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Research of semantic aspects of the Kazakh language when translating into the Kazakh sign language

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ABSTRACT

The article discusses the semantic aspects of Kazakh sign language and its characteristics. Semantics, a field within linguistics, focuses on examining the meanings conveyed by expressions and combinations of signs. The author delves into the inquiry of the degree of similarity between verbal and sign languages, highlighting their fundamental distinctions. The primary objective of the research is to scrutinize the characteristics of parts of speech in the Kazakh language when expressed gesturally, along with the principles governing the translation of verbs and adverbial tenses. The article explains in detail the formulas for translating the text into sign language, based on the subject-object-predicate. Examples are given that illustrate the subject-object relationship and determine who acts as the speaker, "object" or "subject" of the utterance. It is necessary to note that for successful translation it is necessary first to understand the meaning of the sentence. The article concludes by emphasizing the importance of understanding both structural elements and contextual nuances in the fascinating world of the semantics of the Kazakh sign language. It inspires further research aimed at uncovering the complexities and exceptions that contribute to a deep understanding of linguistic nuances in this unique form of communication.

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1. INTRODUCTION

In our time, when globalization and digitization become universal, the development of technologies aimed at reducing language barriers becomes an urgent task. Automated translators, sign language translators, and advanced algorithms supported by artificial intelligence play an important role in this context. Automated translators providing more effective interaction in a multilingual and multicultural world.

With the development of computer linguistics and the integration of mathematical models in the field of translation, new opportunities appear to improve the accuracy and speed of information processing [1]. The study of algorithms and formulas underlying these technologies becomes an important direction for the creation of more effective communication systems. Special attention is paid to translation from text to gesture and the creation of avatars, which is an important step in ensuring the inclusion of people with different language needs. These innovative developments are relevant to increase access to information and provide a deeper understanding of the diversity of linguistic and cultural contexts [2].

Thus, this research is aimed at understanding the synergy between algorithms, formulas, development, and artificial intelligence, as well as current aspects of their influence on modern technologies of automated translators and sign language translators. The results of this research are important for current social and technological development, providing a basis for further improvement and dissemination of these innovations [3]. Research in the field of computer linguistics and automated sign language translation technologies has shed light on the grammatical aspects of sign languages, encompassing phonology, syntax, and semantics. These studies highlight both the similarities to spoken languages, revealing shared grammatical structures, and the distinctive features that set sign languages apart. The examination of these parallels and disparities addresses theoretical issues, providing insights into the nature of natural language grammar. A significant aspect of linguistic discussions related to sign languages stems from the unique channel of information transmission they employ. Unlike spoken languages that use auditory signals, sign languages utilize visual elements, including hand gestures, facial expressions, and body movements. Remarkably, despite these fundamental differences in sensory channels, the internal structure of sign languages is impacted less than one might anticipate [4], [5]. Deaf individuals face a range of challenges that many hearing people are not even aware of: i) Limited access to education: Deaf people encounter restricted access to quality education in sign language, impacting their development and opportunities in society; ii) Lack of access to information: Deaf individuals experience difficulties in accessing vital information, such as news, medical information, and government services, due to the absence of translation into sign language; iii) Absence of tools for learning sign language: In Kazakhstan, there are very few schools and educational centers that teach deaf people. Additionally, there is no guide for Kazakh sign language (KSL). Many deaf individuals use guides for Russian sign language and face challenges in communicating with other deaf individuals. Since Russian guides lack signs for the Kazakh language, deaf individuals in Kazakhstan have their jargon and signs for Kazakh words. However, there are no official sources for these signs.

To address these issues, we are creating an automated sign language interpreter. Subsequently, we identify crucial aspects of sign language for the development of algorithms and formulas. These elements form the foundation for writing an automated sign language translator, contributing to ongoing efforts to overcome communication barriers for the deaf community [6]; i) Aspects of gesture synthesis and technological requirements: In the context of creating 3D avatars for deaf interpreters, it is crucial to consider aspects of gesture synthesis. This involves analyzing hand movements, facial expressions, and poses that must be accurately reproduced to convey the meaning of statements. Technological requirements for creating such avatars include high-precision motion scanning, real-time image processing, and the use of computational algorithms for precise mapping of gestures to textual information [7], [8]; ii) Absence of 3D models in Kazakhstan and problem-solving approaches: It is important to note that, at present, there is a lack of ready-made 3D avatar models for deaf interpreters in Kazakhstan, posing challenges to the development and implementation of corresponding technologies. To overcome this issue, we meticulously study the characteristics of sign language, analyze existing global solutions, and devise innovative approaches to creating 3D avatars capable of effectively translating textual information into sign language; and iii) Development perspectives and social significance of the project: The advancement of automated deaf interpreters and sign language translation technologies holds significant social importance by fostering profound understanding and involvement of individuals with hearing impairments in various aspects of life. This encompasses education, employment, social interaction, and cultural events. Through the refinement of algorithms and technologies, we aspire to create innovative solutions that can ease the daily lives of individuals with hearing impairments and contribute to their integration into society [9], [10].

In this regard, our research is directed not only toward a scientific understanding of the peculiarities of sign language and automated deaf interpretation technologies but also toward the development of practical solutions that can be implemented to enhance the quality of life for the deaf community. The primary objective of this research is to explore the grammatical aspects of sign languages through the lens of computer linguistics, with a specific focus on phonology, syntax, and semantics. By uncovering both the shared grammatical structures with spoken languages and the unique features that distinguish sign languages, we aim to address theoretical issues and gain valuable insights into the nature of natural language grammar. In the field of sign language, many countries are more advanced than Kazakhstan; in Turkey and Ukraine, there are already virtual assistants that can translate text into sign language. However, these projects have their shortcomings. In Kazakhstan, there is a website called *surdo.kz* for learning sign language, but its word database is limited—only about 100 to 150 words, and unfortunately, it has not been updated since 2013. Currently, scientific researchers are actively working on the development of sign language, including significant studies in the field of gesture recognition.

However, at the moment, a working automated sign language translator is still absent. This article represents an initial approach to creating such a translator, focusing on sign language and taking into account the semantic features of the Kazakh language. In the context of creating 3D avatars for deaf interpreters, our research emphasizes the importance of gesture synthesis. This involves analyzing hand movements, facial expressions and poses for accurate reproduction to convey the meaning of statements. Technological requirements, such as high-precision motion scanning and real-time image processing, are integral to the development of these avatars. Acknowledging the absence of ready-made 3D avatar models for deaf interpreters in Kazakhstan, our research proposes problem-solving approaches. Through meticulous study of sign language characteristics, analysis of global solutions, and innovative thinking, we aim to create 3D avatars capable of effectively translating textual information into sign language [11]–[13].

2. METHOD

The effective creation of 3D avatars for deaf interpreters capable of conveying the meaning of textual information into sign language, particularly within the context of the Kazakh language, presupposes that understanding the semantic nuances of the Kazakh language is a crucial stage. The hypothesis is based on the assumption that an in-depth analysis of semantic features will allow the development of more precise algorithms for translating text into sign language and determine specific hand movements, facial expressions, and poses corresponding to these semantic nuances [14], [15]. The object of the study is the process of creating 3D avatars for deaf interpreters capable of efficiently conveying the meaning of textual information into sign language, considering the semantic features of the Kazakh language. The study includes an analysis of the semantic structure of the Kazakh language, the development of algorithms and formulas for accurate understanding and translation of text into sign language, as well as the determination of relevant hand movements, facial expressions, and poses ensuring the correct visual representation of the semantic context when using 3D avatars [16]–[18].

The development of a system for translating Kazakh text into sign language with access to a database is a complex task that involves several stages and components. Numerous research efforts have been made for the development of such an application. This work includes the use of various methods and technologies to ensure accurate and efficient translation of text into sign language. Some of the key methods include:

a. Deep semantic analysis: Studied the features of the Kazakh language, analyzed its semantic structure, and carefully examined the meanings of words, phrases, and context to create more accurate translations.
b. Collaboration with sign language interpreters: Worked closely with professional sign language interpreters to obtain up-to-date information on signs. Also collaborated with close associates of deaf and hard-of-hearing individuals to verify the gathered information.
c. Analysis of scientific works: Analyzed around 90 foreign and domestic works on sign language, machine translation, and Kazakh linguistics. After reviewing these works, key points were identified to consider when creating an automated sign language interpreter. Works by Turkish authors were significant breakthroughs in sign language research, and the work of Rakhimova *et al.* [19] served as the basis for machine translation.
d. Algorithm development: Formulas and algorithms were developed for automated translation from text to sign language, aiming for more precise translation and continuous avatar operation.
e. Database work: Integrated 50-100 Kazakh words into the database, focusing on those most commonly used in everyday life.
f. Motion synthesis: Using the Godot program, created a 2D version of the avatar, followed by the development of a 3D avatar with sign language movements from various perspectives to make the translation more natural and understandable.
g. Machine learning: Applied machine learning algorithms to enhance sign language translation accuracy and effectiveness.

A general overview of a possible architecture for such a system is shown in Figure 1.

a. Receiving text: The user enters text in Kazakh. The system receives this text and prepares to process it.
b. Analysis of the proposal: The Kazakh text needs to be converted into a structured representation that will be understandable for the following steps. This includes converting words into infinitives and the connection between object and action.
c. Component analysis: Spaces and punctuation are removed, and all letters are converted to small letters.
d. Semantic relation: Some words can have multiple meanings, and the context of the text may influence the selection of the correct meaning. This stage examines the meaning of words and phrases.
e. Database connection: The database contains pre-recorded gestures for the most frequently used phrases or expressions. We turn to the database to search for appropriate gestures for a specific text.
f. Gesture output.

The primary goal of this research is to conduct an in-depth semantic analysis of Kazakh words using advanced computational linguistics methods. This aims at developing cutting-edge technologies, incorporating innovative algorithms of artificial intelligence, to create an automated sign language interpreter. The research object is the Kazakh language with its rich semantics [20]. We apply state-of-the-art computational linguistics methods for systematic semantic analysis of words and expressions, striving to identify language-specific features. A key focus of the research is the creation of technologies, including advanced artificial intelligence algorithms, necessary for implementing an automated sign language interpreter. These technologies encompass high-precision scanning of the semantics of Kazakh words, real-time data processing, and profound analysis of ambiguity and context. Using advanced computational linguistics and artificial intelligence methods, a comprehensive semantic analysis of Kazakh words and phrases is carried out. This analysis includes identifying semantic nuances, contextual relationships, and semantic interconnections between words.

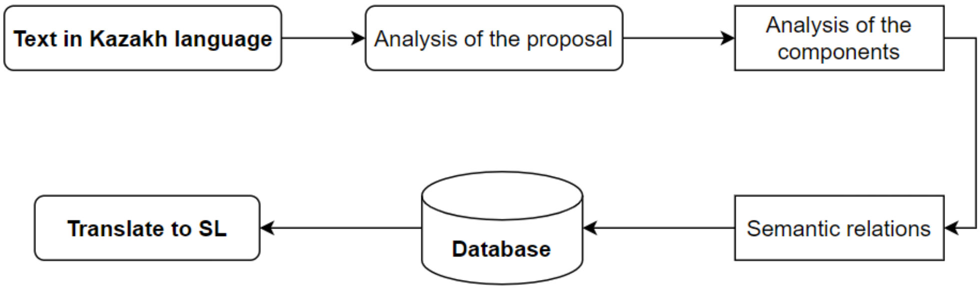

Figure 1. Overview of the proposed framework providing translation of Kazakh text into sign language

The semantic analyses of Kazakh words are conducted to develop a highly effective algorithm for translating text into sign language. This algorithm will serve as the foundation for creating an innovative automated sign language interpreter, ensuring accurate and comprehensible translation of textual data into sign language. This, in turn, will improve communication quality for individuals with hearing impairments and contribute to their more active participation in society [21], [22].

When classifying gesture verbs, it is crucial to consider verb tenses as gestures are typically used in the infinitive form. Understanding the timing of the gesture occurrence is particularly important. Temporary meanings are conveyed through two primary methods. First of all, with gestures *БОЛДЫ* (was/were), *БОЛЫП ЖАТЫР* (is being), *БОЛАДЫ* (will be). With this gesture *БОЛЫП ЖАТЫР/БАР* (is being) to communicate that the action applies to the present time, as a rule, is not used. Table 1 illustrates the translation from verbs to infinitives. To transfer the meaning of *ОЙЛАНЫП ЖАТЫРМЫН* (thinking), *ОЙЛАНДЫМ* (thought), *ОЙЛАНАМЫН* (will think), the corresponding gesture-nominative *ОЙЛАНУ* (think), expressions *ОЙЛАНУ БОЛДЫ/ӨТТІ* (was think) and *ОЙЛАНУ БОЛАДЫ* (will think) will be used. In the second, gestures are attached to the gesture-nominative, denoting the time: *КЕШЕ* (yesterday), *БҮГІН* (today), *АРҒЫ КҮНІ* (the day after tomorrow) [23]–[25].

Table 1. Translation from verb tenses to initial form

Tenses	Verbs	Adverbs/Verb
Present simple/continuous	Verb + *ЖАТЫР/ОТЫР/ТҰР/ЖҮР* auxiliary verbs	ad.: *ҚАЗІР* (now), *ЖАҢА* (right now)
Past simple/continuous	Verb + *ды/ді/ты/ті* (Past tense endings)	ad.: *КЕШЕ* (yesterday), *БЫЛТЫР* (last year). v: *БОЛДЫ* (was/were)
Future simple/continuous	Verb + *а/й* (suffix) + *ды/ді/ты/ті* (endings)	ad.: *ЕРТЕҢ* (tomorrow), *КЕЛЕСІ АПТА* (next week). v: *БОЛАДЫ* (will)

In addition to all the aforementioned methods, there are several other types that we are excluding or planning to add in the future:

a. Gesture recognition: We are excluding this method from our current work because our colleague N. Amangeldy is researching gesture recognition. In the future, we plan to merge our efforts and create a robot that will serve as a complete sign language interpreter in social settings.
b. Use of neural networks: Applying deep neural networks for image and audio processing is planned for the future.
c. Multimodal analysis: At this stage, we are already working with other non-verbal elements, such as facial expressions, gaze, and body posture. This approach undoubtedly enhances the comprehensiveness of understanding communication in sign language. In our upcoming work, we will provide a complete description of the multimodal analysis of non-verbal elements and their integration into our avatar [26].

3. RESULTS AND DISCUSSION

Due to the visual nature of sign language, it is common practice to establish context before conveying actions. Sign language interpreters often wait briefly before beginning translation to grasp the full sentence structure and understand the precise meaning. In Kazakh, the typical sentence structure follows the subject-definition-object-predicate order, though there can be variations. Sign language interpreters may seek clarification to ensure accurate interpretation, especially when the Kazakh language places the definition before the subject [27], [28]. In sign language, this would mean positioning the subject after the object, and keeping additions in front. However, these rules may not always apply universally. Since the sentence, "*КІШКЕНТАЙ ҚЫЗ КӨК ДОППЕН ОЙНАДЫ* (A little girl played with a blue ball)", this phrase can be interpreted in various manners:

a. *ҚЫЗ КІШКЕНТАЙ КӨК ДОП ОЙНАУ БОЛДЫ* (A girl little blue ball was play).
b. *КІШКЕНТАЙ ҚЫЗ КӨК ДОП ОЙНАУ БОЛДЫ* (A little girl blue ball was play).
c. *ҚЫЗ КІШКЕНТАЙ ДОП КӨК ОЙНАУ БОЛДЫ* (A girl little ball blue was play).

In the first instance, it appears, that the subject – attribute – attribute – object – predicate SAAOP is obtained. And in the second version, attribute – subject – attribute – object – predicate ASAOP, and this is the most correct in meaning. So, in the final sentence, subject – attribute – object – attribute – predicate SAOAP. In all three instances, if we remove the attribute or the definition, we are left with formula (1), which is worth using as a basis for translation.

$$SOP = subject - object - predicate \tag{1}$$

Translating from text to sign language involves more than simply converting all words to their infinitive forms.

$$R^F(A) \coloneqq F \tag{2}$$

$$F := \begin{Bmatrix} \{A_{sem}(ch.pr), A_{sem}(obj)\}, \\ \{A_{sem}(ch.pr), A_{sem}(sub)\}, \\ \{A_{sem}(ch.pr), A_{sem}(sub)\}, \\ \{A_{sem}(sub), A_{sem}(act)\}, \\ \{A_{sem}(obj), A_{sem}(act)\} \end{Bmatrix} \tag{3}$$

ойнады [{көк} доп,{кішкентай} қыз]
$(\text{play}[\{blue\}\ \text{ball}, \{\text{little}\}\text{girl}])$

where, F is a set of semantic phrases, A a finite set of semantic attributes; R^F a set of semantic rules at the level of sentence phrases *ю*. Based on the study of text translation into computer language and linking it with sign language, the following basic structures have been developed that show the construction of semantic rules at the level of a simple sentence. In (2) and (3), the main groups of semantic attributes were investigated and proposed: action ($A_{sem}(act)$), subject ($A_{sem}(sub)$), object ($A_{sem}(obj)$) and the characterizing parameters ($A_{sem}(ch.pr)$). It should be noted that when working with the translation of the text into sign language, they referred to the scientific research of the Rakhimova *et al.* [29]. The main reason is that the researcher is working on the translation of the Kazakh text language into machine language. After analyzing several works in this field, we realized that this method can be developed and used when translating from Kazakh text language into sign language. Taking into account the grammatical features of the Kazakh language and the semantic interrelationships of semantic attributes when translating into sign language, we can say that (1) plays a special role since the subject-object-predicate is taken as the basis. The formula (3) is designed for simple sentences because compound sentences when translated into sign language are divided into several simple sentences.

3.1. Developing algorithms and formulas for automated sign language translator

The dependency grammar will serve as the basis for the algorithm for determining and constructing semantic relations since the syntactic analysis of the text is based on this method. The text's main (key) object will be words describing the action (verb) and having a semantic attribute. It should be borne in mind that lexica-semantic analysis was performed on the text of the work, semantic attributes to the words of the work were determined and assigned lexica-semantic analysis, and semantic attributes to the words of the sentence were determined and assigned. The algorithm for determining semantic relations is shown in Figure 2. Figure 2 represents the general principle of determining the structure of the sentence (subject-object) in the text, especially for simple sentences. Naturally, each stage is a complex system with its conditions and rules. Let's look at each module of the algorithm. Reading input text: Reading the input text involves determining the number of objects in the text, their length, and syntactic and semantic attributes.

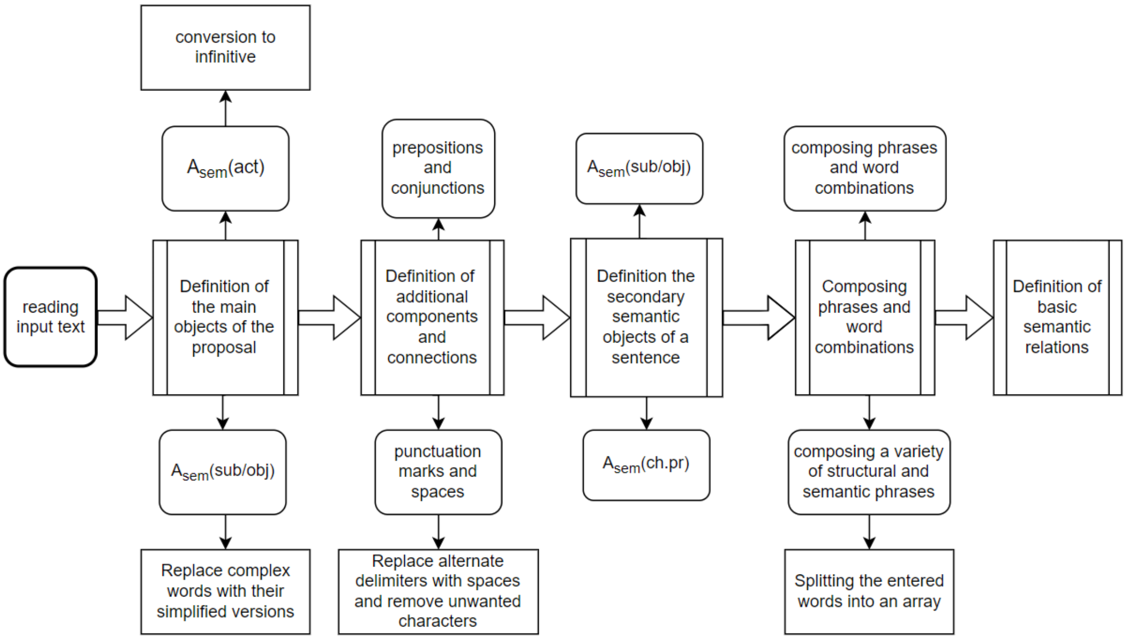

Figure 2. Algorithm for determining semantic relations

Definition of the main objects of the proposal: determining the main (key) objects of a sentence involves identifying words with a semantic action attribute (($A_{sem}(act)$), while verbs are translated into the infinitive form. From this key object, words with semantic attributes of the subject or object are searched to the left, otherwise, the search is carried out to the right of the keyword. The found word is assigned the status of a keyword in the sentence since all connections are built from these components [30]. The dominant objects in the text are words with the semantic attribute of action. In the absence of a verb and action words, the search and connections of semantic relations are determined from keywords with attributes ($A_{sem}(sub/obj)$. In this case, complex words are replaced with simple ones, removing suffixes and prefixes, and words with the same root are grouped.

a. Definition of additional components and connections: The meaning and sentence structure of a text can also be influenced by prepositions, conjunctions, and punctuation. This module describes the rules for connection and translation into the target language. In this regard, alternate delimiters are replaced with spaces, and unwanted characters are removed
b. Definition of secondary semantic objects of a sentence: After identifying the key semantic objects and the general structure of the sentence, it is necessary to identify the remaining objects of the text. This module uses a specific set of rules and exceptions to define objects with semantic attributes ($A_{sem}(obj)$, ($A_{sem}(ch.pr)$.
c. Composing phrases and word combinations: In this module, connections between objects are determined and all possible structural and semantic phrases of a sentence are created. The resulting words are divided into an array.
d. Definition of basic semantic relations: From the entire set of phrases, it is necessary to determine the main sentences that carry the main context, and reduce the number of semantic relations to a minimum.

If we analyze complex sentences, then we will have to divide them into several simple ones without losing their meaning. Let's consider an example, *КІШКЕНТАЙ БАЛА ҚЫЗЫЛ АЛМА ЖЕДІ, БІРАҚ ОНЫҢ АҒАСЫ ЖЕМІСТЕРГЕ ТИІСПЕДІ* (A little boy was eating a red apple, but his brother did not touch the fruit) ((4) to (9) formulas). It should be understood that in sign language complex sentences are not used as in verbal. Because of this, we have divided the above example into two parts.

бірақ<жеді[{қызыл} алма,{кішкентай} бала], тиіспеді [{оның} ағасы,жемістерге] >
$(but < eat[\{red\}\ apple, \{little\}\ boy], did\ not\ touch\ [\{his\}\ btother, fruits] >)$

$s_k = \{s_1, s_2, \ldots, s_i\}$ lots of simple suggestions:

$$S := \{s_k\} \tag{4}$$

$$R^S(A) := S \tag{5}$$

$$R^F(A) := F \tag{6}$$

where, R^S: a lot of semantic rules at the sentence level, R^F: a set of semantic rules at the level of sentence phrases,

$$F = \{F_1, F_{2,} \ldots, F_i\},\ F_k \subset s_k \tag{7}$$

$$F_1 := \begin{Bmatrix} \{A_{sem}(ch.pr), A_{sem}(obj)\}, \\ \{A_{sem}(ch.pr), A_{sem}(sub)\}, \\ \{A_{sem}(sub), A_{sem}(act)\}, \\ \{A_{sem}(obj), A_{sem}(act)\} \end{Bmatrix} \tag{8}$$

$$F_2 := \begin{Bmatrix} \{A_{sem}(ch.pr), A_{sem}(obj)\}, \\ \{A_{sem}(sub), A_{sem}(act)\}, \\ \{A_{sem}(obj), A_{sem}(act)\} \end{Bmatrix} \tag{9}$$

All these arguments and research serve as just the initial steps in analyzing the semantics of sign language. It is important to recognize that sign language constitutes a distinct language that necessitates scientific investigation. Moreover, it is a multimodal form of communication. In addition to gestures, semantic content can also be conveyed through non-visual components such as gaze, facial expressions, and the positioning of the speaker's head and body [31]. While verbal language communication is also multimodal, its reliance on non-visual elements is comparatively limited, and it can even exist in a single-modal form such as written text. However, written notations of sign language are not utilized as a means of communication.

Comparative analysis with other sign languages has been conducted and is described in other works by the authors, which are in the process of publication. However, as an overview of these articles, we decided to provide an example comparing it with the Turkish avatar, which served as the basis for creating our 3D translator. The Turkish sign language features a three-dimensional avatar capable of transforming words and text into gestures, as shown in Figure 3. Developed using Unity, this program stands out for its user-friendly interface. Unity, commonly associated with video game development, ensures a high level of visualization for the created avatar. Its functionality includes the ability to view gestures from various angles, adjust the speed of gesture execution, and translate both individual words and entire sentences [32]. However, during testing, it became clear that the database's word count is limited, and in translating some words, the avatar uses finger spelling.

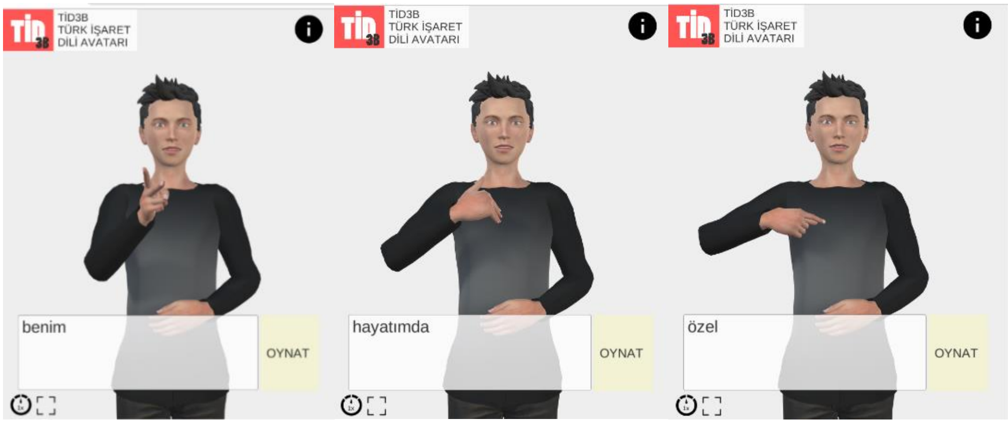

Figure 3. 3D avatar of the Turkish sign language [33]

After analyzing and fully studying the 3D translator from the text of the Turkish language to the Turkish sign language, we made our avatar with a database of Kazakh words for translation into the Kazakh sign language. Figure 4 shows the gestures "*Сәлеметсіз бе! Қалай көмектесе аламын?* (Hello! How can I help?)". All of these gestures are dynamic.

Figure 4. 3D avatar of the Kazakh sign language (developed by us)

3.2. Discussion of results

The discussion of the results in this article represents an important stage of analysis, allowing the highlighting of key aspects and conclusions made by the author. Initially, it is worth noting that the author actively employs formulas and algorithms for the development of an automated translation of text from Kazakh to sign language. The adoption of the subject-object-predicate (SOP) formula as the foundation for translation is recognized as a crucial step. Attention is also given to the identification of semantic attributes, such as action, subject, object, and characterizing parameters.

The approach to breaking down complex sentences into several simple ones is intriguing, enabling a more structured translation. The presented examples from the text and their subsequent translation into sign language illustrate the effectiveness of the proposed algorithms and formulas [33]. An important question is raised about the semantic relationships explored at the sentence and phrase levels, leading to the formulation of sets of semantic rules. The results demonstrate that the SOP formula, adopted as the basis for translation, remains a central element in the algorithms developed for automated translation. A significant point is the discussion of the use of dependency grammar as the basis for determining and constructing semantic relations. Dealing with the main objects of the text described by semantic attributes allows for better structuring of the algorithm for determining semantic connections.

The discussion also addresses the issue of semantic load in sign language, encompassing not only gestures but also non-verbal components such as gaze, facial expressions, and body position. This research direction is considered crucial, acknowledging the multimodal nature of sign language. In conclusion, the article contributes significantly to the field of automated translation from Kazakh to sign language by proposing new formulas and algorithms. However, for a more comprehensive understanding, further research is needed in the area of gesture semantics and their non-verbal context.

4. CONCLUSION

In conclusion, Kazakh sign language is identified as a distinctive and intricate linguistic system, necessitating a profound comprehension of its semantic intricacies for the successful and precise translation from oral Kazakh text to sign language. This study aims to analyze not only the lexical and grammatical aspects of Kazakh sign language but also the semantic nuances to develop an algorithm for automated translation. A crucial aspect is the application of the SOP formula in interpreting Kazakh sign language. Steps such as translating verbs into infinitives, adding adverbs of place, time, and subject, and swapping object and predicate require in-depth analysis to ensure translation accuracy and adequacy. However, it is important to acknowledge that these formulas are not universally applicable, and exceptions may arise. In the development of an automated translator, algorithms, technologies, and databases are considered to optimize the process and enhance translation functionality.

This research work marks just the initiation of a more profound analysis of sign language semantics. Understanding that sign language involves not only gestures but also multimodal means of communication, where meaning can be conveyed through gestures as well as non-meaningful components like gaze, facial expressions, head, and body position. Our subsequent work involves creating an application serving as an automated sign language interpreter, opening new horizons in research within this captivating field.

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