Statistical Machine Translation between Myanmar Sign Language and Myanmar Written Text

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Abstract

This paper contributes the first evaluation of the quality of automatic translation between Myanmar sign language (MSL) and Myanmar written text, in both directions. Our developing MSL-Myanmar parallel corpus was used for translations and the experiments were carried out using three different statistical machine translation (SMT) approaches: phrase-based, hierarchical phrase-based, and the operation sequence model. In addition, three different segmentation schemes were studies, these were syllable segmentation, word segmentation and sign unit based word segmentation. The results show that the highest quality machine translation was attained with syllable segmentations for both MSL and Myanmar written text.

Keywords: Hierarchical Phrase-based Machine Translation, Myanmar sign language, Operation Sequence Model, Phrase-based Machine Translation, Word Segmentation.

1. Introduction

There are 673,126 persons with hearing disability in Myanmar [1]. They are suffering substantial exclusion and isolation from social networks for the hearing. The main reasons for this exclusion are communication problems. To help them to integrate the society and to communicate easily with the hearing people, there is a big requirement to develop an automatic machine interpreter that can translate Myanmar spoken or written language and MSL. Machine Translation of MSL would be useful in enabling hearing people who do not know MSL to communicate with Deaf individuals.

This paper contributes the first evaluation of the quality of Machine Translation (MT) between the MSL and Myanmar written text in both directions. One more contribution is we are developing a parallel corpus of MSL and Myanmar written text and we used the current version of the corpus for our experiments. We did experiments with baseline Phrase-based statistical machine translation (PBSMT) and other advanced techniques hierarchical phrase-based (HPBSMT) and operation sequence model (OSM).

The structure of the paper is as follows. In the next section, we present a brief review of machine translation systems for text to SL. Section 3 presents a sketch of MSL describing phenomena common to many other SLs and also

Section 4 presents preparation of the MSL corpus for machine translation experiments. Section 5 gives the detail information about all three segmentation schemes. Then, in Section 6, we describe the methodologies used in the machine translation experiments. Section 7 presents statistical information of the corpus and the experimental settings. The results together with some discussions are presented in Section 8. Section 9 presents the error analysis of translated sentences. Finally in Section 10, we present our conclusions and indicate promising results for future research.

2. MT for Sing Language

MT is an application of computers to translate from one natural language to other languages that convey the meaning of the original source language. An automated sign language machine translation is in great demand to make more information and services accessible to persons with hearing and speaking disabilities on a more economical basis when an interpreter is unavailable.

MT translation systems between spoken and sign languages had a start in the late 90s. Strategies used for developing MT system are also used for developing text to sign language MT system including direct MT, template-based MT, transfer-based MT, interlingua-based MT, rule-based MT, knowledge-based MT, example-based MT, syntax-based MT and statistical-based MT. Details of each strategy can be found in several books as follows: Hutchins and Somers, 1992 [2]; Hutchins, 2000 [3]; Nirenburg and Raskin, 2004 [4]. A number of text to sign language translation systems have been carried out around the world, e.g. TESSA system (Bangham & Cox, 2000) [5], weather reports generate system (Angus & Smith, 1999) [6], ViSiCAST Translator (Safar & Marshall, 2000) [7], TEAM Project (Zhao & Kipper, 2000) [8], ZARDOZ system (Veale & Collins, 1998) [9], ASL Workbench (Armond & Speers, 2001) [10], South African sign language machine translation system (Zijl & Barker, 2003) [11], TGT system-polish text into sign language (Suszczanska & Szmal, 2002) [12], spatial and planning models of ASL classifier predicates for MT and American sign language generation: Multimodal natural language generation (NLG) with multiple linguistic channels (Huenerfauth, 2004, 2005) [13] [14] [15] [16] [17] [18] [19], experiments in sign language machine translation using examples (Morrissey & Way, 2006) [20] and Morpho-syntax base statistical methods for automatic sign language translation (Stein, Bungeroth, & Ney, 2006) [21]. Most of them are English-to-American sign language.

3. Sign Language

Sign language is a language that uses manual communication to convey meaning. This can include simultaneously employing hand gestures, movement, orientation of the fingers, arms or body, and facial expressions to convey a speaker's ideas [22]. As spoken language use throat, nose and mouth as articulators, also SL uses fingers, hands, arms and facial expressions. These articulators can be classified as phonemes articulators similar to those uses in spoken languages that occur simultaneously, however they are linear and sequential in spoken languages [23].

SL is not universal language. There are different native sign languages all over the world, just as there are different native spoken languages. SLs have developed in communities of Deaf people, just as spoken languages have developed in communities of hearing people. Each displays the kinds of structural differences from the country’s spoken language that show it to be a language in its own right [24].

3.1. MSL and Myanmar Language

MSL like other known SLs depends on three basic factors that are used to represent the Manual Features (MFs): hand shape, hand location and orientation. In addition to the MFs, MSL also has Non-Manual Features (NMFs) that are related to head, face, eyes, eyebrows, shoulders and facial expression like puffed checks and mouth pattern movements. Postures or movements of the body, head, eyebrows, eyes, cheeks, and mouth are used in various combinations to show several categories of information, including lexical distinction, grammatical structure, adjectival or adverbial content, and discourse functions [25]. Grammatical structure that is shown through non-manual signs includes questions, negation, relative clauses [26], boundaries between sentences [27], and the argument structure of some verbs [28]. Similar to American Sign Language (ASL) and British Sign Language (BSL), Myanmar Sign Language use non-manual marking for yes/no questions. They are shown through raised eyebrows and a forward head tilt [29] [30] [31]. Figure 1 shows an example of MSL sentence "မွေး ဘယ်မှာ" + "NMFs – chin up and raised eyebrows for wh-question". The meaning of the MSL sentence is "မင်း ဘယ် ဇာတိ လဲ ။" in Myanmar language and "Where are you born?" in English respectively.

Sign language is different in Yangon and Mandalay regions with many dialects. To the best of our knowledge, MSL using in the Mary Chapman School for the Deaf Children, Yangon is mainly different with MSL of Mandalay region. Figure 2 shows two examples of different signs used in Yangon and Mandalay which correspond to the same meaning. Figure 2 (a) is for a Myanmar word "အမေ" (mother in English) and Figure 2 (b) is for a Myanmar word "မနက်" (morning in English). The left sides of the figure are the signs used in Mandalay and the right sides are the signs used in Yangon. Figure 2 (a) in Mandalay three times repeated rotation the sign; the hand shape and movement are different with Yangon. Figure 2 (b) one handed sign is used in Mandalay and two handed sign is used in Yangon. This difference gives the difficulty of communicating and dealing between Deaf or hearing disabilities in different cities. A government project was set up in 2010 to establish a national sign language with the aid of the Japanese Federation of the Deaf.

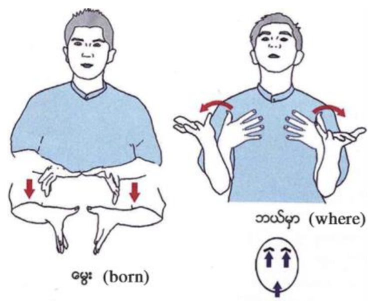

Figure 1. An example of MSL sentence that used non-manual features (from Myanmar Sign Language Basic Conversation Book)

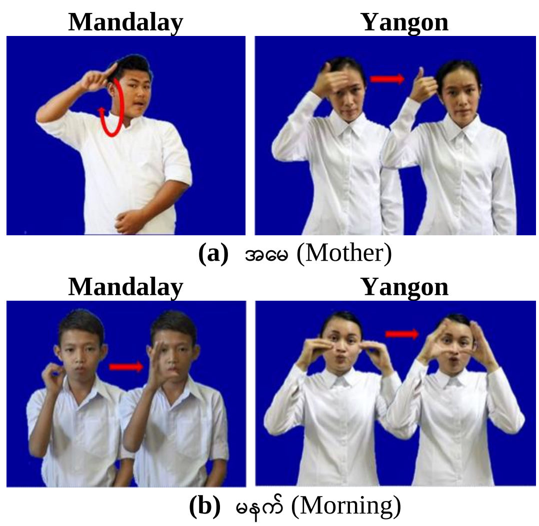

Figure 2. Examples different signs used in Mandalay and Yangon which correspond to the same Myanmar word

Naturally, hearing problems can affect the ability to read or write the Myanmar language. This is due to the differences between their native language SL and the spoken Myanmar language. Moreover, Myanmar language is tonal and syllable-based. MSL does not have the same grammar, syntax, and vocabulary as Myanmar. Examples of different grammar, syntax and vocabulary between Myanmar and MSL can be seen in the followings.

English: Which months are the hottest months?
Myanmar: ဘယ် လ တွေ က အပူဆုံး လ တွေ လဲ ။
MSL: ပူ (hot) အရမ်း (very) လ (month) ဘာလဲ (what)

English: It is 10 past 6.
Myanmar: ၆ နာရီ ထိုး ပြီး လို့ ၁၀ မိနစ် ရှိ နေ ပြီ ။
MSL: နာရီ (clock) ၆ (six) ကျော် (pass) မိနစ် (minute) ၁၀ (ten) နဲနဲကျော် (pass a little)

English: Extinguisher
Myanmar: မီးသတ်ဆေးဘူး ။
MSL: အနီ (red) ဘူး (aerosol bottle) ဖြန်း (spray)

English: Please call an ambulance!
Myanmar: ကျေးဇူးပြုပြီး လူနာတင်ကား ခေါ်ပေး လို့ ရ မလား ။
MSL: ကြက်ခြေနီ (red cross) ကား (car) အရေးပေါ် (emergency) ဖုန်းဆက် (phone call) ကျေးဇူးပြု၍ (please)

3.2. Myanmar Fingerspelling

MSL uses fingerspelling like in other sign languages. Myanmar fingerspelling is the representation of Myanmar characters and numbers with hands. It is used especially for signing names, city names and words, which do not exist in sign language. As we mentioned in Section 3.1, there are also two different fingerspelling character sets for MSL; one is used in northern Myanmar and the other is used in southern Myanmar [32].

4. Corpus Preparation

Myanmar NLP researchers are facing with many difficulties arising from the lack of resources; in particular parallel corpora are scare [33]. Currently, there is no parallel corpus for MSL. Therefore, as a first step, we are building a multimedia parallel MSL corpus with the purpose of developing a Machine Translation (MT)-based approach for using technology to assist hearing and speaking disabilities with limited Myanmar language in their daily life basic conversation.

For this purpose data collection with 22 SL trainers and Deaf people: males and females, age range from 11 to 48, from School for the Deaf (Mandalay), Mary Chapman School for Deaf Children (Yangon), School for the Deaf (Tamwe), Myanmar Deaf Society and Literacy and Language Development for the Deaf in Yangon and Mandalay regions has been carried out. We also considered covering different MSL dialects.

The MSL corpus contains MSL video, a textual representation of Myanmar sign language and translated Myanmar written text. Here, we have to carefully consider boundaries of MSL video segmentation for transcription with Myanmar text. Currently, there is no defined Myanmar gloss transcription for MSL and we are developing an unambiguous textual representation that covers start and end points of SL sentences. This textual glossing scheme development is the most challenging part of MSL corpus building. MSL videos were annotated using EUDICO Linguistic Annotator (ELAN). Figure 3 shows an example video annotation with ELAN. Video segmentation is based on MSL word units.

Figure 3. An example of MSL video annotation with ELAN

5. Segmentation

In SMT, word segmentation is a necessary step in order to yield a set of tokens upon which the alignment and indeed the whole machine learning process can operate. Based on the previous studies relating to effectiveness of Myanmar word segmentation schemes for SMT [34], we also decided to use three word segmentation schemes for SMT between MSL and Myanmar written text.

5.1. Syllable Segmentation

Generally, Myanmar words are composed of multiple syllables and most of the syllables are composed of more than one character. Syllables are also basic units for pronunciation of Myanmar words. If we only focus on consonant based syllables, the structure of the syllable can be described with Backus Normal Form (BNF) as follows:

Syllable := C{M}{V}[CK][D]

Here, C for consonants, M for medials, V for vowels, K for vowel killer character and D for diacritic characters [35]. Myanmar syllable segmentation can be done with rule based [36], [34], finite state automaton (FSA) [37] or regular expression (RE) [38]. In our experiments, we used RE based Myanmar syllable segmentation tool named “sylbreak” [38].

5.2. Word Segmentation for Myanmar Language

In Myanmar text, spaces are used for separating phrases for easier reading. It is not strictly necessary, and these spaces are rarely used in short sentences. There are no clear rules for using spaces in Myanmar language, and thus spaces may (or may not) be inserted between words, phrases, and even between a root words and their affixes. Although we can implement conditional random fields (CRF) approach word segmentation model by using freely available word segmented Myanmar corpus such as myPOS [39], we did manual word segmentation for Myanmar text of our corpus. The reasons are the current myPOS corpus size is only 12K and we assumed that manual word segmentation is more suitable for the domain of our corpus. We applied the word segmentation rules proposed by Win Pa Pa, et al (2015) [40].

5.3. Sign Unit Based Segmentation for MSL

We considered different segmentation schemes for Myanmar language sentence and MSL sentence. For MSL sentence, segmentation is based on meaningful MSL word other sign languages such as ASL, BSL and Japanese Sign language (JSL). Some examples of Myanmar sign language word category are repeated sign (e.g. two or more repeated “thank you” sign for “please”), sign with multiple meanings (e.g. one MSL sign for “blood” and “red”), compound sign (e.g. combination of MSL signs “car”, “emergency” and “fire extinguishing” for “fire truck”), name sign (e.g. Pyin Oo Win city), fingerspelling sign (e.g. “O” sign + “2” sign for

"O2"), fingerspelling shortcut sign ("O" for Octane, Myanmar consonant "မ" (Ma) for Mandalay city) and phrase or sentence level signs (e.g. MSL sign for စိတ်ငြိမ်ငြိမ်ထား (calm down), ကားတိုက် (car accident)). The following shows the different word segmentation between MSL and Myanmar written text ("How is the weather today?" in English):

Word segmentation for Myanmar sentence:
ဒီ နေ့ ရာသီဥတု အခြေအနေ ဘယ်လို ရှိ သလဲ ။

Sign Unit based segmentation for MSL:
မနက်က ညနေထိ မိုးရွာ လေတိုက် ကောင်း မကောင်း

6. Experimental Methodology

6.1. Phrase-based Statistical Machine Translation (PBSMT)

A PBSMT translation model is based on phrasal units [41] [42]. Here, a phrase is simply a contiguous sequence of words and generally, not a linguistically motivated phrase. A phrase-based translation model typically gives better translation performance than word-based models. We can describe a simple phrase-based translation model consisting of phrase-pair probabilities extracted from corpus and a basic reordering model, and an algorithm to extract the phrases to build a phrase-table [43].

6.2. Hierarchical Phrase-based Machine Translation (HPBSMT)

The hierarchical phrase-based SMT approach is a model [44] based on synchronous context-free grammar. The model is able to be learned from a corpus of unannotated parallel text. The advantage this technique offers over the phrase-based approach is that the hierarchical structure is able to represent the word re-ordering process. The re-ordering is presented explicitly rather than encoded into a lexicalized re-ordering model (commonly used in purely phrase-based approaches). This makes the approach particularly applicable to language pairs that require long-distance re-ordering during the translation process [45].

6.3. Operation Sequence Model (OSM)

The Operation Sequence Model (OSM) [46], combines the benefits of phrase-based and N-gram-based SMT [47] and remedies their drawbacks. It is based on minimal translation units, capture source and target context across phrasal boundaries and simultaneously generate source and target units. Providing a strong coupling of lexical generation and reordering gives a better reordering mechanism than PBSMT. The list of operations can be divided into two groups and they are five translation operations (Generate (X, Y), Continue Source Cept, Generate Identical, Generate Source Only (X) and Generate Target Only (Y)) and three reordering operations (Insert Gap, Jump Back (N) and JumpForward).

7. Experiments

7.1. Corpus statistics

We used 2,510 Myanmar (my) and MSL (sl) parallel sentences of MSL corpus, which is a collection of everyday basic conversation expressions. It contains six main categories and they are people (greeting, introduction, family, daily activities, education, occupations, and communication), food (food, beverage and restaurant), fun (shopping, hobbies and sports), resource (number, time, weather and accuracy), travel (bus, train and airport) and emergency (health, accident, police, fire, earthquake, flood and storm). In our MSL data, 6% of sentences are containing Myanmar fingerspelling characters. 2,000 sentences were used for training, 310 sentences for development and 200 sentences for evaluation.

We prepared four types of segmentation pairs and they are word-word, syllable-syllable, syllable-word and word-syllable. The word segmentation for MSL was done based on the meaningful sign units of MSL as we explained in Section 5.3. Syllable segmentations for both Myanmar written text and MSL, we applied syllable segmentation units defined by the "sylbreak" Myanmar syllable segmentation tool [38].

7.2. Moses SMT system

We used the PBSMT, HPBSMT and OSM provided by the Moses toolkit [48] for training the PBSMT, HPBSMT and OSM statistical machine translation systems. The word segmented source language was aligned with the word segmented target languages using GIZA++ [49]. The alignment was symmetrized by grow-diag-final-and heuristic [50]. The lexicalized recording model was trained with the msd-bidirectional-fe option [51]. We used KenLM for training the 5-gram language model with interpolated modified Kneser-Ney discounting [52] [53]. Minimum error rate training (MERT) [54] was used to tune the decoder parameters and the decoding was done using the Moses decoder (version 2.1.1) [48]. We used default settings of Moses for all experiments.

7.3. Evaluation

We used two automatic criteria for the evaluation of the machine translation output. One was the de facto standard automatic evaluation metric Bilingual Evaluation Understudy (BLEU) [55] and the other was the Rank-based Intuitive Bilingual Evaluation Measure (RIBES) [56]. The BLEU score measures the adequacy of the translations and RIBES is suitable for distance language pairs such as Myanmar and English. The higher BLEU and RIBES scores are better.

8. Result and Discussion

The BLEU and RIBES score results for machine translation experiments with PBSMT, HPBSMT and OSM for word-word, syllable-syllable, syllable-word and word-syllable segmentation pairs are shown in Table 1, 2, 3 and 4, respectively. RIBES scores are shown in brackets. Bold numbers indicate the highest scores among the three SMT approaches.

Table 1. BLEU and RIBES scores of word-word segmentation pair for PBSMT, HPBSMT and OSM

Src-Trg	my (Word) – sl (Word)		
	PBSMT	HPBSMT	OSM
my-sl	25.80 (0.8023)	**26.42 (0.8125)**	25.38 (0.8004)
sl-my	29.77 (0.8280)	29.70 **(0.8332)**	**30.38** (0.8261)

Table 2. BLEU and RIBES scores of syllable-syllable segmentation pair for PBSMT, HPBSMT and OSM

Src-Trg	my (Syllable) – sl (Syllable)		
	PBSMT	HPBSMT	OSM
my-sl	34.42 (0.8392)	**35.11 (0.8402)**	34.81 (0.8389)
sl-my	33.54 (0.8442)	33.01 (0.8414)	**34.78 (0.8446)**

Looking at the results in Table 1, 2, 3 and 4, it is clear that the syllable-syllable segmentation pair scheme was by far the most effective for both Myanmar-MSL and MSL-Myanmar translations. In Table 2, for the Myanmar-MSL translation the highest BLEU and RIBES scores (35.11 and 0.8402) were achieved by HPBSMT and 0.3 BLEU and 0.0013 RIBES scores higher than that of OSM. The BLEU and RIBES scores of PBSMT and OSM are comparable (34.42, 34.81 and 0.8392, 0.8389) respectively. For the MSL-Myanmar translation, OSM gave the highest BLEU and RIBES scores; 34.78 and 0.8446 respectively.

Surprisingly, if we only focus on Myanmar-MSL translation, the HPBSMT gave the highest BLEU and RIBES scores for all segmentation pairs except word-syllable segmentation. On the other hands, for MSL-Myanmar translation, OSM gave the highest BLEU scores for all segmentation pairs. Obviously, not both BLEU and RIBES scores are the highest performance always together. HPBSMT with word-word and PBSMT with syllable-word segmentation pairs achieved the highest RIBES scores 0.8332 and 0.7416 respectively (see Table 1 and 3). The possible explanation is the RIBES metric is more sensitive to reordering.

Table 3. BLEU and RIBES scores of syllable-word segmentation pair for PBSMT, HPBSMT and OSM

Src-Trg	my (Syllable)- sl (Word)		
	PBSMT	HPBSMT	OSM
my-sl	21.02 (0.7847)	**21.96 (0.7945)**	20.55 (0.7685)
sl-my	20.93 **(0.7416)**	20.18 (0.7389)	**21.21** (0.7370)

Table 4. BLEU and RIBES scores of word-syllable segmentation pair for PBSMT, HPBSMT and OSM

Src-Trg	my (Word)- sl (Syllable)		
	PBSMT	HPBSMT	OSM
my-sl	24.17 **(0.6785)**	23.94 **(0.6785)**	**24.38** (0.6757)
sl-my	25.31 (0.7344)	26.03 (0.7382)	**27.23 (0.7411)**

From the overall results, it can be clearly seen that HPBSMT and OSM approaches are significantly better than PBSMT. Although word-word segmentation results are higher than syllable-word and word-syllable segmentations, it is significantly lower than syllable-syllable segmentation scheme.

9. Error Analysis

We analyzed the translated outputs using Word Error Rate (WER). We used the SCLITE (score speech recognition system output) program from the NIST scoring toolkit SCTK version 2.4.10 for making dynamic programming based alignments between reference (ref) and hypothesis (hyp) and calculation of WER. The formula for WER can be stated as equation (1):

$$WER = \frac{S + D + I}{N} = \frac{S + D + I}{S + D + C} \qquad (1)$$

where S is the number of substitutions, D is the number of deletions, I is the number of insertions, C is the number of correct words and N is the number of words in the reference ($N = S + D + C$) [57]. Note that if the number of insertions is very high, the WER can be greater than 100%. The following example shows WER calculation on the MSL-Myanmar where the word segmentation method. In this example, S=2, D=1, I=3, C=4, and N=7 and WER for whole sentence is equal to $6/7 = 86\%$.

Ref: ဒီနေ့ အပူချိန် ဒီဂရီ ၃ ၅ ကျော် ။

Hyp: ဒီ နေ့ နေပူ အပူချိန် ဒီဂရီ ၃၅ ကျော် ကြိုက် ။

WER errors

Reference	Hypothesis	Error type
	ဒီ	Insertion
	နေ့	Insertion
ဒီနေ့	နေပူ	Substitution
၃		Deletion

၅	၃၅	Substitution
	ကြိုက်	Insertion

The following example shows the WER calculation on the MSL-Myanmar where the syllable segmentation. In this case, S=4, D=3, I=1, C=4 and N=11 for PBSMT and HPBSMT, WER for whole sentence of PBSMT and HPBSMT is equal to 72.73%, S=3, D=3, I=0, C=5, N=11 for OSM and WER for whole sentence of OSM is equal to 54.55%.

Source: ငါ လက် ထပ် မ ပြီး သေး ။
Reference: ကျွန် တော် အိမ် ထောင် သည် တစ် ယောက် မ ဟုတ် ပါ ။
PBSMT hyp: ကျွန် တော် လက် ထပ် မ ပြီး သေး ဘူး ။
HPBSMT hyp: ကျွန် တော် လက် ထပ် မ ပြီး သေး ဘူး ။
OSM hyp: ကျွန် တော် လူ လွတ် တစ် ယောက် ပါ ။

Figure 4 and Figure 5 present the WER percentages of translation between Myanmar written text and Myanmar sign language. The results show that syllable-syllable segmentation pairs gave the lowest WER values and the difference is higher for the Myanmar-SL translation (see Figure 4).

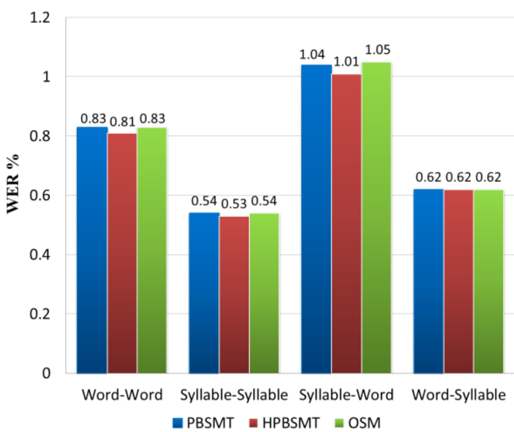

Figure 4. WER of Myanmar written text to Myanmar sign language translation with word-word, syllable-syllable, syllable-word, word-syllable segmentation pairs

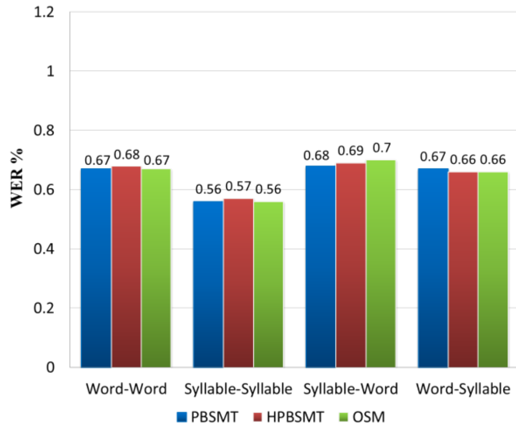

Figure 5. WER of Myanmar sign language to Myanmar written text translation with word-word, syllable-syllable, syllable-word, word-syllable segmentation pairs

We also made manual error analysis on translated outputs of PBSMT, HPBSMT and OSM models, and we found that dominant errors are different in sentence level. Several reordering errors are found in PBSMT and OSM on the Myanmar-MSL translation on both syllable and word segmentation. The following are some examples of reordering errors that we found on PBSMT and OSM (see bold words):

Syllable - Syallable (my-sl)

Source: သူ မြွေ ကိုက် ခံ ရ လို့ ပါ ။
Reference: သူ မြွေ ကိုက်ခံရ ။
PBSMT hyps: သူ **ကိုက်** မြွေ ခံ ရ ။
HPBSMT hyp: သူ မြွေ ကိုက် ခံ ရ ။
OSM hyp: သူ **ကိုက်**_မြွေ ခံ ရ ။

Word - Word (my-sl)

Source: ကျွန်တော် သွား လို့ ရ ပြီ လား ။
Reference: ငါ သွား ရလား ။
PBSMT hyp: ။ ငါ သွား ပြီးပြီလား ။
HPBSMT hyp: ငါ သွား ရ လား ။
OSM hyp: ငါ သွား ။ ပြီးပြီလား ။

Syllable - Word (my-sl)

Source: ကျေး ဇူး ပြု ၍ ဖိ နပ် ချွတ် ပါ ။
Reference: ဖိနပ် ချွတ် ကျေးဇူးပြု၍ ။
PBSMT hyp: **ကျေးဇူးပြု၍ နပ် ဖိ** ချွတ် ။
HPBSMT hyp: ကျေးဇူးပြု၍ ဖိနပ် ချွတ် ။
OSM hyp: **ဟော့ ကျေးဇူးပြု၍ နပ် ။ ဖိ** ချွတ်

Some extra words are found in PBSMT and HPBSMT models for the MSL-Myanmar translation on both syllable and word segmentations. Some examples of extra word errors are as follows (see bold words):

Syllable - Syllable (sl-my)

Source: ဆင်း နေ ရာ ဘာ လဲ ပြော ။
Reference: ဘယ် မှာ ဆင်း ရ မ လဲ ပြော ပါ ။
PBSMT hyp: **ငါ တို့** ဘယ် **နေ ရာ** ဆင်း ရ မ လဲ ပြော ပါ ။
HPBSMT hyp: ဆင်း **နေ ရာ က ဘာ** လဲ ပြော ပါ ။
OSM hyp: ဘယ် မှာ ဆင်း ရ မ လဲ ပြော ပါ ။

Word-Word (my-sl)

Source: ကျွန်တော် သောက် စရာ တစ် ခု ခု လို ချင် တယ် ။
Reference: သောက်စရာ တစ်ခုခု လိုချင် ။
PBSMT hyp: ငါ ခု သောက် စရာ တစ် ခု **ခုံ** ကြိုက် ။
HPBSMT hyp: ငါ သောက် စရာ တစ် ခု ခု **ခုံ** ကြိုက် ။
OSM hyp: ငါ ခု သောက် စရာ တစ် ခု ကြိုက် ။

Furthermore, some words are missing in the translated outputs of PBSMT and HPBSMT especially on the MSL (word segmentation) to Myanmar written text (syllable segmentation) translation as shown in the followings (see hypotheses of PBSMT and HPBSMT):

Syllable - Word (my-sl)

Source: ၁၉၉ ဖုန်းခေါ် ကျေးဇူးပြု၍ ။
Reference: ကျေး ဇူး ပြု ပြီး ၁ ၉ ၉ ကို ဖုန်း ခေါ် ပေး ပါ ။
PBSMT hyp: ၁ ၉ ၉ ကို ဖုန်း ခေါ် ပေး ပါ ။
HPBSMT hyp: ၁ ၉ ၉ ကို ဖုန်း ခေါ် ပေး ပါ ။
OSM hyp: ကျေး ဇူး ပြု ၍ ၁ ၉ ၉ ကို ဖုန်း ခေါ် ပေး ပါ ။

10. Conclusion

This paper has presented the first study of the statistical machine translation between Myanmar sign language and Myanmar written text. We implemented three SMT systems (PBSMT, HPBSMT and OSM) with our developing MSL-Myanmar written text corpus. We also investigated the effectiveness of three word segmentation schemes (syllable segmentation, word segmentation and sign unit based segmentation) for SMT. Our results clearly show that HPBSMT and OSM with syllable segmentation for both source and target languages achieved the highest BLEU and RIBES scores for translation between MSL and Myanmar written text. We plan to extend our study on neural machine translation in the near feature.

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