Developing a Sign Language Writing System: Focus on Necessity and Sign Language-Specific Features

Nobuko Kato, Yuito Nameta, Megumi Shimomori, Sumihiro Kawano, Yuhki Shiraishi
Faculty of Industrial Technology
Tsukuba University of Technology
Tsukuba, Japan
e-mail: {nobuko, a191009, a171013, kawano, yuhkis}@a.tsukuba-tech.ac.jp

Akihisa Shitara
Graduate School of Library, Information and Media Studies
University of Tsukuba
Tsukuba, Japan
e-mail: theta-akihisa@digitalnature.slis.tsukuba.ac.jp

***Abstract*—Achieving universal access in professional settings necessitates the development of computer-assisted sign language writing support system, considering the perceptual characteristics of the deaf and hard of hearing individuals. This study explores sign language-specific features to elucidate the requirements for a sign language writing support system. Analysis of news sentences expressed in sign language reveals the prevalence of distinct expressions like topicalized and wh-cleft sentences. We explore a writing system that incorporates these features and conduct experiments involving transcribing sign language movies. We first examine whether it is necessary to write sign language when learning in specialized contexts, thus identifying the key features of sign language sentences that need to be written effectively and clarify the functions required for the system based on actual writing experiments.**

Keywords-deaf and hard of hearing; sign language; visual language; sign writing; communication support.

I. INTRODUCTION

The purpose of this study was to develop a computer-based sign language writing support system tailored to the perceptual characteristics of deaf and hard-of-hearing (DHH) individuals, considering the visual and spatial nature of sign language and the unique characteristics of signed sentences. This study complements the previous work [1] by discussing the need for such a system and examining the issues involved in developing a computer-based writing support system for sign language writing.

The enrollment of individuals with disabilities in higher education institutions and the emphasis on lifelong learning are increasing, necessitating expanded learning opportunities tailored to individual disabilities. In specialized educational settings such as higher education, it is necessary to ensure that effective information and communication methods align with the unique characteristics of each disability.

Various services are employed to facilitate communication among DHH individuals in higher education institutions, including real-time captioning by transcriptionists, automatic speech recognition (ASR), sign language interpretation, and notetaking. ASR technology is increasingly being explored to automatically generate caption text for DHH users [2]. However, it is crucial to recognize that DHH individuals are bicultural and have the right to be educated in their native sign language [3]. Quality education delivered in national sign languages and written languages is a key factor in the education of deaf children and adult learners [4].

While some countries use sign language with word orders that mirror spoken language, they can pose comprehension challenges for deaf individuals [5]. Research on sign language interpretation in universities has indicated that deaf students must receive information using the correct sign language structure [6]. Studies on sign language interpretation in universities have highlighted the significance of instructors' clear use of sign language, as perceived by deaf students [7].

In other words, it is considered important for quality education that direct instructors and sign language interpreters use the sign language accurately and that students receive information using the correct sign language structure. Consequently, there is an anticipated increase in opportunities for specialized content learning facilitated by interpreters or direct sign language instruction in various countries.

Writing has also been considered an important process in higher education. However, writing presents a significant challenge in sign language learning. Existing writing systems for spoken language (Figure 1d) are ill-suited for sign language, which is a distinct language. Unlike hearing individuals, who can write while listening (Figure 1a), deaf individuals must write while simultaneously watching sign language (Figure 1b).

Therefore, the development of a computer-based support system for writing sign language is essential for streamlining the writing process and allocating more time to the comprehension of specialized content. To achieve this, it is imperative to delineate the functions that such a system should encompass, based on sign language characteristics.

This study aims to address the following research questions:

RQ1: Is a new system for writing sign language necessary in professional and learning situations?

RQ2： What are the sign language-specific features crucial for writing specialized sign language content?

RQ3: How can sentences be written while preserving sign language-specific expressions?

RQ4: What challenges are faced by the proposed sign language writing method in developing a computer-based support system for writing sign language?

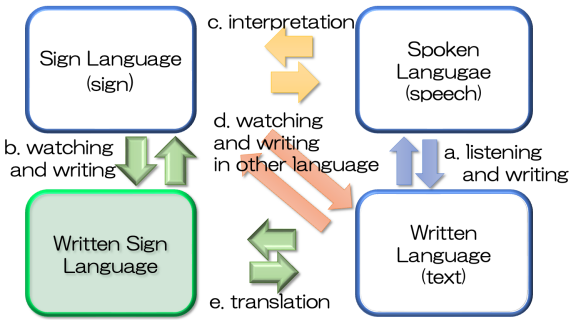


Figure 1. The relationship between spoken and written language.

The remainder of this paper is structured as follows: Section II provides insights into sign languages and relevant prior research. Section III describes the verifications to assess the necessity of a sign language writing system. Section IV outlines the characteristics of signed sentences and presents the proposed method based on these characteristics. Section V elaborates the experimental methodology and results, and Section VI discusses the findings based on the experimental results. Finally, Section VII summarizes this study.

II. Sign Language Notation Methods

After discussing the differences between signed and spoken languages from the perspective of writing signs, this chapter reviews related previous studies.

A. Sign Language

Sign language serves as a visual language used by the deaf community, where linguistic information is communicated not only through hand shapes and movements but also through nonmanual markers (NMMs) such as facial expressions, gaze, and head movements [5].

Unlike spoken languages such as English, which are linear and rely on speech, sign languages are intricate and employ hand gestures, facial expressions, body movements, and spatial elements [5]. Thus, devising a writing system for sign languages demands innovative approaches that are distinct from those used for spoken languages.

B. Related Work

Efforts to transcribe sign language into writing have adopted two main approaches: iconographic and alphabetic (using letters from existing spoken languages) [8].

Iconographic methods entail symbolizing hand actions and describing words and sentences, offering the advantage of representing novel words and actions, but often result in a high number of descriptions per word, primarily suited for analysis [9][10]. Notational systems such as Si5S and ASLwrite prioritize writing, but use specialized fonts for sign language, which makes it difficult for learners to correlate these systems with existing spoken language texts.

ASL-gloss, another method, employs characters from existing spoken languages using English words as labels to describe American Sign Language (ASL). This system follows the ASL word order and grammatical rules, with glosses used to teach sign language and grammar [11]. Few studies have examined the use of ASL-gloss in actual educational settings, and examples that have examined the use of ASL-gloss as a potential method for improving reading and comprehension skills in people with severe hearing loss have not supported it as an effective method for improving comprehension [12].

One example of using Japanese as a label is when it is used as an intermediate language for machine translation between Japanese and signed Japanese [13].

In university settings, where comprehension hinges on understanding key spoken words, it is crucial for deaf students to receive information that is semantically and syntactically correct in the sign language structure [6].

Therefore, our study adopts existing characters to describe terms, and explores a method for diagrammatically representing the structure of sign languages to address these challenges.

III. Verification in a Learning Environment

DHH individuals who use sign language have been learning to use both sign language and Japanese since an early age, using Japanese texts. This raises the question of whether it is necessary to learn and write using sign language in professional and learning situations.

To address RQ1, verification was conducted using two types of sign language videos–Expressions 1 and 2–to assess the necessity of a sign language writing system in learning environments.

Expression 1: Signed words were arranged according to Japanese word order, along with Japanese mouthing and fingerspelling, and the sign language expressions for each word were taken from a sign language dictionary designed for learning.

Expression 2: Spatial and visual expressions were employed using Japnanese Signe Language (JSL) grammar.

Ethical approval was obtained from the Research Ethics Review of Tsukuba University of Technology, where the experiments were conducted.

A. Verification 1

The video used in Verification 1 explained spatial geometry in mathematics and focused on explaining specialized content in sign language without using any materials or whiteboards, relying solely on sign language for the explanation. A deaf individual proficient in JSL created videos for Expressions 1 and 2 after fully understanding the content. The duration of the videos was 78.9 seconds for Expression 1 and 69.0 seconds for Expression 2.

Eight DHH students who regularly use sign language participated in the experiment. They watched the videos either in the order of Expression 1, followed by Expression 2, or in reverse order.

Immediately after watching each video, participants rated its clarity on a 7-point scale (1: very unclear, 4: neutral, 7: very clear) and attempted to explain the content of the video

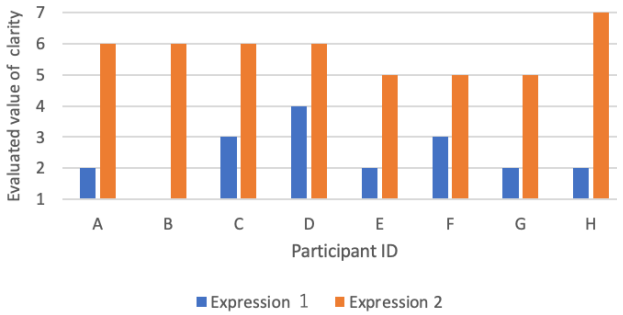


Figure 2. Results of the questionnaire on the clarity of Verification 1 (1: very unclear, 4: neutral, 7: very clear).

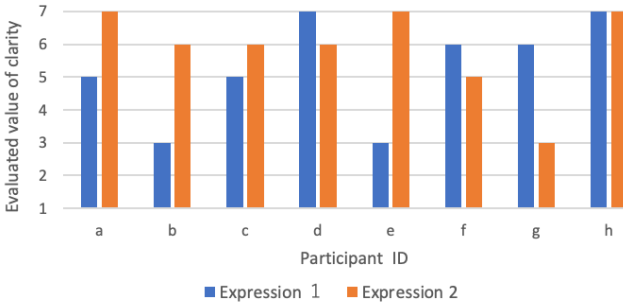


Figure 3. Results of the questionnaire on the clarity of Verification 2 (1: very unclear, 4: neutral, 7: very clear).

in their own words. Additionally, after viewing both videos, they answered a follow-up survey on each expression.

As a result of the evaluation, all eight participants rated Expression 2 as easier to understand than Expression 1 (Figure 2). The average clarity ratings were 2.4 for Expression 1 and 5.8 for Expression 2. A paired t-test revealed a significant difference ($p<0.01$).

Additionally, in the follow-up survey, the following comment was made:

- In Expression 1, it was difficult to read Japanese (through mouthing or fingerspelling, etc.).
- In Expression 2, it was easier to form a visual image.

In the explanations provided by the experiment participants regarding the video content, it was observed that

- In Expression 1, they understood the mathematical terms (with examples in which they reproduced the Japanese directly from their notes).
- In Expression 2, providing a detailed explanation was more difficult.

The average accuracy of the reproduced sentences was 55% for Expression 1 and 52% for Expression 2, with no significant difference between them. In both cases, the reproduction rate was low.

In other words, although Expression 2, which used the grammar of JSL, was rated as easier to understand, accurately reproducing the content was difficult. It was confirmed that a method for writing sign language is necessary to fully comprehend and reproduce the content.

B. Verification 2

In Verification 1, we found differences in the level of mathematical knowledge among students. To eliminate the influence of prior knowledge, the content of the video was set to "Denseness of real numbers," a topic that was unknown to all participants.

Participants were eight DHH students who regularly used sign language. Participants watched Expression 1 and responded to a comprehension test and questionnaire, then watched Expression 2 and responded to a comprehension test or questionnaire, or vice versa.

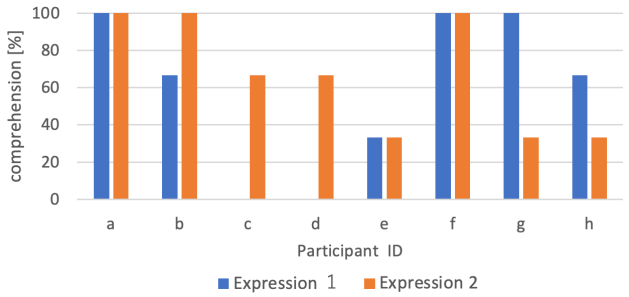


Figure 4. Comprehension in Verification 2.

TABLE I. RESULTS OF QUESTIONNAIRE AND COMPREHENSION TEST IN VERIFICATION 2.

	Expression 1	**Expression 2**
Average of questionnaire results for clarity	5.25	5.88
Average of comprehension test	58.3	66.7

The results of the comparison between Expression 1, which follows the Japanese word order, and Expression 2, which uses the grammar of JSL and spatial/visual expressions, are shown in Figure 3 and Figure 4.

The average values of the survey ratings and comprehension test results are presented in Table I. Although only two participants indicated that they used JSL and the others were not familiar with JSL expressions, there were no significant differences in the rating values and comprehension test results for the two types of signs.

Additionally, in Expression 1, two participants scored zero on the comprehension test, whereas in Expression 2, no participant scored zero.

Even when technical terms and particles that connect words and phrases were explicitly indicated using fingerspelling and mouthing, the comprehension of the content presented in Japanese word order did not reach 60% (Expression 1).

In the follow-up survey regarding Expression 2, comments included the following:

- It is easy to form a visual image.
- There is a need to reconstruct the sentence in Japanese.

TABLE II. EXAMPLES OF NMMS OBSERVED DURING THE ANALYSIS OF NEWS SENTENCES.

Sentence type	NMMs
Topicalization	Eyebrows raised and eyes widened in the topic area at the beginning of the sentence
Wh-cleft sentence	Squinting and slightly shaking head in the middle of a sentence
Causal relationship	Eyebrow raised and head forward and fixed in the part of the condition
Complex sentence	Nodding motion before and after the clause

From these comments and observations during the verification, it was noted that while JSL expressions are understandable even for users who are not familiar with JSL and are more accustomed to Japanese, reconstructing Japanese sentences from sign language proves to be difficult, which impedes the writing process.

This confirms the need for a new way of writing sign language in professional situations.

IV. SIGN LANGUAGE FEATURES AND PROPOSED METHOD

To develop a new writing system, it is first necessary to identify the unique features of sign language sentences.

A. Analysis of News Texts

To address RQ2, an analysis was conducted to explore sign language-specific expressions in texts containing specialized content. Owing to the limited material on signed sentences expressing specialized content, sign language news was chosen for the analysis. News sentences typically employ topic-specific vocabulary and present factual information logically.

We analyzed 44 sentences from Sign Language News presented by four deaf news anchors at the Japan Broadcasting Corporation.

Table II shows examples of NMMs observed during the analysis. Topicalized sentences introduce the topic at the beginning, whereas wh-cleft sentences feature a question word in the middle.

B. Results of the Analysis of Signed Language Sentences

The analysis of signed sentences in Sign Language News yielded the following insights:

- Complex sentences were prevalent in sign language news texts (32 out of 44 sentences).
- Presenting the topic at the beginning of a sentence was frequently used (34 out of 44 sentences).
- Topicalization, wh-cleft sentence, and reason-for-sentence were used to introduce the topic.

Although Japanese sentences lacked topics, sign language sentences frequently present topics using sign language-specific expressions, such as topicalization/wh-cleft sentences or reason-for sentences, explicitly stating the reason at the onset of the sentence.

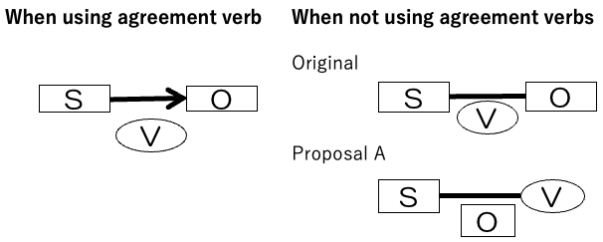


Figure 5. Improvements to the basic writing rule for sentences that do not use agreement verbs.

Thus, presenting a topic at the beginning of a sentence emerges as a sign language-specific feature crucial for facilitating comprehension by DHH individuals.

C. Proposed Method

To address RQ3, we proposed a new writing system that incorporates the identified sign-language-specific features.

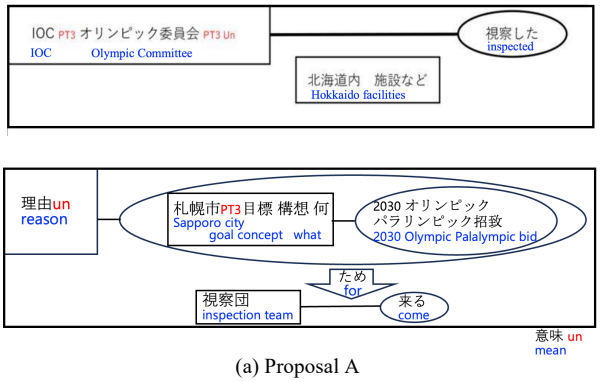
Previously, we proposed a method for representing the spatial structure of sign language on a two-dimensional plane using symbols, such as the spatial representation of the subject and object [14]. After reviewing the basic rules, we consider a writing method that focuses on the macroscopic structure of sentences to highlight and visualize the topic in a manner conducive to DHH comprehension.

The rules of Proposal A for writing sign language are as follows:

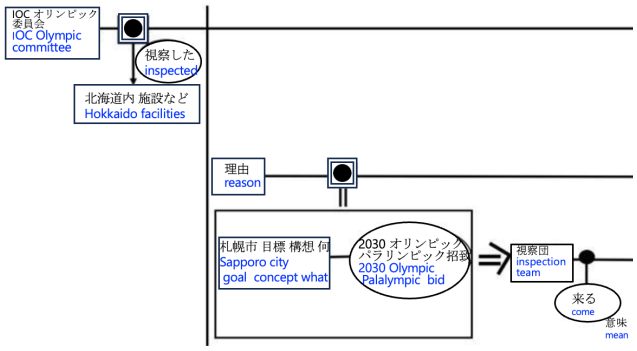
Rule 1: The labels use the same text as the spoken language.
Rule 2: The subject and object are enclosed in squares, the predicate is enclosed in a circle, and the subject and predicate are connected by lines.
Rule 3: Clauses and phrases are represented using squares. In this manner, the hierarchical structure of a sentence can be visualized.
Rule 4: When reading a written sentence, it should be read from left to right and from top to bottom. SOV (Subject-Object-Verb) sentences follow the basic sentence structure for writing.
Rule 5: The upper-left square indicates topics, such as topicalization, wh-cleft sentence, reason-for-sentence.
Rule 6: If there is a phrase that functions as a logical marker, such as "due to," "reason for," it should be written inside an arrow.

To understand specialized content, it is essential to understand the technical terminology used in textbooks and spoken languages accurately. Therefore, the same text as the spoken language is used as a label for writing sign language (Rule 1).

In our previously proposed rules, we reflected on the distinctive use of signing spaces in agreement verbs in the written form (Figure 5: original). However, because the basic word order in sign language is SOV, there was an opinion that it would be easier to write the following word order in cases where agreement verbs were not used. Therefore, we propose a writing method that follows the word order when agreement verbs are not involved (Figure 5: Proposal A).



(a) Proposal A



(b) Proposal B

Translation in English: The IOC Olympic member inspected facilities in Hokkaido. Because Sapporo City is aiming to bid for the 2030 Olympic and Paralympic Games.

Figure 6. Examples of a topicalization sentence and example of a reason sentence (Blue letters indicate translated English).

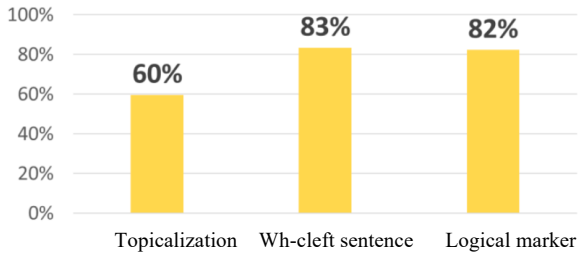
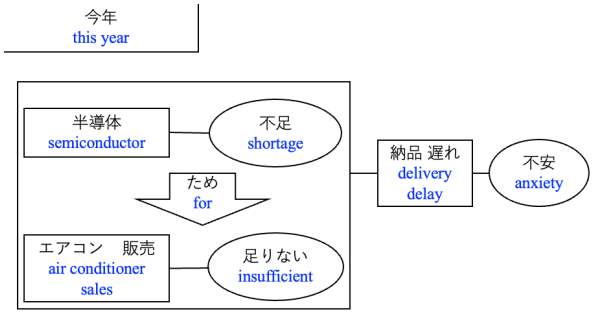
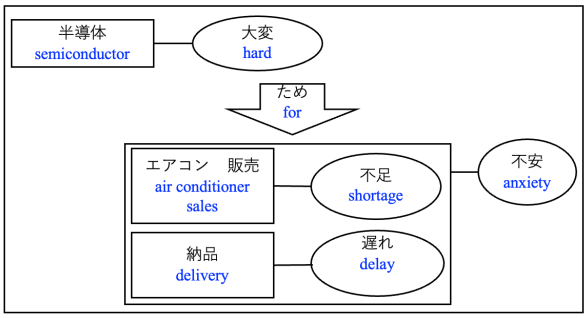


Figure 7. The accuracy rate of topicalization, wh-cleft sentences, and logical markers.



(a) Example Answer 1 for Task 1 using Proposal A.



(b) Example Answer 2 for Task 1 using Proposal A.

The English translation： This year, there were concerns about the shortage of air conditioners and delays in delivery due to the semiconductor shortage.

A list of sign labels: {this year} {semiconductor} {shortage} {due to} {air conditioners} {sales} {lack} {etc.} {delivery} {delay} {etc.} {concerns} {there were}

Figure 8. Examples of participants writing from a sign language video using the proposed method in Task1 (Reproduced from handwritten experimental results. Blue letters indicate translated English.).

Rules 5 and 6 notate structures specific to sign language sentences derived from the analysis of news scripts.

Examples of news scripts based on these rules are shown in Figure 6.

Figure 6(a) illustrates an example of a topicalized sentence using Proposal A. The sentence is enclosed in an outer-frame rectangle, with squares and circles representing the subjects, objects, and predicates. The rectangle in the top-left denotes the topic (Figure 6(a)).

In Proposal B, which employs a single line to preserve a word's position in the sign space across consecutive sentences, the branching point is surrounded by a double square to signify that the subject is the topic (Figure 6(b)).

V. EXPERIMENT

. To verify the effectiveness of the proposed method, two experiments were conducted.

A. Experiment 1

1) Experimental Method for Experiment 1

We conducted an experiment to test the efficacy of the proposed sign language writing methods, specifically those based on Proposals A and B.

The participants were 12 university students who were either deaf or hard of hearing. Initially, the participants were briefed on the rules of the writing system and engaged in practice sessions to familiarize themselves with reading written signs using the proposed methods.

During the experiment, the participants were presented with a choice between Proposals A and B based on their preference for ease of understanding. They were then shown a video featuring a sign language news program.

Task 1: They were shown a video which contains only one sentence, without any ticker.

Task 2: They were shown a video in which the first and second sentences were accompanied by a ticker displaying only the main points. The third sentence was presented in sign language without tickers. The participants were instructed to transcribe the third sentence using their chosen writing method.

This setup aimed to simulate scenarios commonly encountered in academic settings, where signs are often displayed alongside textual materials, such as slides, allowing students to simultaneously view both sign language and written spoken language, such as English or Japanese.

Ethical approval was obtained from the Research Ethics Review of Tsukuba University of Technology, where the experiments were conducted.

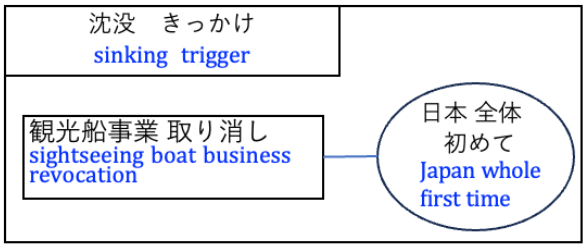
2) Experimental Results for Experiment 1

In the sign language news watching and writing experiment, 10 out of 12 participants opted for Proposal A, while two participants preferred Proposal B.

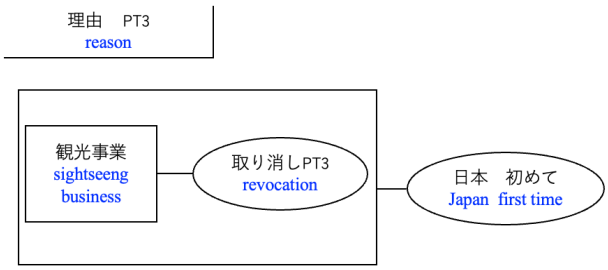
After a short practice session, participants answered whether each of the written signs contained a topic, logical marker, etc. The percentages of correct responses are shown in Figure 7. Logical markers and wh-splitting revealed a high percentage of correct answers, whereas the percentage of correct answers for topicalization was low. This is because it is difficult to distinguish between the case in which the subject of the sentence is surrounded by a square and the case in which it is the topic. Therefore, it was necessary to improve the topic by creating a double square.

In Task 1, when the ticker was not displayed, a problem arose where participants could not write because they did not know the labels for the sign language words. Therefore, in Task 1, when there were questions about the labels, the experimenter provided answers before transcription (e.g., semiconductor or air conditioner).

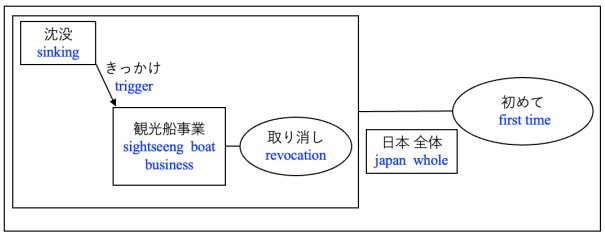
Figure 8 illustrates examples of the participants' writing in Task 1. The structure of a sentence is clearly visualized using logical markers. Nine out of ten people correctly used symbols for logical markers in the proposed method. However, different



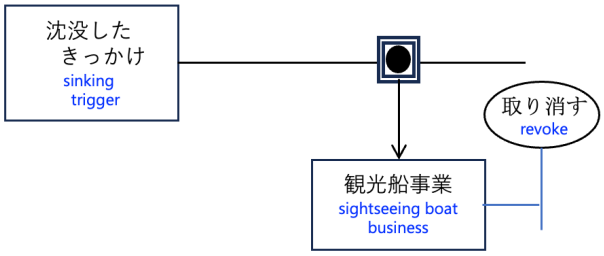
(a) Example Answer 1 for Task 2 using Proposal A.
(An example where "revocation" was transcripted as a noun.)



(b) Example Answer 2 for Task 2 using Proposal A.
（An example where "revocation" was transcripted as predicate.)



(c) Example Answer 3 for Task 2 using Proposal A.
(An example of summarizing "a tourist boat business license was revoked due to sinking" into a single phrase.)



(d) Example Answer 1 for Task 2 using Proposal B.

Translation in English: This is the first time in the nation that a sightseeing boat business license has been revoked as a result of an accident.

A list of sign labels: {sinking} {trigger} {sightseeing} {boat} {business} {revocation} {Japan} {whole} {first time}

Figure 9. Examples of participants writing from a sign language video using the proposed method in Task 2 (Reproduced from handwritten experimental results. Blue letters indicate translated English.).

notations were observed in other parts of the sentence structure, indicating that the understanding of the sentences varied.

In Task 2, there were no questions regarding the labels for sign language words. Although there were multiple possible labels for a single sign word, 11 of the 12 participants opted for technical terms as their label. However, errors in symbol selection and placement were observed, presumably owing to the misinterpretation of sign language or the influence of the preceding context (Figure 9).

In Figure 9(a), "sinking trigger" is correctly selected as the topic, with the proposed symbol correctly employed. In Figure 9(b), there is a misreading of the sign word {reason}; however, the topic and pointing to the third person (PT3) were used as cues for structuring. Figure 9(c) shows that the topic is considered part of the phrase structure. Conversely, Figure 9(d) depicts the correct topic selection; however, errors in the placement of the symbols were observed. It can be inferred that the participants placed the topic in the subject position, possibly because of its placement at the beginning of the sentence.

B. Experiment 2

1) Experimental Method for Experiment 2

To clarify the challenges of writing sign language sentences, a deaf individual proficient in JSL read 44 sign language sentences and attempted to transcribe them by following predetermined rules. Assuming automatic transcription by computer, features such as topicalization, wh-question, pointing, and nodding were recorded and used as cues for transcription.

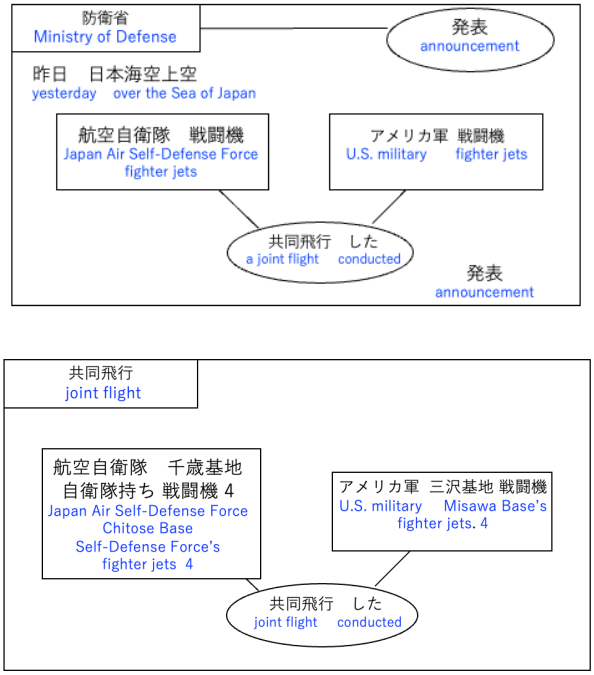
Following rules 1–6 for Proposal A, the procedure used for actual writing is as follows:

Step 1: When there is a topicalization marker, such as raised eyebrows, it is written as the topic in a rectangle touching the upper-left corner.
Step 2: When there is a wh-question, everything up to the wh word is written in a square touching the upper-left corner.
Step 3: For words indicating time and place, the label is written directly in the diagram as is.
Step 4: When there is a PT3, the word or the phrase up to that point is enclosed in a square as the subject or noun phrase.
Step 5: If the phrase following the subject is an object, enclose it in a square; if it is a predicate, enclose it in a circle.
Step 6: Logical markers, such as "due to," should be clearly indicated by writing them inside an arrow.

2) Experimental Results for Experiment 2

The experimental results identified the following challenges in structuring and writing sign language sentences using the proposed method:

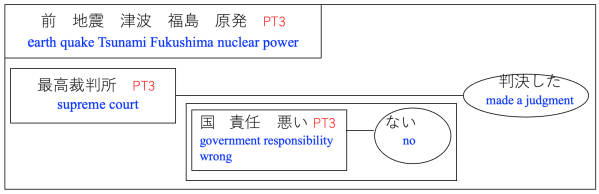
- When the signing space is differentiated between the left and right, rules and procedures that reflect this are necessary (Figure 10(a)).
- There was a phrase considered a topic by PT3, even though there was no raised eyebrow marker (Figure 10(b)).
- In some cases, topicalization, wh-cleft, and logical markers were mixed in same sentence. Thus, the priority must be determined.



Translation in English:
(1st sentence) The Ministry of Defense announced that fighter jets from the Japan Air Self-Defense Force and the U.S. military conducted a joint flight over the Sea of Japan yesterday.
(2nd sentence) It has been reported that the joint flight involved four F-15 fighter jets from the Japan Air Self-Defense Force's Chitose Base and four F-16 fighter jets from the U.S. military's Misawa Base.

A list of sign labels:
(1st sentence) {Ministry of Defense} {announcement} {yesterday} {the sea of Japan} {overhead} {Japan Air Self-Defense Force} {fighter jets} {U.S. military} {fighter jets} {joint flight} {finished} {announce}
(2nd sentence) {a joint flight} {Japan Air Self-Defense Force}{Chitose Base}{Self-Defense Force's} {fighter jets} {4} {U.S. millitary} {Misawa Base's} {fighter jets} {4} {a joint flight} {conducted}

(a) An example illustrating the use of the signing space.



Translation in English: The Supreme Court has ruled that the government was not responsible for the Fukushima Daiichi nuclear power plant accident.

A list of signs labels:
{earth}{quake}{Tsunami}{Fukushima}{nuclear}{power} {supreme court} {government}{responsibility}{wrong}{made}{judgement}

(b) An example where the phrase up to the PT3 at the beginning of the sentence is considered the topic.

Figure 10. Example that could not be written using only the predetermined steps.

- Phrases and clauses are also expressed through other clues, such as NMMs, and computers must accurately recognize such clues.

VI. Discussion

In this section, the experimental results are analyzed in relation to the research questions.

A. RQ1: The need for a sign language writing system,

In the survey results of Verification 1, which compared explanations of mathematics using the Japanese word order for sign language words (Expression 1) and JSL grammar (Expression 2), all eight participants rated Expression 2 higher than Expression 1. A significant difference was observed in the average evaluation scores ($p<0.01$).

Additionally, when comparing the lengths of the videos for Expressions 1 and 2, although Expression 2 included supplemental expressions not found in Expression 1, the videos for Expression 2 were shorter for all sign language sentences. In Expression 1, the use of finger spelling for technical terms made the videos longer, whereas in Expression 2, the information was conveyed more efficiently using spatial references and classifiers.

Through two verifications, in Expression 1, the participants were able to take notes in Japanese, but it was difficult in some cases for them to re-explain the content in their own words and score points on the comprehension test.

However, in Expression 2, the meaning was conveyed as an image, but it was difficult to write because the participants did not know the technical terms needed for writing, making it challenging to obtain high scores on comprehension tests.

In other words, it was confirmed that although it is easy to understand explanations using the grammar of JSL, it is difficult to write them in written Japanese, and a method of writing sign language is needed.

B. RQ2: Sign Language-Specific Features

When comparing the two videos created for Verification 1 and Verification 2, the following differences were observed:

- [Explicit subject] In Japanese (Expression 1), the subject is omitted, whereas in the JSL (Expression 2), it is sometimes explicitly stated.
- [Additional explanations] In Expression 2, there were supplemental expressions and repetitions that were not present in Expression 1.
- [Use of CL] In Expression 1, technical terms were expressed using fingerspelling and mouthing, whereas in Expression 2, CL (classifiers), which are sign language elements that express the characteristics of objects and movements with hand shapes, were used extensively.

To clarify the structural characteristics of more sign language sentences, news scripts were analyzed.

Comparison between Japanese and signed news sentences revealed the following features:

- Complex sentences were often used, with over 70% of the sentences exhibiting complexity, contrary to the common belief that sign sentences are short and simple.
- The structuring of complex sentences in sign language often involves presenting the topic at the sentence outset.

Sign language employs specific expressions such as topicalization and the wh-cleft to introduce and emphasize topics. For instance, in sentences indicating reasons, sign language presents the word “reason” at the beginning, followed by the logical marker “for,” and conclude with a phrase expressing the result, a structure not mirrored in Japanese (Figure 6(a)).

These specific expressions are considered to aid in conveying technical concepts in a digestible manner for DHH individuals.

C. RQ3：Writing Sign Language Sentences

Developing a writing system for sign language requires consideration of the perceptual characteristics of DHH individuals and their information processing. Therefore, such a system must incorporate spatial representations, time-series depictions, and the visualization of grammatical and logical structures.

We propose a method that projects spatial and time series representations onto a 2D (two-dimensional) plane, and uses symbols to represent grammatical and logical structures. In addition to basic spatiotemporal representation, our approach focuses on the macroscopic structure of sentences, represented by NMMs and other visual cues.

The experimental preference for Proposal A by 10 of the 12 participants underscores that emphasizing the topic at the beginning is effective. Topic sentences are represented by NMMs such as raised eyebrows (Table II). Although NMMs are said to be challenging for learners to master, written signed sentences can aid in comprehending these expressions.

Regarding sign labels, 11 of the 12 participants used technical terms in their real-time sign writing. To use technical terms as labels, we must consider how sign language and slides are presented.

Although the explanation and practice of the proposed method were brief, in Task 1, six out of ten participants were able to write a topicalization and nine out of ten participants were able to write a logical marker. This was the same trend as the comprehension of the reading of the structure of written signs (Figure 7). It is necessary to highlight topicalization with a double rectangle.

In this experiment, the participants did not necessarily consider the structure of the whole sentence before writing it, but rather tended to record the sign labels in the order of the time series.

The experiment revealed difficulties in selecting and positioning symbols (Figure 9(d)), highlighting the need for computer support such as automatic placement and insertion of symbols.

D. RQ4: Challenges of the proposed sign language writing method

1) Sign language labels as technical terms

In Experiment 1, it was found that by displaying sign language and tickers simultaneously, users could write down technical terms. In specialized explanatory contexts, it is assumed that sign language will be used alongside slides and it will be necessary to identify labels from a larger amount of text.

For instance, when fingerspelling is used, it can be used to identify technical terms [15], or when pointing gestures are made, the corresponding technical terms can be extracted. In such cases, computer support is considered to be effective.

2) To identify sentence structure

In the actual transcription experiment, there were many variations in the choice of symbols and positioning of each label. Many of the experiment participants were not familiar with JSL, and it is thought that many NMMs were overlooked.

However, we found that even users unfamiliar with JSL were able to write, read, and distinguish the macrostructures of sentences, such as topicalization and logical markers, using the proposed method after a short practice.

Although the basic word order in JSL is typically SOV, word order can be changed to present a topic, and the first position in a sentence does not always indicate the subject. Moreover, in JSL, there are homonyms between nouns and verbs, which make it difficult to distinguish between similar signs.

For example, In Figure 9(a)(b)(c)(d), there are some notational distortions between the verb “revoke” and the noun “revocation,” and between the subject enclosed in a square and the predicate enclosed in a circle.

For users unfamiliar with JSL, we tried a writing procedure using relatively easy-to-recognize NMMs, such as pointing (PT3), nodding (Un), and raising eyebrows. In the procedure we envisioned, PT3 was used to identify the subject noun or noun phrase. However, because PT3 is frequently used for other meanings, ambiguity remained.

Additionally, clauses and phrases can be represented by other NMMs, such as head movement, head position, and the timing of the nod [16]. Therefore, it is necessary to add rules that use NMMs to identify sentence structures in specialized texts.

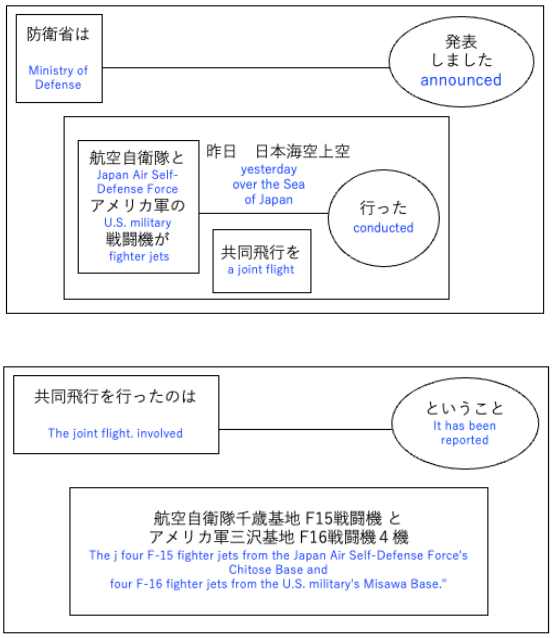
To create a computer-assisted sign language writing system, it is important not only to properly recognize technical terms in the signed text but also to properly discriminate these NMMs. It is necessary to sequentially incorporate known areas, such as the differences between nods that mark the boundaries of a clause and other nods.

The sentence structures in Figure 8(a) and (b) are different because the grammar of JSL cannot be read. In other words, transcribing sign language sentences can be viewed as a way to visualize the level of understanding of sign language content.

3) Reflects the signing space

When the signing space is used effectively, it is considered appropriate to reflect it in the writing (Figure 10(a)).

When compared to the Japanese transcription in Figure 11, Figure 10 clearly distinguishes the roles of the left and right



Translation in English:
(1st sentence) The Ministry of Defense announced that fighter jets from the Japan Air Self-Defense Force and the U.S. military conducted a joint flight over the Sea of Japan yesterday.

(2nd sentence) It has been reported that the joint flight involved four F-15 fighter jets from the Japan Air Self-Defense Force’s Chitose Base and four F-16 fighter jets from the U.S. military’s Misawa Base.

Figure 11. In the case of writing a sentence with sign language words arranged in Japanese word order.

and maintains these roles consistently between the first and second sentences, making the sentences easier to understand.

To automatically perform such a transcription, it is necessary to prioritize the identification and representation of the signing space when arranging the layout.

E. Limitation

The limitations of this study include the small number of participants, variability in sign language proficiency, and the limited number of signed sentences. Further research with a larger number of expressions and sentence patterns is required to design a system that is useful for improving the learning performance of DHH individuals.

VII. Conclusion and Future Work

This study aimed to develop a computer-assisted writing system tailored to the perceptual characteristics of DHH individuals by considering the visual and spatial nature of sign language and the unique characteristics of signed sentence.

First, to examine the necessity of such a writing system, we conducted verifications while conveying specialized content using two types of sign language expressions. The

verifications revealed that while JSL expressions effectively convey the image and are highly rated by DHH users, the inability to write them down presents challenges, indicating the need for a system to write sign language.

By analyzing news sentences in sign language, we confirmed that numerous expressions specific to sign language, such as topicalized and wh-cleft sentences, were used. To establish a new method of expression that is intuitive and understandable for the deaf, we proposed a writing system that reflects these features and conducted an experiment in which participants wrote a sign language video.

The results of the experiment demonstrated that by using the proposed method, participants could write signed sentences with sign language-specific features.

Furthermore, to represent the structure of sign language sentences of specialized contents, it is necessary to recognize not only the presence or absence of raised eyebrows, nodding, and pointing is important, but also spatial expressions, the intensity of pointing and nodding, and elements such as eye movement and head orientation.

In addition, writing signs while maintaining the structure of the signed sentence leads to the visualization of each student's comprehension of the content and is expected to be applied to learning in the future, such as checking comprehension independent of the power of the spoken language.

In future, we intend to expand our research by conducting a broader survey involving a larger sample of sentences. This will enable us to further refine our proposed writing system and provide support for communication and learning among DHH individuals.

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