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SCIENTIFIC ASPECTS OF MODERN APPROACHES TO MACHINE TRANSLATION FOR SIGN LANGUAGE

Abstract: Scientific research in the field of automated sign language translation represents a crucial stage in the development of technologies supporting the hearing-impaired and deaf communities. This article presents a comprehensive approach to addressing semantic and technical challenges associated with the uniqueness of sign language. The research goal is to create an innovative system that combines semantic analysis, sign synthesis, and facial mimicry for the most accurate conveyance of emotional context. The study focuses on the unique features of the Kazakh language and cultural contexts that influence sign communication. The research centers on the development of a semantic system capable of adequately interpreting metaphors, idioms, and classifier predicates of sign language. The three-dimensional nature of signs is analyzed, and a solution to the formal description problem is proposed. The article introduces a database, analysis algorithm, and a prototype 3D avatar capable of translating textual data into sign language. Special attention is given to the processing of idioms and variability in expressing emotions in sign language. Utilizing machine learning principles and computational linguistics algorithms, the authors present an integrated approach to sign language translation, considering linguistic, cultural, and emotional aspects. The proposed algorithms and formulas facilitate effective interaction between textual information and sign expression. The research results not only provide an overview of current challenges in automated sign language translation but also offer practical approaches to addressing them. The developed approach could be a key step towards creating more efficient communication systems for the hearing-impaired and deaf. Which in the future may solve numerous issues with Kazakh sign language.

Keywords: automated translator, 3D avatar, sign language, machine translation algorithm, deaf translation

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Introduction

Amidst the world of modern technologies, the relevance of research in the field of automated sign language translation is garnering increasing attention. Sign languages, rich in iconicity and unique semantics, pose a complex challenge for machine translation. This article presents the results of research aimed at addressing key issues in this domain.

Primary challenges arise from the three-dimensional nature of sign language, posing difficulties for the formal description of signs. Traditional methods of linguistic analysis and machine translation encounter limitations in representing and conveying spatial movements. Metaphors and idioms inherent in sign languages present additional challenges, requiring a deep understanding of semantics and the creation of corresponding signs. Processing classifier predicates representing three-dimensional situations poses a challenge for traditional computational linguistics methods [1].

In this study, we present a semantic system based on the analysis and synthesis of text, capable of considering context, intonational elements, and the emotional component in sign language. The approach, grounded in semantic analysis and the processing of emotionally expressive elements, represents a promising step toward the development of more effective automated sign language translation systems.

The article also provides an overview of the developed database, analysis algorithm, and a prototype 3D avatar designed to translate textual data into sign language. The research results not only outline the current state of automated sign language translation but also offer practical approaches to solving complex problems in this innovative field [2]. To improve the functionality of this automated sign language translator, a survey was conducted among specialists and members of the deaf association in Kazakhstan, highlighting a positive societal response to the need for automated sign language translation tools. The accuracy of avatar-based sign transmission was evaluated by over 60% of participants, indicating the potential and importance of this innovative approach. The developed approach can be applied in the creation of automated sign language translators, ensuring effective communication for the hearing-impaired and deaf. The technology also holds potential in the fields of education, interaction with computers, and virtual reality, enhancing information accessibility and communication for sign language users.

Literature review and problem statement

Modern information technologies are rapidly advancing, opening new perspectives in the field of communication and interaction. One key direction in this context is the development of automated sign language translators designed for the effective transformation of natural language into sign form, thereby ensuring the accessibility of information for individuals with hearing impairments.

In the context of this research, the significance of the work by Amangeldy, Bekmanov, et al. (2023) is noteworthy, as they conducted a comprehensive study on the features of the Kazakh sign language. The authors emphasized the importance of considering semantic and syntactic aspects in the development of sign language translators, ensuring a more accurate and natural translation [3, 4].

Over the past few years, active attention has also been given to research in the field of sign languages from various countries. Ramadhani and Kartal (2018, 2023) made an interesting contribution to this area by conducting a comparative analysis of different sign systems. The obtained results can serve as an important source for adopting best practices in the development of sign language translators [5, 6].

Reviewing the works of many researchers, problems were identified in translating from text to Kazakh sign language. There are several issues related to sign language that pose difficulties in coding for automated sign language translation. Firstly, the iconicity of sign language signs creates challenges for their formal description, as they manifest in three-dimensional space, making the use of a discrete inventory of signs insufficient [7].

Secondly, difficulties arise in forming metaphors and idioms in sign language. Unlike spoken languages, sign languages have specific constraints that can hinder the use of metaphors and fixed phrases. The form of an iconic sign may limit the ability to create metaphors, which differ from spoken languages. For example, the phrase "КҮННІҢ КӨЗІ КӨРІНІПТІ ҒОЙ БҮГІН" (literally translated as "today the sun's eyes are visible, meaning it has warmed up today"). A direct translation of this metaphor into sign language would be incorrect. To address this, an AI is planned to be used in the future for our avatar to understand the meanings of such phrases [8].

The third problem is related to classifier predicates in sign languages. These predicates represent three-dimensional situations where the movement of the hand corresponds to the movement of the object, and the hand's shape reflects the properties of the object. This creates challenges for applying traditional methods of computational linguistics in the development of automatic translation systems, as classifier predicates provide infinite variations of sign language signs.

The aim and objectives of the study

The aim of this research is the development and improvement of an automated sign language translator using the Kazakh language. The primary focus is on integrating semantic analysis and sign synthesis. Additionally, an analysis is conducted on the possibility of incorporating facial expressions for the most accurate and natural reproduction of emotions and context during the translation process from natural language to sign form.

Scientific significance: This study contributes to the field of computational linguistics and technologies for individuals with hearing impairments. The emphasis is on integrating semantic analysis and sign synthesis into the automated sign language translator, which poses a complex task in natural language processing. The development of formulas, algorithms, and a database for this process opens new avenues for more precise and culturally oriented sign language translation. Experiments with facial expression integration provide an additional level of emotional expressiveness in sign language translation, which has been a challenging aspect for automation. The obtained results can contribute to further research in the field of technologies for individuals with limited communicative abilities [8, 9].

Practical significance: The development of an automated sign language translator has direct application in facilitating communication for deaf and hearing-impaired individuals. The integration of semantic analysis and sign synthesis, considering the features of the Kazakh language, enhances the quality of translation, making it more accurate and understandable. The incorporation of facial expressions improves the conveyance of emotions, a key aspect of communication [10]. The database created during the research becomes a valuable tool for enriching lexicons and supporting language applications, encompassing the semantic diversity of both spoken and sign language communication. The work on integrating facial expressions, machine learning, and translation algorithms opens new perspectives for the development of technologies in the field of deaf communication.

Materials and methods

The object of the research is the process of developing and operating an automated sign language translator using the Kazakh language and sign form as communicative means. The study examines the features of semantic analysis, sign synthesis, translation algorithms, as well as the implementation of machine learning to enhance translation quality. Important components of the research also include formulas, algorithms, and a database covering various as-

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pects of language and culture for a more precise and adapted sign language translation [11].

To address the issues described in paragraph 2, we created an avatar that translates text into Kazakh sign language. Fig. 1 illustrates the scheme of the semantic analysis system for machine translation into text. The analysis algorithm includes two key stages. During the pre-processing, the text undergoes a step-by-step analysis within each sentence. The result of this stage is a list of words in their base forms, their morphological characteristics, and the establishment of semantic relationships. The syntactic part is then analyzed, involving the relationship between the subject and the action or the subject with characteristic parameters and so on. In the next step, the meaning of phrases is determined, and similar words are selected. The information obtained in the first stage serves as input for the second stage [12].

The main goal of the second stage is to generate independent descriptions for each word and determine the semantic-grammatical type of each of these alternatives. This process involves several stages. In the first stage, various descriptions are created for each word. In the second stage, an important procedure is performed: each alternative for each word is assigned a unique number and identification, a number for the semantic class of the word is assigned, and all arguments are extracted from the semantic description.

Unveiling Figure 1: Architecture of Machine Translation Stages

1. Text Reception: the user enters text in Kazakh, which the system then receives and prepares for further processing.
2. Morphological Analysis of the Sentence: the system converts the Kazakh text into a structured representation, including transforming words into their base forms (infinitives).
3. Component Analysis: The system removes spaces and punctuation, converts all letters to lowercase, and establishes connections between objects, actions, subjects, and other elements of the sentence.
4. Semantic Relations: some words can have multiple meanings, and the context of the text may influence the selection of the correct meaning. At this stage, the meanings of words and phrases are examined. Around 90 works by domestic and foreign authors have been analyzed. Most ideas for machine translation were taken from the works of D. Rakhimova [12], particularly the semantic relations of Kazakh words.
5. Database Connection: the database contains gestures for the most frequently used phrases or expressions, which we have already tested. Here, there is a classification of related words, for example, АНА: АНАҒА, АНАНЫ, АНАДАН, etc. As we know, there are far fewer gestures than words, so in most cases, one gesture corresponds to several words. We refer to the database to find appropriate gestures for specific text.
6. Gesture Output: the system outputs gestures corresponding to the entered text, providing the user with a visual representation of the translation. The idea of a 3D avatar was taken from Turkish researchers [13]. We analyzed their works, identified strengths and weaknesses, and approximately modeled our virtual demonstrator on the Godot platform.

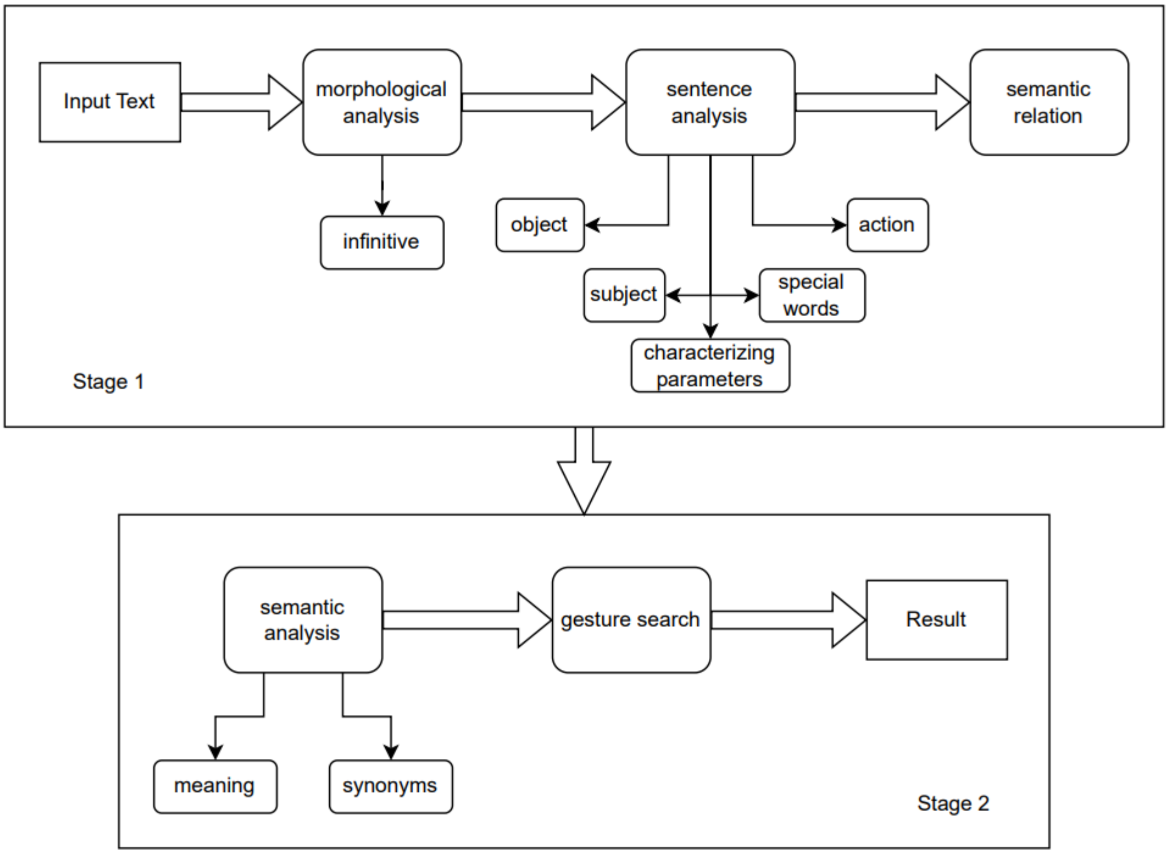

Figure 1. Architecture of Stages in Machine Sign Language Translation

The compiled description consists of a set of alternatives, each of which includes two key parts: morphological with an indication of the semantic class of the word and semantic. The first part of the alternatives contains information about which words this word can be associated with, while the second part indicates which words it can be associated with. When combined, two closely located constructions interact [14]. The next stage of the semantic module's work focuses on processing idioms. In the semantic dictionary, idioms are presented as separate variants. To reduce the number of alternatives, idioms are processed first, and then unnecessary variants are removed for corresponding words. This simplifies the subsequent work of the module.

Here we briefly explain the process of translating from Kazakh language to sign language. More detailed descriptions are available in our previous works [15]. This work particularly emphasizes the results of surveys that we conducted. For general understanding, below we show the text as initially entered, translated into infinitives, and replaced with words that are more suitable in meaning for gestures.

Certainly, and of course, it's worth noting that despite our efforts, within such a short timeframe, we haven't been able to implement many aspects fully.

1. Avatar's Facial Expressions: We are still studying and working on incorporating facial expressions. While we have managed to add a few interjections, we are still facing challenges with facial expressions.
2. Machine Learning (Please do not confuse machine translation and machine learning): Currently, our system involves machine translation, but we plan to integrate machine learning by collaborating with N. Amangeldy. This work still requires a lot of refinement, which we plan to address in the future. For some tasks, we are attempting to collaborate with other researchers, as our resources are limited.

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Results

In previous works, research was conducted on various sign languages of different countries. Conducting a comparative analysis, algorithms, and a prototype of a 3D avatar were developed, which translates simple sentences into signs. Based on these works, the SOP formula was adopted, in which the subject-object-predicate is mandatory, and attributes and locatives are added as needed. Each sentence before translation into sign language must be more understandable in meaning. The main reason is the analysis of each word in terms of meaning and lexicon, whether a particular word is a homonym or synonym. Then a more similar sign is selected based on meaning, as there are significantly fewer signs than words. For example, considering the Kazakh proverb – 'АНАНЫҢ ОЙЫ ҰЯДА, БАЛАНЫҢ ОЙЫ ҚИЯДА' (A mother strives for home, a child for freedom), we can see how the search for synonyms is first performed, and then the sign itself is found. When translating into sign language, instead of ҰЯДА (at home), the sign ҮЙДЕ (at home) is used, as these two words are synonyms, and for the word ҚИЯДА (freedom), the word ОЙНАУ (to play) is used because they are closer in meaning. Although ҚИЯДА (freedom) is a subject and ОЙНАУ (to play) is an action. On the other hand, for the word ҚИЯДА (freedom), the synonym would be the word ДАЛАДА (outside). But as we already know, in sign languages, we need to look at the meaning of expressions. In these two words (ҚИЯДА (freedom) and ҰЯДА (at home)), the most similar signs are used. This means that in automated translation, not only syntactic parsing and word analysis should be considered, but also the basic rules of lexicon and semantic meanings of phrases should be uniformly observed [16].

$$F1 := \{A_{sem}(ch.pr), A_{sem}(obj), A_{sem}(sub)\} \tag{1.1}$$
<[{ананың} ойы] үйде> (mother's thoughts about home)

$$F1 := \{A_{sem}(obj), A_{sem}(act), A_{sem}(sub)\} \tag{1.2}$$
<[{ана} ойлау] үй> (mother think home)

$$F2 := \{A_{sem}(ch.pr), A_{sem}(obj), A_{sem}(sub)\} \tag{2.1}$$
<[{баланың} ойы] қияда> (the thoughts of a child on the street)

$$F2 := \{A_{sem}(obj), A_{sem}(act), A_{sem}(sub)\} \tag{2.2}$$
<[{бала} ойлау] ойнау> (a child think play)

Formulas 1.1 and 2.1 represent the direct translation of these phrases, while in Formulas 1.2 and 2.2, they are transformed in meaning for gestural representation. As observed, a direct gestural translation would only convey nouns, i.e., objects and subjects, without capturing the action. To achieve a comprehensive understanding of these phrases in sign language, action is added as a connecting link [16-17].

In our analysis of Kazakh proverbs and fairy tales, focusing on approximately 50 proverbs and 20 fairy tales, presented on the website surdo.kz, careful examination was conducted. Collaborating with experts in this field, the analysis aimed at a deeper understanding of the peculiarities of sign language and its impact on sign language translation. Fig. 2 illustrates the results of an automated sign language translator, demonstrating the transmission of gestures. This visual analysis compares human actions with those performed by an animated avatar. Clearly, despite the challenges in conveying emotions through an animated character, our efforts are directed towards minimizing differences between it and a human performer. However, we acknowledge that there are motion inaccuracies, and, in this regard, we are actively continuing development and planning to incorporate facial expressions into the avatar. This step will undoubtedly enhance the conveyance of emotions and help make the interaction experience for deaf users closer to native communication. Our research and developments in this field are in an active stage, and we strive for continuous improvement of the technology to ensure maximum accuracy and satisfaction for users with hearing impairments [18].

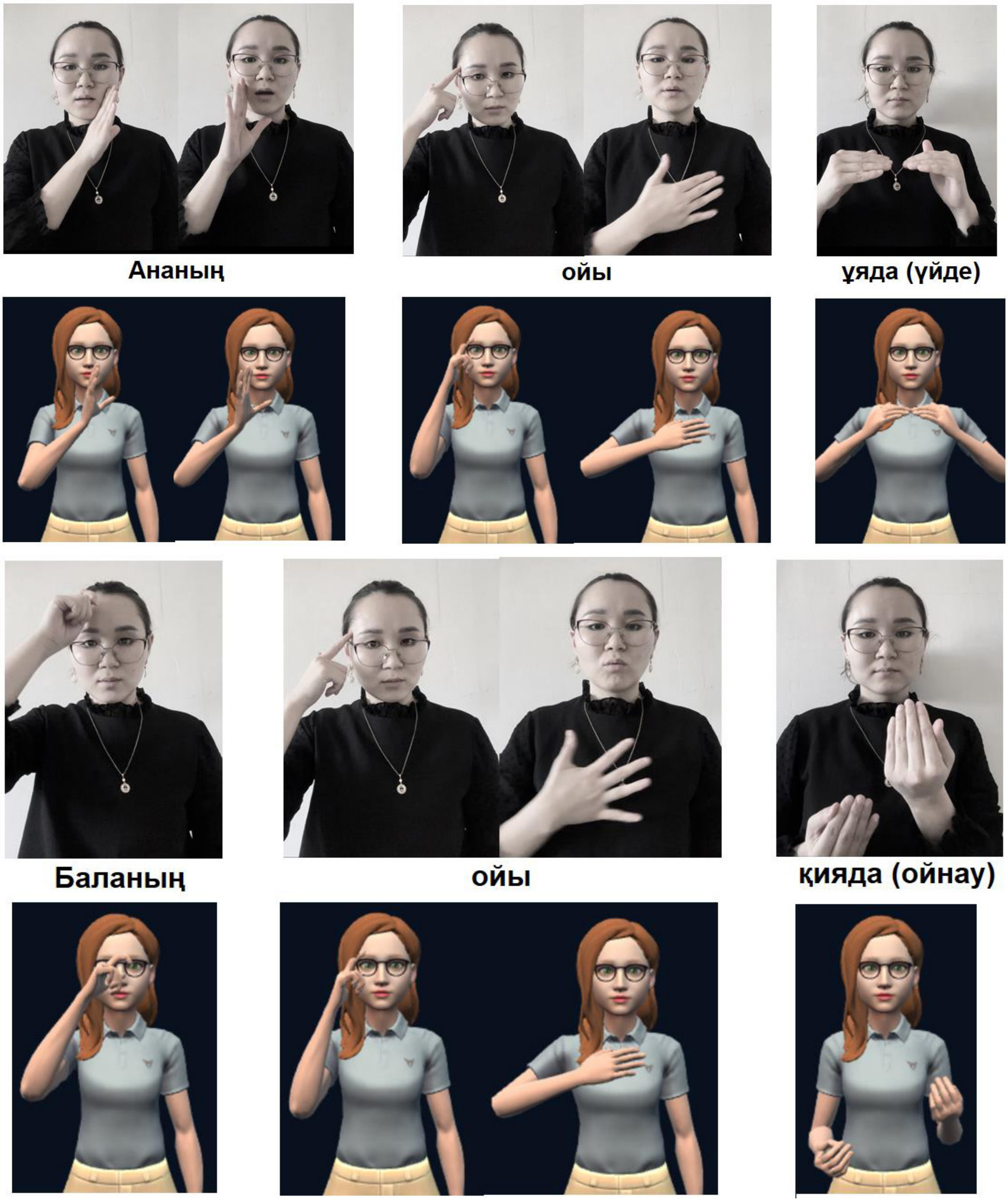

Figure 2. Comparison of Avatar and Human Gestures

To further enhance the performance of our automated sign language interpreter, a survey was conducted among 23 specialists and experts actively studying sign language, including members of the Deaf Association of Kazakhstan. The participants possess a deep understanding of Kazakh Sign Language or are actively involved in its research. The survey included ques-

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tions about the gestures performed by the avatar and the necessity of such a sign language interpreter. The results of one of the questions are presented in Fig. 3, where the rating from 1 to 5 reflects the degree of similarity between the entered text and the gestures reproduced by the avatar. The question was formulated as follows: 'How accurately does the avatar convey gestures by the entered text?' More than 60% of the survey participants assessed that the text and gestures reproduced by the avatar are similar. These results indicate that our efforts to improve the sign language interpreter are yielding positive outcomes. The next step in technology development will involve the incorporation of facial expressions, and we hope that this addition will further enhance the accuracy of conveying emotions and gestures. Our efforts are dedicated to the continuous improvement of the technology to better meet the communication needs of deaf users [19].

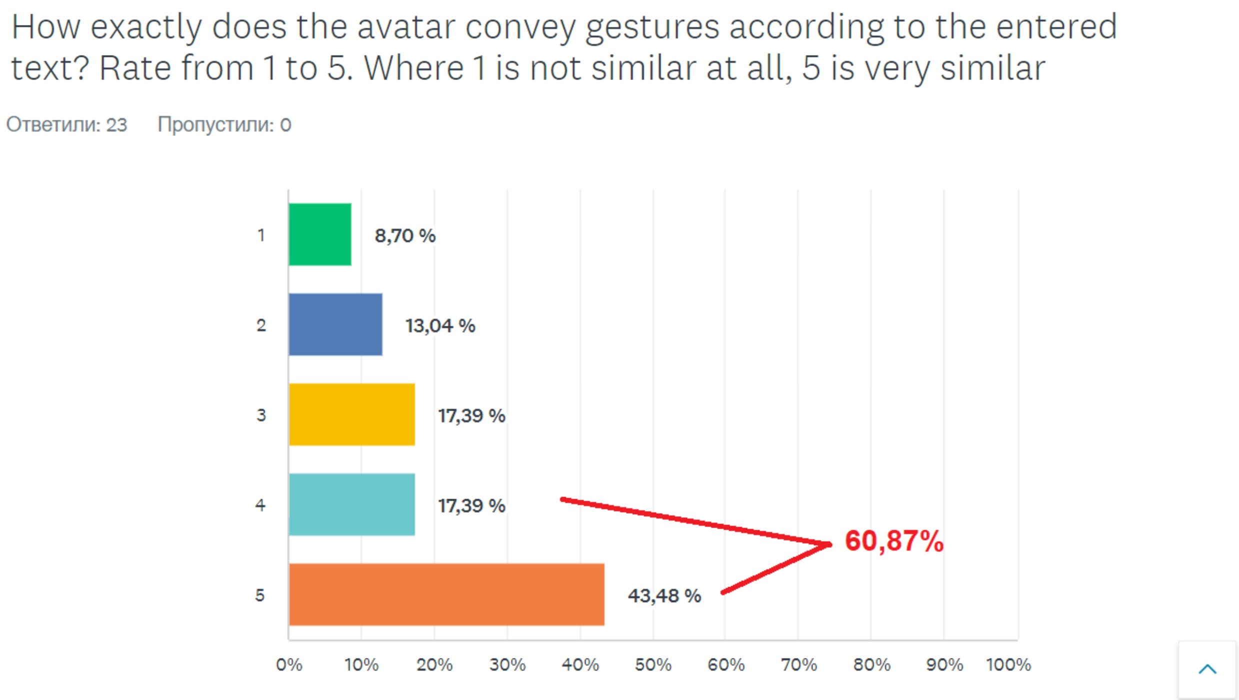

Figure 3. Survey Results #1

The responses to questions about the necessity of an automated sign language interpreter and its impact on professionals translating between natural language and sign language indicate a positive societal reaction. Over 56% of the respondents expressed a positive opinion on the need for such an avatar, while only 10% rejected the idea (Fig. 4). These results suggest that society indeed recognizes the need for the development of sign language and the implementation of technology in this field [20]. This confirms that an automated sign language interpreter can play a crucial role in facilitating more effective interaction between the worlds of sign and natural languages. Such technological innovations can significantly ease the work of professionals translating between these forms of communication and improve information accessibility for deaf and hard-of-hearing individuals.

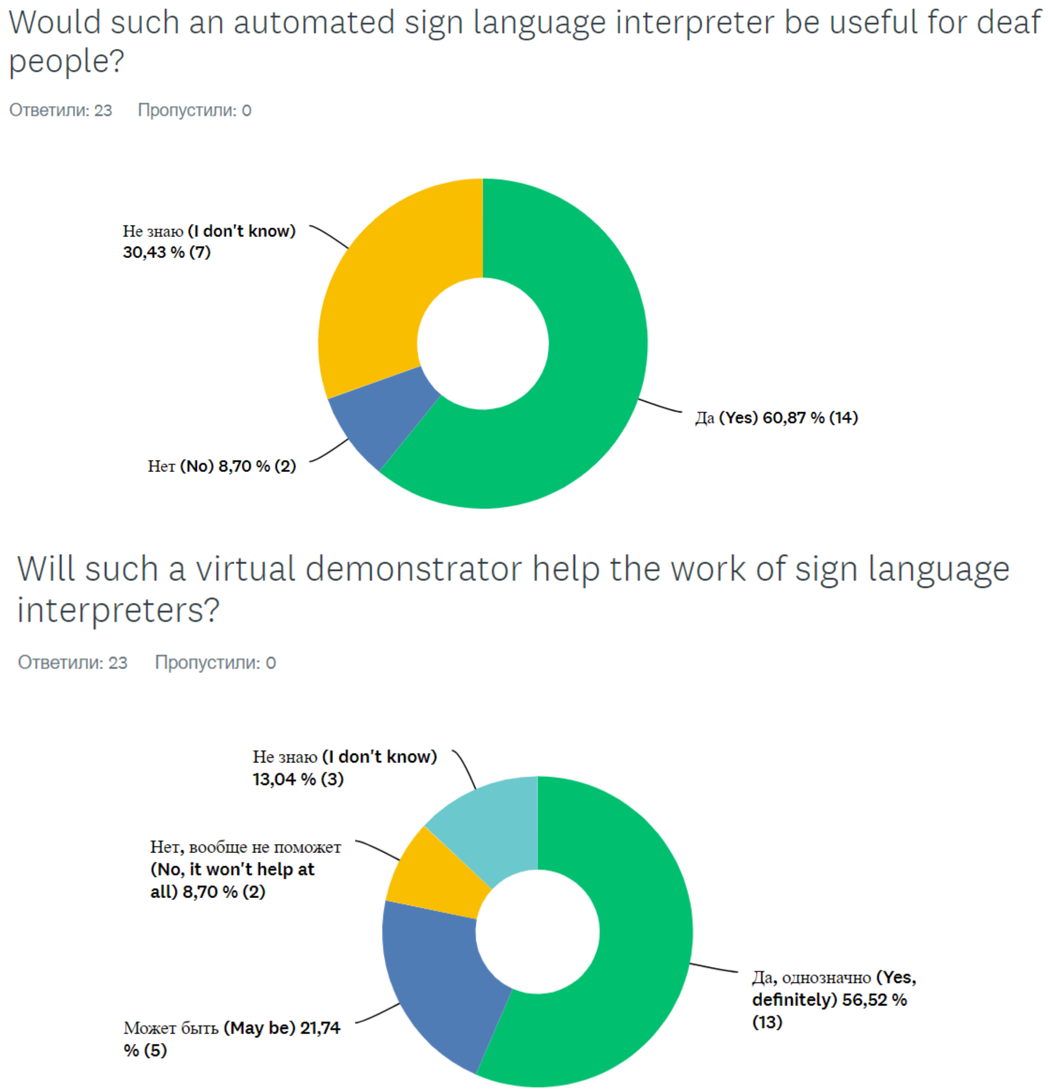

Figure 4. Survey Results #2

The developed database, based on the semantic dictionary, is presented in Fig. 5. Currently, the database contains over 100 words reflecting everyday aspects of life. This resource becomes a valuable tool for enriching vocabulary and supporting language applications that cover the semantic diversity of general speech and communication.

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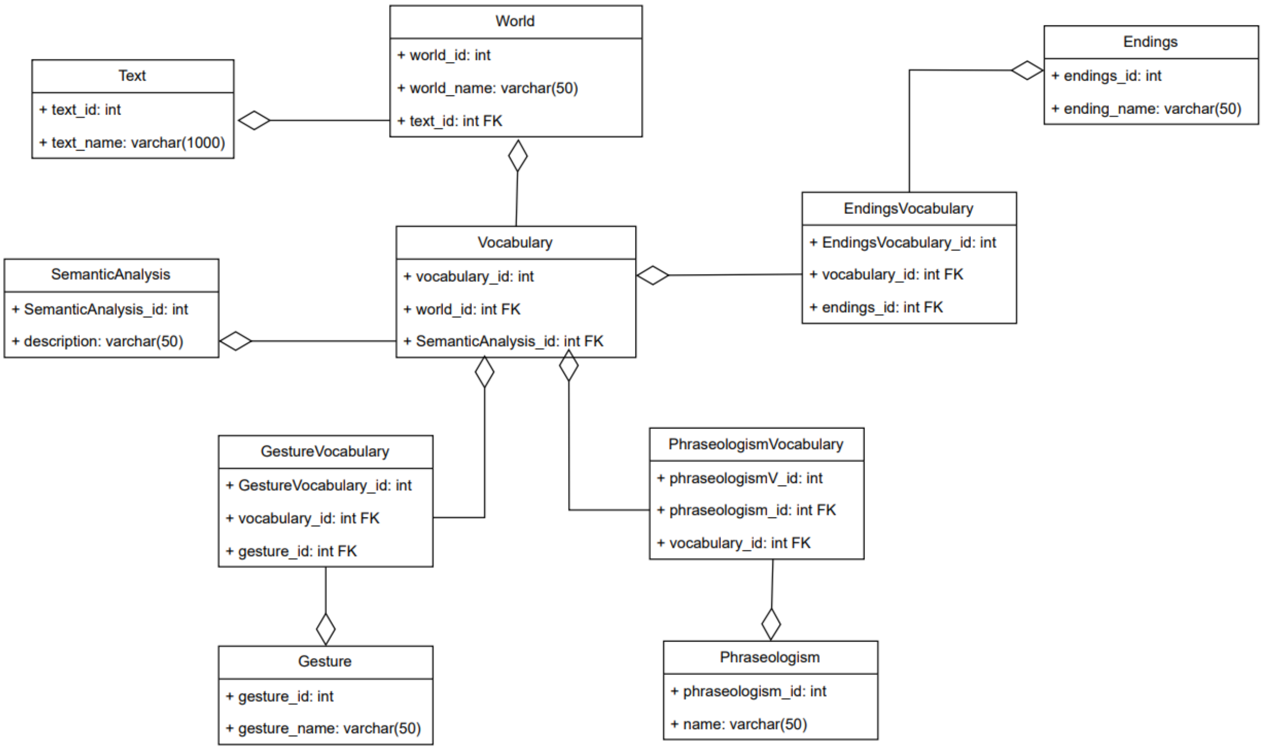

Figure 5. Semantic Dictionary Database Schema

For an automated sign language interpreter from Kazakh text to sign language, a comprehensive database is needed, including various elements for the effective functioning of the system [21]. Several key components that may be part of the sign language interpreter database are presented:

1. Lexical Database:
- Kazakh language dictionary: Includes basic words and expressions in the Kazakh language.
- Sign language lexicon: Contains signs corresponding to each word or expression in the Kazakh language.
2. Syntactic Database:
- Syntax rules: Describe the word order and sentence structure in the Kazakh language.
- Syntactic rules for sign language: Determine how signs can be combined to convey the meaning of a sentence.
3. Morphological Database:
- Grammatical features of words: Help adapt signs considering the morphological features of the Kazakh language.
4. Phraseological Database:
- Idioms and phrases: Contains information on how to translate such expressions into sign language.
5. Cultural Database:
- Specific signs for cultural and social contexts: Factors in the peculiarities and customs of Kazakh culture to ensure correct and culturally sensitive interaction.
6. Specialized Databases:
- Medical terms: If the sign language interpreter is used in medical contexts.
- Technical terms: If applied in technical fields.
7. Training Data:

- Machine learning data: If the system employs machine learning algorithms, the database should contain training data to improve translation quality.

It is important to note that the database should be supported and updated over time to allow the system to adapt to new words, expressions, and changes in language and culture. Among all these points, progress has been made in points 1, 2, 3, and 4, while work is ongoing for the others [22].

Just as intonation exists in spoken language, sign language also has the concept of emotional expressiveness, in simpler terms, the same as intonation, and the ways to convey it through various means of expressiveness in sign language. These include:

- Facial expressions,
- Logical emphasis, through accelerating or slowing down the execution of a sign,
- Psychological pause,
- Introduction of sign parallels,
- Use of dialectal signs,
- Involvement of the second hand, and more.

For example, "СӘЛЕМЕТСІЗ БЕ…" (Hello…) can be expressed indifferently, joyfully, or sarcastically. A pause before "АЛ ЕНДІ …" (Now…) can add surprise, and the use of a second hand and specific gestures can emphasize the message. Just as there is intonation in spoken language, the same applies to sign language. In a normal sign language communication situation, there is always visual contact between interlocutors. This is related to the characteristics of the information transmission channel and, in part, to the rules of speech etiquette – speaking in sign language without looking at the interlocutor is considered impolite. For imperative and interrogative contexts in sign language, a more intense, "penetrating" gaze into the eyes of the interlocutor is characteristic, compared to affirmative statements. Imperative and interrogative sentences differ in eye and eyebrow characteristics: imperative signs are associated with slightly narrowed, easily converging eyes and furrowed brows, while questions involve wide-open eyes and raised eyebrows. The analysis of the material shows that the gaze into the eyes of the interlocutor in imperative statements, similar to interrogative and affirmative ones, can be interrupted.

Discussion

In the context of contemporary technological advancements and the growing interest in developing automated sign language interpretation systems, our research results contribute significantly to enriching sign language and creating effective communication tools for the deaf and hard of hearing.

One of the key challenges we encountered is the three-dimensional nature of sign language. Traditional methods of linguistic analysis and machine translation face limitations in conveying spatial movements. Our semantic system, based on text analysis and synthesis, aims to overcome these challenges by considering context, intonational elements, and emotional components in sign language. A pivotal aspect of our research was the necessity to develop a system capable of adequately interpreting metaphors, idioms, and classifier predicates in sign language. Metaphors and idioms specific to sign languages present additional complexities, requiring a deep understanding of semantics and the creation of corresponding signs.

Our developed approach, based on semantic analysis and processing of emotionally expressive elements, represents a promising step towards creating more efficient automated sign language interpretation systems. The integration of facial expressions and other expressive elements will enhance emotion transmission, making the interaction with the system closer to natural communication. The survey conducted among sign language specialists, experts, and members of the Deaf Association of Kazakhstan was a significant step. The survey results clearly demonstrate society's positive reaction to the necessity and importance of an automated sign language interpreter. Over 60% of participants assessed the accuracy of the avatar's sign reproduction, indicating a substantial contribution to the development of effective communication tools.

Our database, comprising lexical, syntactic, morphological, and phraseological components, has become a valuable resource for enriching lexicons and creating applications covering the semantic diversity of everyday speech. The introduction of machine learning training data is also a crucial step that will allow the system to continually improve and adapt to changes in language and culture. Despite the positive results, we acknowledge that work on perfecting the technology is far from complete. Planned improvements include adding facial expressions, refining machine learning algorithms, and regularly updating the database in line with language and culture development.

In summary, our research results highlight the importance of developing and improving automated sign language translation technologies to facilitate more effective interaction between the worlds of sign and spoken languages. Such innovations contribute to easing communication for the deaf and hard of hearing and emphasize the significance of integrating technologies into the realm of equal opportunities.

Conclusion

In conclusion, our research represents a significant step in the development of sign language translation technologies tailored to adapt to the Kazakh cultural context. At the current stage of the research, we have successfully developed a prototype of an automated sign language interpreter that integrates semantic analysis and sign synthesis. The analysis of various sign languages, including features of the Kazakh language, was a crucial stage in the development of our project.

Surveys among specialists and active participants in the Deaf Association of Kazakhstan confirmed substantial societal interest in automated sign language translation tools. The results indicate a high appreciation for the accuracy of the avatar's sign reproduction, emphasizing the potential of our innovative approach and its importance for deaf and hard-of-hearing users.

Our efforts in creating a comprehensive database, encompassing lexical, syntactic, morphological, and phraseological elements, have become a valuable resource for enriching lexicons and developing language applications covering the semantic diversity of daily speech. However, despite the achievements, we recognize that this is just the beginning of a long journey in the development of sign language translation technologies. Our future steps include the integration of facial expressions, improvement of machine learning algorithms, and regular updates to the database to adapt to changes in language and culture.

Overall, our research underscores the importance of innovations in the field of sign language translation to facilitate communication between communities with different linguistic characteristics. Automated sign language translation technologies, such as our avatar, are becoming key means of ensuring information accessibility and improving interaction for the deaf and hard of hearing. We aspire to further develop and enhance sign language translation technology to create a more inclusive and accessible society for everyone.

Acknowledgment

We express profound gratitude to all participants in the research whose valuable insights and suggestions significantly contributed to the development of our project. We thank sign language experts, members of the Deaf Association of Kazakhstan, and everyone who participated in surveys and testing the sign language interpreter prototype. This work was carried out with the support of the scientific community and utilizing modern methods and technologies. We are deeply thankful to everyone who supports our commitment to innovation in the field of sign language translation.

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