction of compound word structures using morphological rules • Spatial graphs representation	Doll control language	Not mentioned
TEAM project (2000), English - American Sign Language [19]	Syntax level	• Synchronous tree adjoining grammar	Glosses, 3-D human modeling & simulation	Non-manual features are handled through synchronous tree adjoining grammar
Visicast Project (2001), English to American Sign Language [20]	Syntax level	• The input text is parsed by the CMU link grammar parser • Discourse Representation Structure for intermediate representation • Head-driven phrase structure grammar for sign grammar features representation	HamNoSys/ SiGML	Non-manual features are handled using manual intervention
Szmal and Suszczańska (2001), Polish to Polish sign language [21]	Semantic level	• Morphology, syntax level transfer • Handling of limited number of semantic relations	B. Szczepankowski's gestographic notation	Limited non-manual features are handled through semantic relations
Information system for translation into Ukrainian sign language on mobile devices. (2017) [22]	Syntax level	• Weighted affix probabilistic context-free grammar parsing • Dependency tree-based translation • Use of grammatically augmented ontology for synonym, hypernym handling	Not noted	Not mentioned
Automatic translation of Arabic text-to-Arabic sign language (2019) [23]	Syntax level, Semantic level	• Morphology, syntax level transfer • Semantic analysis of sentences in the health domain	Sequence of GIF images	Sentence-level simultaneous morphology features are included in the glosses, not in the visual representation
An Open-Source Gloss-Based Baseline for Spoken to Signed Language Translation (2023), Multiple spoken & sign languages [24]	Word level	• Multiple approaches: rule-based word reordering and Neural machine translation	Video-based skeletal poses	Not mentioned

Integrating non-manual information into the final output of the spoken-to-sign translation system is one of the crucial aspects that have been overlooked. By integrating non-manual information into the final output of the translation system, [26] successfully bridges the divide between the translation and animation stages. They have treated the generation of non-manual information as a sequence classification task after the machine translation step.

In the context of translating to ISL, it has been noted that there has been limited attention given to addressing simultaneous morphology features. The proposed system holds promise in rectifying this research gap.

Table 2 Comparative overview of some prominent rule-based spoken-to-Indian sign language machine translation systems

Project/Source-Target Language	Translation/ Transfer Level	Highlights	Sign Representation	Comments regarding simultaneous morphology handling
INGIT (2008), Hindi - ISL [12]	Syntax level	• Fluid construction grammar for parsing and generation of ISL glosses	HamNoSys, SiGML 2-D Animation	Only sentence-level non-manual features like negation and interrogation are handled.
Dictionary-based prototype system (2008), English – ISL [13]	Syntax level	• LFG functional structure (F structure) to encode grammar features of the input sentence	HamNoSys, SiGML 2-D Animation	Some features like discourse, directionality, and classifier predicates are handled minimally
Mapping Hindi text to Indian sign language with extension using Wordnet (2016) [25]	Syntax level	• Dependency parser • Extension of dictionary using wordnet	HamNoSys, SiGML 2-D Animation	Not mentioned
Sign language generation system based on ISL grammar (2020) English – ISL [15]	Syntax level	• Standford parser to parse input sentence • Syntax tree transfer	HamNoSys, SiGML 2-D Animation	Not mentioned
Proposed framework Marathi – ISL [1] [2]	Phrase-level	• Customized PoS tag set • Shallow parsing of input text using regular expressions • Reordering of chunks to generate ISL glosses	HamNoSys, SiGML 2-D Animation	Simultaneous morphology features are handled dynamically using phrase-level translation

3 BRIEF LINGUISTIC ANALYSIS OF MARATHI AND ISL

With roots tracing back to the Maharashtri Prakrit, Marathi has evolved over centuries and boasts a diverse range of literary works. Its linguistic structure encompasses distinct phonetics, phonology, morphology, syntax, and semantics. The basic word order followed by Marathi is Subject-Object-Verb and it employs a diverse set of PoS categories, contributing to the language's nuanced structure. Nouns, verbs, adjectives, adverbs, pronouns, prepositions, conjunctions, interjections, and particles constitute the primary PoS categories in Marathi. The language exhibits a robust inflectional system, where words change to convey distinctions of tense, aspect, mood, gender, number, and person [27] [28].

The exploration of linguistic studies on ISL commenced in 1978 with Vasishta [29]. In 2004, Ulrik Zeshan conducted noteworthy field research and linguistic documentation [30]. Despite the historical use of ISL, the study of its linguistics has gained significant momentum in the past decade.

Sign languages, including ISL, utilize both manual signs and non-manual elements, collectively referred to as phonological parameters of a sign. The manual components in a sign are hand shape, palm orientation, hand location, and hand movement. The non-manual elements include facial expressions, head movement, body posture, etc. In sign language grammar the space around the signer also holds grammatical importance. There are some instances where a change in one of the phonological parameters leads to a change in the morphological feature of a sign. This phenomenon, referred to as 'simultaneous morphology,' distinguishes sign languages from spoken languages, where morphological changes typically occur sequentially through prefixes or suffixes attached to the morpheme. Note that all spoken languages follow sequential morphology while ‘simultaneous morphology’ is a key feature of sign languages including ISL. Most of these features are based on the physical characteristics (E.g., appearance, size, shape, location, etc.) of the subject or object or both [31].

Table 3 enlists and contrasts the morphological characteristics of Marathi and ISL.

Table 3 Morphological difference between Marathi and ISL word categories

Word Category	Language	Gender	Number	Person	Case	Tense	Aspect	Mood	Physical Appearances of Object	Comment (if any)
Common Noun	Marathi	✓	✓	X	✓	✓	✓	✓	NA	Only common nouns inflect for number and gender.
	ISL	X	✓	X	X	X	X	X	X	
Proper Noun	Marathi	X	X	X	✓	✓	✓	✓	NA	
	ISL	X	X	X	✓	X	X	X	X	Only animate proper nouns' sign inflect to show "possession"
Abstract Noun	Marathi	X	X	X	✓	X	X	X	NA	
	ISL	X	X	X	X	X	X	X	X	
Pronoun	Marathi	X	X	X	X	✓	✓	✓	NA	
	ISL	X	X	X	X	X	X	X	X	
Adjective	Marathi	✓	✓	X	X	X	X	X	NA	Only adjectives ending with 'आ' are inflected.
	ISL	X	X	X	X	X	X	X	X	
Adverb	Marathi	✓	✓	X	X	X	X	X	NA	Very few examples
	ISL	X	✓#	X	X	X	X	X	X	
Verb	Marathi	✓	✓	✓	✓	✓	✓	✓	NA	In ISL, appropriate tense, mood, and aspect marker signs are used.
	ISL	X	X	✓*	✓	X	X	X	✓+	
Postposition, Conjunction, Interjection	Marathi	X	X	X	X	X	X	X	X	In ISL prepositions like "IN", "ABOVE", and" UNDER" inflect according to the shape, size, and location of the corresponding noun
	ISL	X	X	X	X	X	X	X	✓	

✓: Availability of morphological inflection on a given feature.

X: Non-availability of morphological inflection on a given feature.

✓*: Sign of directional verbs (like give, pay) agrees with the person feature

✓+: Handshape of locomotive verbs changes according to the appearance of an object

✓#: Handshape of calendric adverbs like day, week, and year inflect according to quantifiers

Some important morphological and syntactical characteristics of ISL that have helped us to form system rules are as follows.

- **Word Order:** The arrangement of main components (Subject, Object, and Verb) in an ISL sentence follows the same sequence as in Marathi (i.e., Subject-Object-Verb).
- **Nouns:** The plurality of common nouns is indicated by repeating the respective sign.
- **Pronouns:** Standard signs representing various morphological forms of pronouns are available and employed.
- **Adjectives:** Adjectives precede nouns, akin to the structure in Marathi.
- **Adverbs:** Manner adverbs are signed after the verb phrase, while locative and temporal adverbs are positioned at the start of the sentence.
- **Verbs:** Unlike spoken languages, verb signs do not undergo inflection based on syntactic features like tense, aspect, and mood. The present tense is not specifically indicated. Past and future tenses are conveyed using specific standard signs at the beginning of a sentence. Mood and aspect are represented using specific standard signs following the verb sign. Key tense, aspect, and mood marker signs are depicted in Figure 3.
- **Negation:** A standard Negation sign is included after the verb phrase to signify negation.

- **Open interrogative sentences:** Interrogative pronouns (e.g., who, whom, what, which, why) are signed at the end to emphasize the WH-sentence structure. In the case of a negative interrogative sentence, they are signed after the negation sign.
- **Closed interrogative sentences:** These are indicated through distinct facial expressions (head nodding with raised eyebrows) in conjunction with the final sign in the sentence. This simultaneous morphology feature of ISL is referred to as 'Non-Manual Feature Incorporation'.

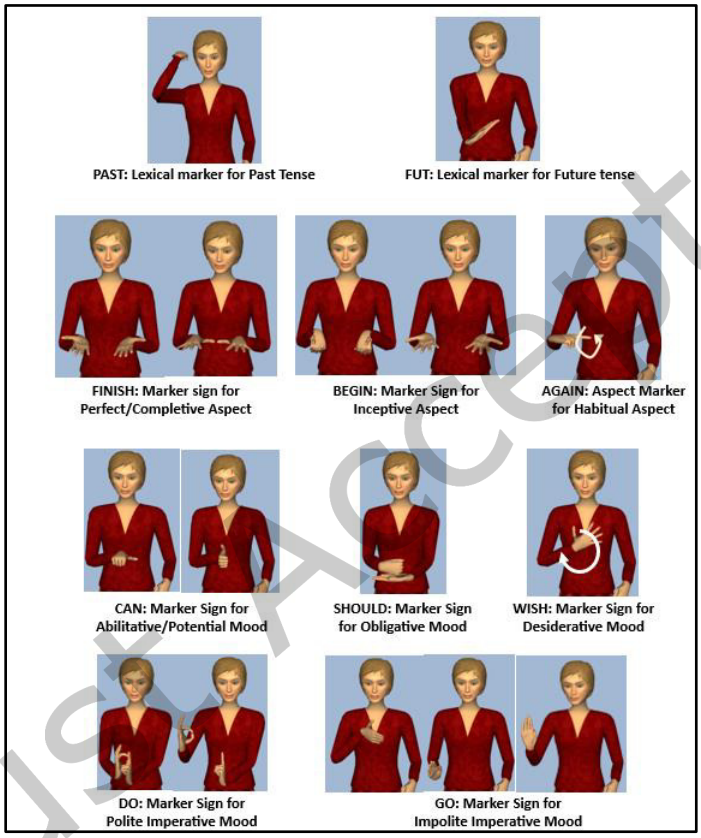

Figure 3 Marker signs for various tense, aspect, and mood features

Table 4 enlists instances of simultaneous morphology exhibited by ISL. These simultaneous morphological features convey essential grammatical and semantic information, including tense, aspect, mood, negation, and other linguistic nuances.

Table 4 Indian sign language's key simultaneous morphology features

Simultaneous Morphology Feature	**Description**	**Examples & Explanation**
Verb agreement using spatial features	The movement direction in directional verbs' signs (such as give, take, ask, answer, etc.) is adjusted based on the 'person' features of the subject and object.	मी तुला पुस्तक देते. (mi tula pustak dete – I give you a book) The direction of movement for "GIVE' is from the signer to the addressee. तू मला पुस्तक देते.(tu mala pustak dete - You give me a book) The direction of movement for "GIVE' is from addressee to signer.
Non-manual Feature incorporation	A distinct facial expression is incorporated with the final ISL glosses in a sentence for closed interrogative sentences.	तू पुस्तक वाचतो. (tu pustak vachato - You read the book) There are no special facial expressions as this is a declarative sentence. तू पुस्तक वाचतो? (tu pustak vachato - You read the book?) Special facial expressions (lowered eyebrows and head nodding) are added while signing the last sign to mark a closed interrogative sentence.
Numeral incorporation	The handshape of calendric adverbs (such as "day," "week," "year") is adjusted to align with quantifier adjectives (like "two," "three," "four," etc.).	तो दोन दिवसांनी येईल.(Tō dōna divasānnī yē'īla - He will come in two days) The handshape for 'DAY' will reflect that there are two days i.e. two fingers will be in a pointed position. तो तीन दिवसांनी येईल.(Tō tīna divasānnī yē'īla - He will come in three days) The handshape for 'DAY' will reflect that there are three days i.e. three fingers will be in a pointed position.
Classifier incorporation	The handshape of locomotive verbs (such as "put," "pick," "give," etc.) is adjusted to match the shape and size of the object being referred to.	मी पुस्तक ठेवते.(Mī pustaka ṭhēvatē - I keep the book) The handshape of 'PUT' is rectangular as if we handling a book. मी चेंडू ठेवते.(Mī cēṇḍū ṭhēvatē - I keep the ball) The handshape of 'PUT' is roundish as if we handling a ball.
Ad position incorporation	The sign for an adposition is combined with the associated noun to create a compound sign.	तो घराच्या आत आहे.(Tō gharācyā āta āhē - He is inside the house) The root signs of 'HOME' and 'IN' are compounded. पुस्तक टेबलाखाली आहे.(Pustaka ṭēbalākhālī āhē - The book is under the table) The root signs of 'TABLE' and 'UNDER' are compounded.

These morphological and syntactical characteristics of ISL are well-thought-out to design translation rules. The system architecture is discussed in the next section.

4 SYSTEM ARCHITECTURE

Accepting a basic Marathi sentence as input, our system produces ISL glosses and Animation as the output. Figure 4 provides a comprehensive visualization of the system architecture. The subsequent subsections explore the underlying principles guiding the design of each module, accompanied by pseudocode and additional relevant details.

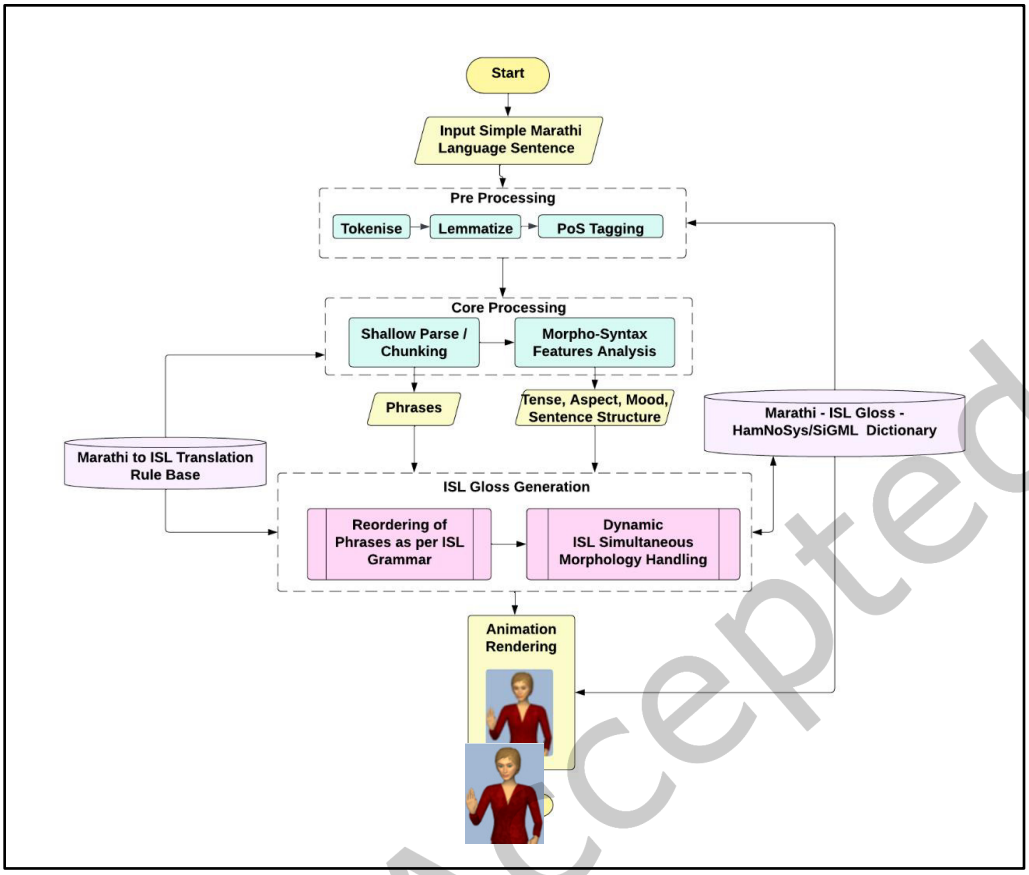

Figure 4 System architecture

We have performed white space tokenization to separate the words in given sentence. The morphological variations of the same form in the input text are handled using a look-up table-based lemmatization. As main focus of research is on translation we have discussed key modules in system architecture in following subsections.

4.1 Marathi-ISL Gloss-HamNoSys-SiGML Dictionary

The developed framework comprises a bilingual dictionary where every entry associate Marathi word, ISL gloss, HamNoSys notation, and SiGML file, along with crucial grammar features integral to the translation process. An illustration of the dictionary's structure is presented in Figure 5.

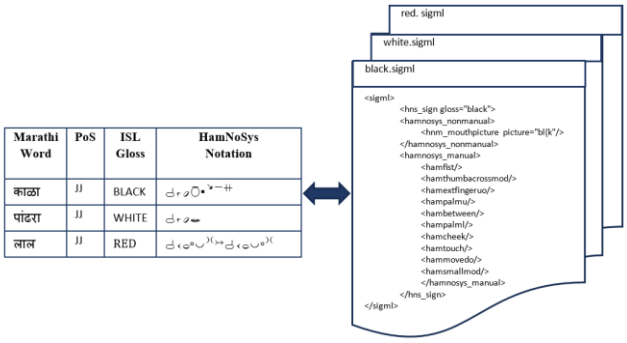

Figure 5 Dictionary overview

SQL database is utilized to construct the dictionary, represented as a table in Figure 5. The respective SiGML code files are stored in a separate folder.

4.2 Part-of-Speech (PoS) Tagging

The proposed framework performs PoS tagging using a self-contained lookup table, customized to the specific scope of this work. The system employs a customized PoS tag set, meticulously crafted from scratch and incorporates both broad and detailed PoS categories. The PoS categories of the proposed PoS tag set are based on a morphological study that has been discussed in the previous section. Refer to Table 5 for a comprehensive compilation of PoS categories, accompanied by examples and a rationale for their significance in the translation process.

Table 5 Details of customized PoS tag set for the proposed framework

Sr. No.	PoS-Tag	Description	Example	Significance concerning Marathi to ISL Translation
1	NNC	The common noun, (Singular)	झाड (Jhāḍa – Tree) फुल (phula – flower))	Common nouns undergo GNPC feature change; it needs to be distinguished.
2	NNS	The common noun, (Plural)	पुस्तके (Pustakē – Books) घरे (gharē - houses)	
2	NNP	Proper Nouns	जानेवारी (Jānēvārī - January) आंबा (āmbā - Mango	Proper nouns are only inflected for case features.
3	NNA	Abstract noun,	नृत्य (Nṛtya - Dance) तारुण्य (Tāruṇya - Youth)	Abstract nouns are inflected for case features. They are used as 'light verbs (krudant)'
4	WH	Open Interrogative pronouns (WH)	कोण (Kōṇa - who) कुठे (kuṭhē - where) काय (kaya - what) कधी (kadhī - when)	WH-Interrogative pronouns are signed at the end of the sentence.
5	YN	Closed Interrogative pronouns (Yes/No)	का (Kā) ना (Nā)	Yes/No interrogative pronouns are marked by the use of specific non-manual signs.
6	PRP	Personal, demonstrative, reflexive pronouns	तो (Tō - he), तू (tū - you) ते (tē - they), ती (tī - she)	All these types of pronouns are processed similarly.

7	VM	Main verbs	खाणे (Khāṇē – to eat) उठणे (uṭhaṇē – to get up) बसणे (basaṇē – to sit)	All action verbs are treated in the same manner. So further distinction is not needed. Few locomotive and direction verbs are handled using exceptional rules
8	VAUX	Assertive auxiliary verb	अस (Asa - yes), होय (Hōya - yes)	They are used to extract the tense and aspect, mood information
9	NEG	Negative auxiliary verb	नाही (Nāhī - no) नको (nakō - no) नये (nayē – don't)	They carry negative polarity along with tense, aspect, and mood information.
10	JJ	Adjectives	लाल (Lāla - red) दहा (dahā - ten) थोडा (thōḍā - few)	All types of adjectives (qualitative, quantitative, etc.) are processed similarly. So, there is no need for further distinction.
11	RBT	Temporal adverbs	सकाळी (Sakāḷī – in the morning) उद्या (udyā - tomorrow) पूर्वी (pūrvī - ago) नंतर (nantara - afterwords) दोन दिवसांनी (dōna divasānnī – after two days)	In ISL, these types of adverbs constitute the tense marker phrase that is placed at the beginning of the sentence. So, they needs to be distinguished.
12	RBM	Adverb of manner, frequency, degree	भरभर (Bharabhara - fast) नेहमी (nēhamī - always) कमी (kami - less)	These types of adverbs are post verbally marked in ISL
13	RBL	Locative adverbs	इकडे (ikaḍē - here) लांब (lāmba - away)	They are pre-verbally or even at the beginning of sentences marked in both Marathi and ISL
14	PP	Post positions	_च्यावर (_Cyāvara – above) _च्याखाली (_cyākhālī - under) _च्याआत (_cyā'āta - in)	They constitute the ad-position incorporation phrase in ISL.
15	CC	Conjunctions	आणि (Āṇi - and) किंवा (kinvā - or)	No need to distinguish conjunctions further as all of them are treated similarly in the proposed framework.
16	QTF	Numbers only from "one" to "five"	एक (Ēka - one) दोन (dōna - two) तीन (tīna - three) चार (cāra - four) पाच (pāca - five)	They are needed to be identified separately as they contribute to the "Numeral Incorporation Phrase" in ISL.

4.3 Shallow Parsing

Due to the analogues order of main components in sentence (subject – object – verb) for both Marathi and ISL, we did not find it necessary to perform deep parsing of source sentences. Based on syntactical contrastive analysis, we have pinpointed phrases that needed to be identified and rearranged for translation purpose. We have implemented shallow parser using regular expressions.[4] Table 6 provides a detailed explanation of these phrases, which serve as the foundation for our translation rules.

[4] https://www.nltk.org/api/nltk.chunk.html?highlight=regex

Table 6 Details of phrases used for shallow parsing

Phrase	Structure	Regular Expression	Examples
Noun Phrase	One or more occurrences of common, proper, or abstract noun	NP: {((<GRND> | <NNP> | <NNA> | <NNC>) *)}	झाडाची फांदी (Jhāḍācī phāndī – tree's branch) पळणारा घोडा (paḷaṇārā ghōḍā – running horse)
Pronoun Phrase	One or more occurrences of pronoun	PRPP: {<PRP>*}	मी त्याला (Mī tyālā – I to him) तो तिला (tō tilā – he to her)
Adjective Phrase	One or More occurrence of adjectives	JJP: {<JJ>*}	लाल जुने (Lāla junē – red old) जड नवीन (jaḍa navīna – heavy new)
Manner adverb phrase	Optional intensifier followed by manner adverb	RBMP: {<INTF>*<RBM>}	खूप जोरात (Khūpa Jōrāta – very fast) थोडा हळूहळू (Thōḍā Haḷūhaḷū - A bit slowly)
Locative Adverb Phrase	One or more locative adverbs	RBLP: {<RBL>*}	इथे (Ithē - here) तिकडे लांब (tikaḍē lāmba – there away)
Temporal Adverb Phrase	Optional intensifier followed by temporal adverb	RBTP: {<INTF>*<RBT>}	उद्या (Udyā - tomorrow) खूप वेळाने (khūpa vēḷānē – after a while)
Numeral Incorporation Phrase	Optional numeral quantifier followed by calendric adverb	NINC: {<QTF1 | QTF2 | QTF3 | QTF4> <RBT>}	एक आठवड्याने (Ēka āṭhavaḍyānē – after one week) दोन वर्षांनी (dōna varṣānī – after two years) तीन दिवसांपूर्वी (tīna divasāmpūrvī - before three days)
Verb Phrase	Valid combinations of main verb with assertive and negative auxiliary verbs. Abstract noun and adjectives are also used as	VP: {(<NNA|JJ>)? (<VFM><VFM><VAUX>| <VFM><VFM><NEG>| <VFM><VFM>| <VFM><VAUX>| <VFM><NEG>| <VFM>| <VAUX>| <NEG>)}	मोठा झाला (Mōṭhā jhālā – grew up) अभ्यास करतो (abhyāsa karatō – to study) रडत बसला आहे (raḍata basalā āhē – continuously crying) विचारून गेला नाही (vicārūna gēlā nāhī – didn't ask) वाचत आहे (vācata āhē – is reading) खात नाही (khāta nāhī – not eating) खावून गेला (khāvūna gēlā – ate up) आहे (āhē - yes) झाला (jhālā - become) नाही (nāhī - no)

4.4 Morpho-Syntax Knowledge Analyzer

The 'Morpho-Syntax Knowledge Analyzer' module derives tense, aspect, and mood based on the verb phrase identified by the shallow parser. Additionally, it ascertains the sentence type (such as copular, declarative, imperative, interrogative, WH question, YN- Question, etc.). Furthermore, this module also takes into account whether the sentence conveys an assertive or negative sense. This is achieved through the utilization of a self-contained lookup table that provides detailed mapping of Marathi verb suffixes with various grammar features.

4.5 Generation of ISL Glosses

The previously mentioned modules collect all the essential components for the core processing. Following this, the system puts these phrases in order according to the syntactic grammar rules of ISL.

As discussed in section 3, in ISL, tense, aspect, and mood features are represented separately using specific signs. The corresponding glosses for these signs are incorporated as needed. This rearrangement yields a sequence of signs that comprise the final target sentence.

Table 7 illustrates a comprehensive algorithm operating at the phrase level, employed for the generation of ISL glosses.

Table 7 Algorithm for rearrangement of phrases to generate ISL glosses

```
Algorithm: ISL Gloss Generator Module (LP, PTD, MSK)
Input:
LP[]: List of phrases
PTD[][]: PoS tagged lookup table
MSK[][]: Morpho-syntax knowledge feature structure returned by the morpho-syntax analyzer module
Output:
ISL[]: ISL glosses[]
Procedure:
    1.  Start
    2.  ISL[]← LP[]
    3.  Replace Marathi word in ISL[] by corresponding ISL gloss using PTD[][]
    4.  Repeat step 3 till all phrases in ISL[] are processed
        4.1 Process noun phrase
            If plural noun
               Repeat the noun three times
        4.2 Process adverb phrase
            if locative adverb
                shift locative adverb at the beginning of isl[]
            if temporal adverb
                shift temporal adverb at the beginning of isl[]
            if manner adverb
                shift manner adverb at the end of isl[]
        4.3 Process tense feature
            if past tense
                add PAST gloss at the beginning of ISL[]
            if future tense
                add FUTURE gloss at the beginning of isl[]
        4.4 Process aspect feature
            if continuous aspect
                repeat the verb gloss three times
            if perfect aspect
                add FINISH gloss at the end of ISL[]
            if habitual aspect
                add AGAIN gloss at the end of isl[]
            if inceptive aspect
                add BEGIN gloss at the end of isl[]
        4.5 Process mood feature
            if imperative mood
                add DO gloss at the end of isl[]
            if obligative mood
                add MUST gloss at the end of isl[]
            if desiderative mood
                add WISH gloss at the end of isl[]
            if abilitative mood
               add CAN gloss at the end of isl[]
        4.6 Process polarity
            if negation
              add NO gloss at the end of isl[]
        4.7 Process interrogative feature
            if open interrogative
              shift appropriate WH(WHO/WHAT/WHEN) gloss at the end of ISL[]
    5.  Return ISL[]
    6.  Stop.
```

Figure 6 gives a visual representation of the algorithm for generation of ISL glosses.

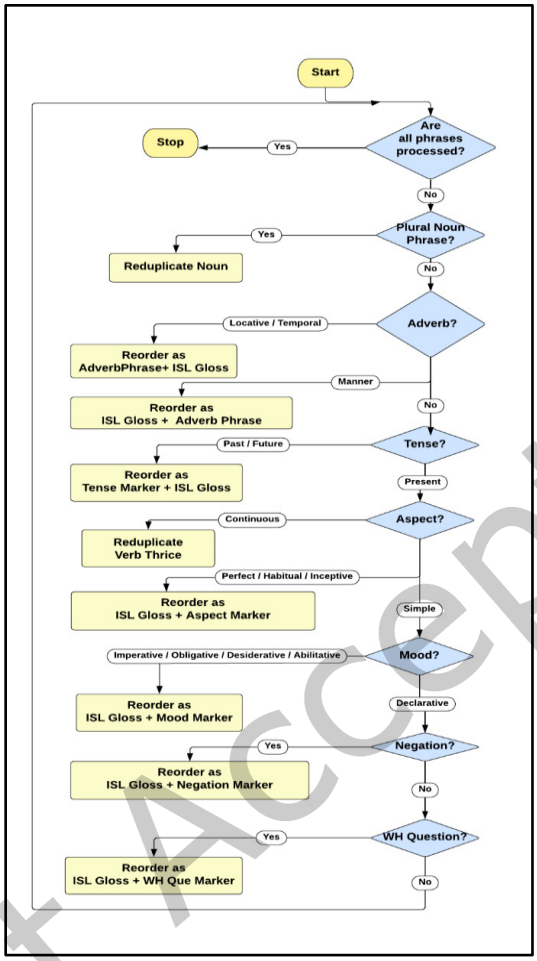

Figure 6 Flowchart for rearrangement of phrases to generate ISL glosses

4.6 Dynamic Simultaneous Morphological Handling Module

Section 3.1 has provided an overview of the simultaneous morphology in the context of ISL. The fundamental concept behind the 'dynamic simultaneous morphology handling module' involves the real-time adjustment of phonological parameters in root signs, guided by the morphological analysis of the input sentence. This module focuses on effectively incorporating/indulging the complex simultaneous morphological features of ISL in target representations in real time.

The shallow parser also produces specific phrases necessary for accounting of the simultaneous morphology in ISL. These phrases guide phonological adjustments within the HamNoSys-SiGML database. An algorithm operating at the phrase level used for handling simultaneous morphology is depicted in Table 8.

Table 8 Algorithm to uphold ISL simultaneous morphology features

Algorithm: Dynamic ISL Simultaneous Morphology Handling Module

Input:

ISL[]: ISL glosses
PTD[][]: PoS tagged lookup table
MSK[][]: Morpho-syntax knowledge feature structure returned by the morpho-syntax analyzer module

Output:

SM_ISL[][]: ISL glosses with simultaneous morphological features

Procedure:

1. Start
2. SM_ISL[0][]←ISL[]
3. Repeat step 3 till all phrases in SM_ISL[][]are processed

   3.1 Process numeral incorporation phrase (Quantifier followed by calendric adverb)
   Open calendric adverb's SiGML file
   Replace the original handshape with the quantifier's handshape
   Save the file by a new name.
   Update the adverb token in SM_ISL[][]according to the new name of the SiGML file

   3.2 Process classifier incorporation phrase (Classifier object followed by a locomotive verb)
   Open the verb's SiGML file
   Replace the original handshape with the object's classifier handshape
   Save the file by a new name.
   Update the verb token in SM_ISL[][]according to the new name of the SiGML file

   3.3 Process directional verb phrases (Directional verbs like give, and take)
   Analyze the personal features of the subject and object
   Choose the appropriate version of the verb's SiGML file from the dictionary
   Update the verb token in SM_ISL [][] according to the new name of the SiGML file

   3.4 Process nonmanual incorporation phrase (Closed interrogative)
   Open the last token's SiGML file
   Add appropriate nonmanual features in SiGML
   Save the file by a new name.
   Update the last token in SM_ISL[][] according to the new name of the SiGML file

   3.5 Process Ad position incorporation phrase (Common noun followed by an adposition)
   Open noun's SiGML file
   Change handshape and palm orientation according to adposition in SiGML
   Save the file by a new name.
   Update the noun's token in SM_ISL[][] according to the new name of the SiGML file

4. Return SM_ISL[][]
5. Stop

Figure 7 provides the flowchart for the algorithm.

4.7 Animation Generation

Sign languages are visual languages. To make the proposed framework practically usable it is necessary to produce the output in visual form. The proposed framework produces ISL glosses which serve as textual output. Glosses represent the sign sequence produced while signing a particular sentence along with its grammar features but it fails to give a visual experience to the user. So, it is further converted to 2-D animation using SiGML URL Player.[5] Figure 8 represents the system's graphical user interface.

[5] https://vhg.cmp.uea.ac.uk/tech/jas/vhg2024/index.html

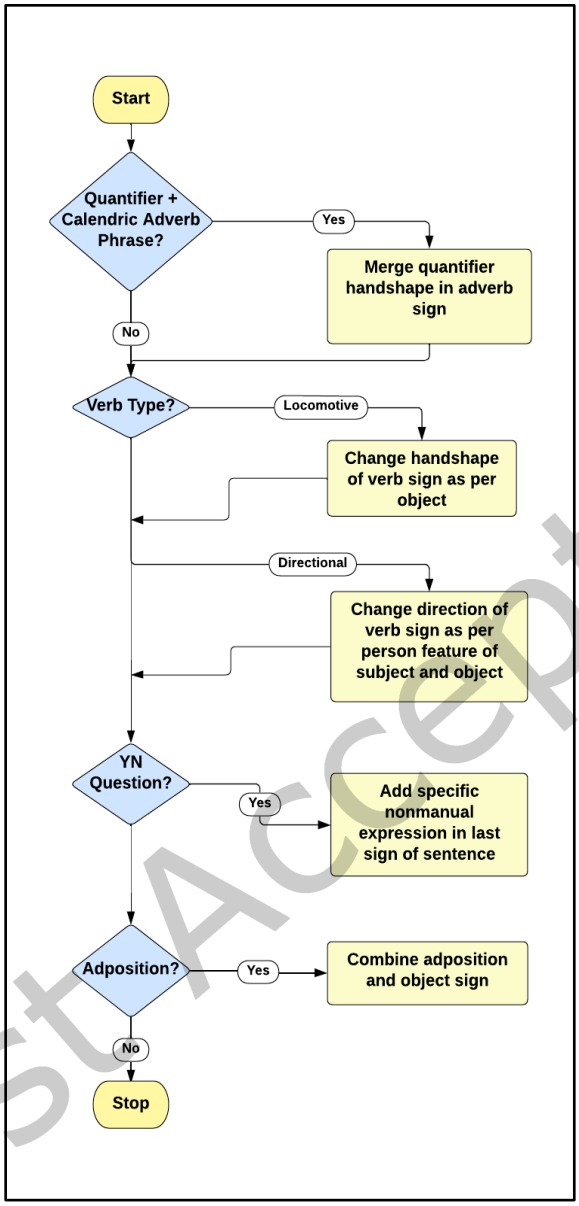

Figure 7 Flowchart for the handling of phrases to uphold ISL simultaneous morphology features

5 EXPERIMENTATION

The system was used to conduct experiments using a dictionary of over 900 words, based on Marathi-ISL Gloss-HamNoSys-SiGML methodology. This corpus encompasses vocabulary essential for everyday communication and is open-ended.

The sentences used for experimentation and evaluation had a full overlap with the bilingual dictionary. This was essential in simulating real-world scenarios and assessing the system's performance in practical applications. The test sentences were thoughtfully curated from general-purpose and healthcare domains, to encompass various linguistic features and real-life nuances. Table

9 presents intermediate outcomes using a sample Marathi sentence, providing valuable insights into the system's functionality.

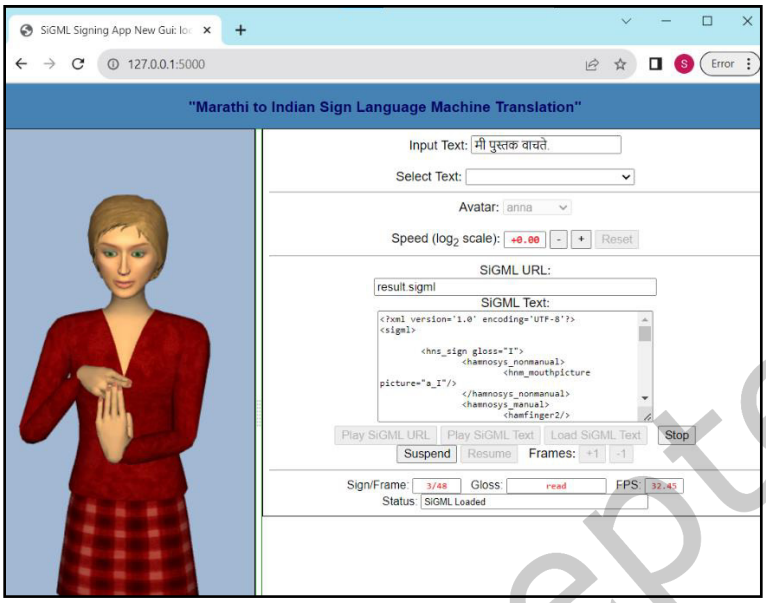

Figure 8 System's graphical user interface

Table 9 Intermediate results for a representative Marathi input sentence

Input Sentence	तू काल सकाळी लवकर शाळेत का गेला नाहीस? (Tū kāla sakāḷī lavakara śāḷēta kā gēlā nāhīsa? - Why didn't you go to school early yesterday morning?)
Tokenization	[('तू', 'PRP'), ('काल', 'RBT'), ('सकाळी', 'RBT'), ('शाळेत', 'NNC'), ('का', 'WH'), ('गेला', 'VFM'), ('नाहीस', 'NEG'), ('?', 'QM')]
Shallow parsing	(S तू/PRP (RBTP काल/RBT सकाळी/RBT) (NP शाळेत/NNC) आत/PSP का/WH (VP गेला/VFM नाहीस/NEG) ?/QM)
Chunks in list form	[('तू', 'PRP', 'O') ('काल', 'RBT', 'B-RBTP') ('सकाळी', 'RBT', 'I-RBTP') ('शाळेत', 'NNC', 'B-NP') ('का', 'WH', 'O') ('गेला', 'VFM', 'B-VP') ('नाहीस', 'NEG', 'I-VP') ('?', 'QM', 'O')]
Rearranged chunks as per ISL grammar	[('काल', 'RBT', 'B-RBTP'), ('सकाळी', 'RBT', 'B-RBTP'), ('तू', 'PRP', 'O'), ('शाळेत', 'NNC', 'B-NP'), ('गेला', 'VFM', 'B-VP'), ('नाही', 'NEG', 'NEG'), ('का', 'WH', 'O')]
ISL glosses	['YESTERDAY', 'MORNING', 'YOU', 'SCHOOL', 'IN', 'GO', 'NO', 'WHY_WH']
ISL glosses with locative and non-manual Features)	['(YESTERDAY,-,-)', '(MORNING,-,-)', '(YOU,-,-)', '(SCHOOL,-,-)', '(GO,-,-)', '(NO,-,-)', '(WHY,-,WH)']

Note: Gloss format: (X, Y, Z) X: Manual sign (Mandatory) Y: Locative Features (Optional) Z: Non-Manual expressions (Optional)

In this particular sentence, phrases like RBTP (Temporal adverb phrase), and VP (Verb Phrase) have been identified. The temporal adverb phrase is relocated to the beginning of the sentence. The WH word (WHY) is moved to the end of the sentence as per the grammar of ISL even after negation (NO).

The results are very encouraging and affirm that the devised rules for converting a Marathi sentence into ISL glosses are versatile, they can accommodate various combinations of tense (present, past, future), aspect (simple, continuous, perfect, inceptive), and mood (imperative, abilitative, desiderative, obligative). They also proficiently manage the translation of copular sentences, assertive and negative sentences, as well as open and closed interrogative sentences. Additionally, we have successfully addressed the simultaneous morphological features of ISL, including classifier incorporation, numeral incorporation, verb agreement, and non-manual feature incorporation. More illustrative examples are presented in Table 10.

Table 10 Some representative input sentences and intermediate results

Sr. No.	Marathi Sentence	Output of Shallow Parser	Key Grammar Features	ISL Glosses
1	तो दररोज शाळेत जायला लागला. (Tō dararōja śāḷēta jāyalā lāgalā. - He started going to school every day.)	(S तो/PRP (RBTP दररोज/RBT) (NP शाळेत/NNC) आत/PSP/PSP (VP जायला/VFM लागला/VFM) ./FT)	Temporal adverb, inceptive aspect	['(EVERYDAY,-,-)', '(HE,-,-)', '(SCHOOL,-,-)', '(IN,-,-)', '(GO,-,-)', '(BEGIN,-,-)']
2	तिला भरभर चालता येते. (Tilā bharabhara cālatā yētē. - She can walk fast.)	(S तिला/PRP (RBMP रभर/RBM) (VP चालता/VFM येते/VFM) ./FT)	Manner adverb, abilitative mood	['(HER,-,-)', '(WALK,-,-)', '(FAST,-,-)', '(CAN,-,-)']
3	मी तुला सकाळी पुस्तक देईल. (Mī tulā sakāḷī pustaka dē'īla. - I will give you the book in the morning.)	(S मी/PRP तुला/PRP (RBTP सकाळी/RBT) (NP पुस्तक/NNC) (VP देईल/VFM) ./FT)	Simultaneous morphology features -verb agreement and classifier incorporation	['(FUTURE,-,-)', '(MORNING,-,-)', '(YOU,-,-)', '(I,-,-)', '(BOOK,-,-)', '(CLF_FLATTHICK=GIVE,1GIVE2,-)']
4	मला चेंडू पकडता आला नाही. (Malā cēṇḍū pakaḍatā ālā nāhī. - I couldn't catch the ball.)	(S मला/PRP (NP चेंडू/NNC) (VP पकडता/VFM आला/VFM नाही/NEG) ./FT)	abilitative mood, negation	['(PAST,-,-)', '(ME,-,-)', '(BALL,-,-)', '(CATCH,-,-)', '(CAN,-,-)', '(NO,-,-)']
5	रुग्णाने गरम पाणी पिले पाहिज. (Rugṇānē garama pāṇī	(S (NP रुग्णाने/NNC) (JJP गरम/JJ) (NP पाणी/NNC) (VP	Obligative mood	['(PATIENT,-,-)', '(HOT,-,-)', '(WATER,-,-)', '(DRINK,-,-)', '(SHOULD,-,-)']

	pilē pāhija. - The patient should drink hot water.)	पिले/VFM पाहिजे/VFM) ./FT)		
6	मी खेळू इच्छित नाही. (Mī khēḷū icchita nāhī. - I don't want to play.)	(S मी/PRP (NP खेळू/NNA इच्छित/NNC) (VP नाही/NEG))	Desiderative mood, negation	['(I,-,-)', '(PLAY,-,-)', '(WISH,-,-)', '(NO,-,-)']
7	तो खेळायला लागला नाही. (Tō khēḷāyalā lāgalā nāhī. - He didn't start playing.)	(S तो/PRP (VP खेळायला/VFM लागला/VFM नाही/NEG) ./FT)	Inceptive aspect, negation	['(PAST,-,-)', '(HE,-,-)', '(PLAY,-,-)', '(BEGIN,-,-)', '(NO,-,-)']
8	सफरचंद झाडाखाली आहे. (Sapharacanda jhāḍākhālī āhē. - The apple is under the tree.)	(S (NP सफरचंद/NNC (NP झाडाखाली/NNC) खाली/PSP/PSP (VP आहे/VAUX) ./FT)	Copular sentence	['(APPLE,-,-)', '(TREE,-,-)', '(UNDER,-,-)']
9	थोडे दिवस चहा पिणे टाळा. (Thōḍē divasa cahā piṇē ṭāḷā. - Avoid drinking tea for a few days.)	(S (RBTP थोडे /JJ दिवस/RBTU) (NP चहा/NNC पिणे/GRND) (VP टाळा/VFM) ./FT)	Imperative sentence	['(FEW,-,-)', '(DAY,-,-)', '(TEA,-,-)', '(DRINK,-,-)', '(AVOID,-,-)', '(DO,-,-)']
10	तू पुस्तक वाचले? (Tū Pustaka Vācalē? - did you read the book?)	(S तू/PRP (NP पुस्तक/NNC) (VP वाचले/VFM) ?/QM)	YN question, simultaneous morphology feature -non-manual sign incorporation	['(YOU,-,-)', '(BOOK,-,-)', '(READ,-,YN)']

6 EVALUATION

To the best of our knowledge, no specific automatic evaluation metrics for sign language machine translation have been reported in the existing literature. Consequently, we opted for manual evaluation, leveraging the expertise of two ISL interpreters and 13 teachers from special schools catering to the hard-of-hearing. Among the teachers, one is a native ISL user. All evaluators are bilingual, i.e., well-versed in both Marathi and ISL. To date, our evaluation spans over 700 sentences.

Acknowledging the time-intensive nature of manual evaluation, we divided the sentences into two equal parts. Each segment underwent evaluation by a team comprising one government-authorized ISL interpreter and 6 to 7 ISL experts. To ease evaluator exhaustion, sets of 30 sentences were evaluated per session. Initial sessions were conducted offline to familiarize evaluators with the system's operation and setup.

We have taken both subjective and objective kind of feedback from evaluators. For subjective feedback, the remarks from evaluators were recorded during the evaluation and then they were summarized. The critical key remarks from evaluators are as follows.

- Regarding post-positions:
    - For sentences listed below the use of the ‘IN’ sign is not needed.

presenting it to evaluators. So, during the evaluation, the generated ISL glosses and the animated translation of each sentence both were shown to evaluators.

Table 11 Description of rank-based evaluation metrics

Adequacy	Fluency	Fidelity
1. The meaning of source and target is different 2. The meaning of source and target matches very little 3. The meaning of source and target matches moderately 4. The meaning of source and target is mostly the same 5. The meaning of source and target is exactly the same	1. Incomprehensible ISL 2. Disfluent ISL 3. Average ISL 4. Good ISL 5. Flawless ISL	1. A particular phrase is handled precisely none of the times 2. A particular phrase is handled precisely a few times 3. A particular phrase is handled precisely sometimes 4. A particular phrase is handled precisely most of the time 5. A particular phrase is handled precisely all of the times

Following the evaluation, the averages of all metrics are computed. The analysis of these average values is conducted for grammar features such as tense, aspect, mood, polarity, and sentence structure. Figure 9 provides a graphical depiction of the evaluation analysis based on grammar features, and a succinct discussion on these aspects follows.

- **Evaluation analysis based on tense:** Sentences in the present tense exhibited lower adequacy and fluency, as some evaluators suggested the inclusion of the sign ‘YES’ for assertive *present tense* copular sentences.
- **Evaluation analysis based on aspect:** The adequacy and fluency of the 'continuous' aspect were comparatively lower due to the apparent unnatural repetition of certain verb signs.
- **Evaluation analysis based on mood:** The adequacy and fluency of the 'imperative' mood were comparatively lower, with some evaluators recommending the use of the 'GO' sign as a mood marker instead of 'DO.'
- **Evaluation analysis based on polarity:** The adequacy and fluency of the 'assertive' mood were comparatively lower, with suggestions for incorporating the sign ‘YES’ for *assertive* present tense copular sentences.
- **Evaluation analysis based on sentence structure:** The adequacy and fluency of the copular sentences were comparatively lower, with some evaluators expressing the need for the sign ‘YES.’

7 CONCLUSION

We introduce a novel system designed to translate simple Marathi sentences into their corresponding ISL glosses and animation, marking a significant milestone as the first automated translation system for this particular language pair. Additionally, we propose a heuristic algorithm for generating simultaneous morphological features in ISL.

The system employs a two-step process involving shallow parsing of the source language sentences followed by the application of translation rules to produce the target language output. Through experimentation with a Marathi-ISL gloss-HamNoSys-SiGML-based corpus containing over 900 words, we evaluated the system's performance using sentences from general-purpose and healthcare domains.

To assess the system's effectiveness, we conducted subjective and objective evaluations with input from linguistic experts. The objective evaluation utilized established metrics including adequacy, fluency, and fidelity. Impressively, the system received commendable rankings ranging from 3.8 to 4.8 on a 5-point scale across various grammatical categories, providing encouraging results. The reported average adequacy and fluency stand at 4.3 and 4.1, respectively, on a 5-point scale.

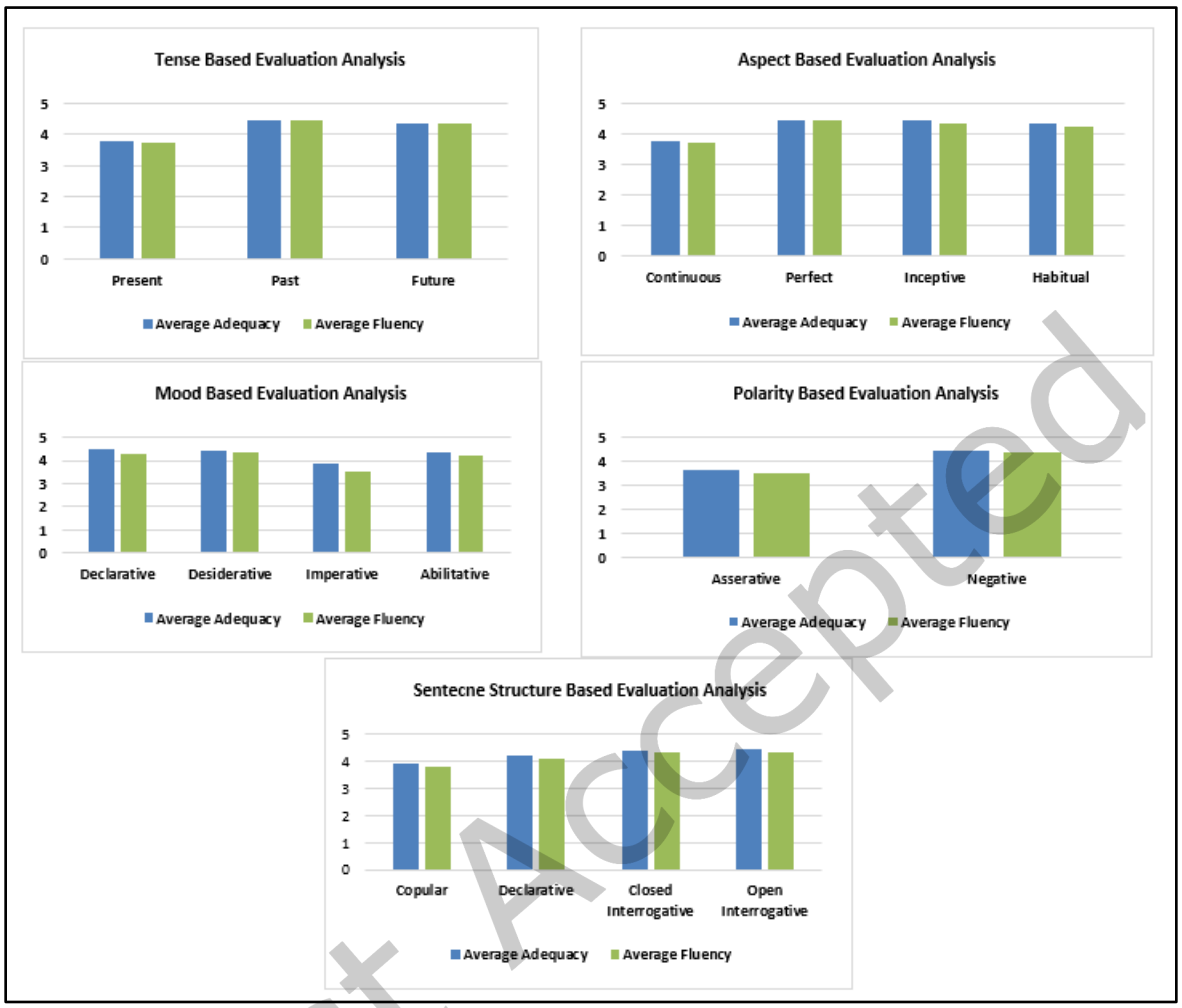

Figure 9 Evaluation analysis based on various grammar features

8 LIMITATIONS AND FUTURE SCOPE

At present, the system is proficient in translating simple sentences. Efforts are in progress to expand the rule base, enabling the translation of more complex sentences. The system lacks the capability to manage instances where a Marathi word doesn't have a corresponding gloss in the dictionary. Such words are omitted during translation producing a target sentence with inadequate meaning. However, we are engaged in solutions where, such scenarios could be addressed through fingerspelling.

To strengthen the system's capabilities, we are focused on enriching the Marathi-ISL bilingual dictionary. Additionally, the output generated by the current system can serve as valuable material for the creation of bilingual parallel corpora. The availability of high-quality resources will significantly benefit the development of statistical transformer-based sign language machine translation.

Moreover, we are in the process of developing a web-based application that can serve as a convenient interpreter for brief communications. This application will also prove beneficial in the

teaching and learning process at Hard-of-hearing schools, further demonstrating our commitment to inclusivity and accessibility.

9 DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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