

ARTIFICIAL INTELLIGENCE-BASED SOFTWARE FOR RECOGNIZING DYNAMIC GESTURES OF THE KARAKALPAK SIGN LANGUAGE IN INCLUSIVE EDUCATION

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Abstract

The development of inclusive education requires the introduction of modern digital technologies that provide equal access to learning for students with special educational needs. In particular, learners with hearing impairments need effective methodological and technological support for mastering sign language as a major means of communication, social interaction, and educational participation. This thesis examines the design and pedagogical application of artificial intelligence-based software for recognizing dynamic gestures of the Karakalpak Sign Language in an inclusive educational environment.

The relevance of the study is determined by the fact that dynamic gestures have a complex spatio-temporal structure. They include hand trajectory, palm orientation, movement speed, gesture rhythm, and a sequence of motion phases. Traditional methods of teaching and assessing gestures often depend on the subjective observation of the teacher and do not always provide immediate, objective, and individualized feedback. Therefore, the use of artificial intelligence, computer vision, and neural network technologies creates new opportunities for improving the quality of inclusive education.

The proposed software system is designed to analyze video sequences of learners' hand movements, extract spatial and temporal features, classify dynamic gestures, and generate pedagogical feedback. The system includes video capture, preprocessing, feature extraction, gesture classification, and feedback modules. Convolutional neural networks are used to identify spatial features of hand movements, while recurrent neural network-based approaches help analyze the temporal dynamics of gesture execution. The software supports repeated practice, self-control, correction of errors, and objective assessment of learning outcomes.

The results of the study show that the integration of artificial intelligence-based gesture recognition software into the learning process contributes to the formation of sign language communicative competence, increases learner independence, and improves the objectivity of assessment. The proposed approach can be considered an effective digital pedagogical tool for teaching regional sign languages, including the Karakalpak Sign Language, in inclusive education.

Keywords: inclusive education, artificial intelligence, dynamic gesture recognition, Karakalpak Sign Language, computer vision, neural networks, digital pedagogy, pedagogical feedback.

1. Introduction

Inclusive education is one of the most important directions in the modernization of the modern education system. Its main purpose is to create equal educational opportunities for all learners, regardless of their physical, social, psychological, or communicative characteristics. In this process, particular attention is paid to students with hearing impairments, because their successful participation in education depends not only on access to learning materials, but also on the availability of effective communication tools.

For learners with hearing impairments, sign language plays a central role in communication and knowledge acquisition. It allows them to understand educational content, interact with teachers and peers, and develop communicative competence. However, teaching sign language, especially dynamic gestures, requires special methodological support. Dynamic gestures differ from static gestures because they are performed through movement in time and space. Their correct execution depends on the direction of hand movement, speed, sequence, rhythm, position of the fingers, and coordination of the whole gesture structure.

The Karakalpak Sign Language is an important means of communication for learners with hearing impairments in the regional educational environment. However, the digital resources and intelligent educational tools designed specifically for teaching and recognizing dynamic gestures of the Karakalpak Sign Language are still limited. This creates the need to develop software solutions based on artificial intelligence that can support both teachers and learners in the educational process.

Traditional assessment of gesture performance is mainly carried out by the teacher. Although the teacher's role remains essential, subjective assessment may not always provide sufficient accuracy, consistency, and immediate feedback. Learners often need repeated practice and instant correction in order to master the correct form of a gesture. In this context, artificial intelligence-based software can become an effective educational assistant that analyzes the learner's gesture performance and provides objective feedback.

The aim of this study is to present an artificial intelligence-based software system for recognizing dynamic gestures of the Karakalpak Sign Language and to justify its pedagogical effectiveness in inclusive education.

2. Research Objective and Tasks

The main objective of the research is to improve the methodology of teaching dynamic gestures of the Karakalpak Sign Language through the use of artificial intelligence-based recognition software in inclusive education.

To achieve this objective, the following tasks were defined:

1. To analyze the pedagogical and technological requirements for teaching dynamic gestures in inclusive education.

2. To identify the main characteristics of dynamic gestures of the Karakalpak Sign Language.
3. To develop a software architecture for recognizing gestures based on video analysis.
4. To apply artificial intelligence methods for extracting and classifying spatio-temporal gesture features.
5. To integrate pedagogical feedback mechanisms into the software system.
6. To evaluate the role of the proposed software in improving gesture competence and learner independence.

The research focuses not only on the technical recognition of gestures, but also on the pedagogical function of the software. Therefore, the system is considered as a digital educational tool that supports learning, assessment, correction, and individual development.

3. Materials and Methods

The methodological basis of the research includes the principles of inclusive education, digital pedagogy, computer vision, machine learning, and neural network-based pattern recognition. The developed software is intended to recognize dynamic gestures from video sequences that record the hand movements of learners.

The architecture of the software consists of the following functional modules:

Video capture module. This module receives video input from a camera and records the learner's gesture performance. The quality of the video stream is important for the correct recognition of hand movements, gesture direction, and movement phases.

Image preprocessing module. At this stage, the system processes video frames, reduces unnecessary visual noise, detects the hand area, and prepares the image data for further analysis. Preprocessing improves the stability and accuracy of gesture recognition.

Feature extraction module. This module identifies the main spatial and temporal characteristics of the gesture. These include hand trajectory, palm orientation, speed of movement, sequence of gesture phases, and changes in hand position during execution.

Gesture classification module. The extracted features are compared with gesture patterns stored in the system. Artificial intelligence algorithms classify the performed gesture and determine whether it corresponds to the required gesture model.

Pedagogical feedback module. After classification, the system provides feedback to the learner and teacher. Feedback may include information about the correctness of the gesture, detected mistakes, and recommendations for correction.

Convolutional neural networks are used to analyze spatial characteristics of hand movements. These networks are effective in recognizing visual patterns, hand positions, and frame-based gesture features. In order to analyze the temporal structure of dynamic gestures, recurrent neural network-based approaches are applied. They make it possible to consider the sequence and duration of movements, which are essential for recognizing dynamic gestures.

The combination of computer vision and neural network methods allows the system to analyze gestures more accurately than traditional visual observation alone. At the same time, the software does not replace the teacher, but supports the teacher's pedagogical activity by providing objective data and analytical feedback.

4. Pedagogical Model of Using the Software

The proposed pedagogical model of inclusive teaching of dynamic gestures of the Karakalpak Sign Language includes several interrelated components: target, content, technological, intellectual, and evaluative-resultative components.

The **target component** defines the main educational goal: the formation of gesture communicative competence among learners with hearing impairments. This competence includes understanding, performing, correcting, and using dynamic gestures in educational and social communication.

The **content component** includes selected dynamic gestures of the Karakalpak Sign Language, methodological materials, practical exercises, and tasks aimed at developing gesture performance skills.

The **technological component** is represented by the artificial intelligence-based software system. It organizes video analysis, recognition of gestures, and automatic feedback.

The **intellectual component** includes algorithms for recognizing gestures, analyzing movement patterns, and comparing learner performance with correct gesture models.

The **evaluative-resultative component** provides objective assessment of learning outcomes. It helps the teacher monitor the learner's progress, identify difficulties, and adapt the teaching process according to individual needs.

The use of the software creates a cyclical learning process:

gesture performance — automatic analysis — feedback — correction — repeated performance.

This cycle is important for developing stable gesture skills. Learners can repeat gestures several times, compare their performance with the required model, and correct mistakes independently. As a result, the learning process becomes more individualized, interactive, and objective.

5. Results and Discussion

The implementation of artificial intelligence-based gesture recognition software in the educational process demonstrated several pedagogical advantages.

First, the software increased the objectivity of assessment. In traditional teaching, the evaluation of gesture performance may depend on the teacher's individual perception. The proposed system provides additional objective data based on movement trajectory, gesture speed, orientation, and sequence of motion phases. This allows the teacher to make more accurate conclusions about the learner's progress.

Second, the software supported the development of learner independence. Learners were able to practice gestures repeatedly and receive feedback without waiting for constant direct correction from the teacher. This increased their confidence and reduced psychological tension connected with public evaluation.

Third, the system contributed to the formation of self-control skills. Since learners could see the results of their performance, they became more aware of their mistakes and more actively participated in correcting them. This is especially important in inclusive education, where the development of autonomy and active learning behavior is a key pedagogical objective.

Fourth, the software helped the teacher organize differentiated instruction. The data collected by the system made it possible to identify which gestures were difficult for specific learners. Based on this information, the teacher could adjust exercises, repeat necessary materials, and provide individualized support.

Fifth, the proposed approach expanded the possibilities of teaching regional sign languages. Many existing digital solutions are focused on widely used sign languages, while regional sign languages often remain insufficiently represented in intelligent educational systems. Therefore, the development of software for recognizing dynamic gestures of the Karakalpak Sign Language has both scientific and practical significance.

The results show that artificial intelligence-based recognition technologies can serve as an effective bridge between digital innovation and inclusive pedagogy. They provide technical support for recognition and assessment, but the educational value of the system depends on its correct methodological integration into the learning process.

It is important to emphasize that artificial intelligence should not be understood as a replacement for the teacher. The teacher remains the main organizer of the educational process, interprets the results, provides emotional support, and ensures the humanistic orientation of inclusive education. The software acts as an intelligent assistant that strengthens the teacher's methodological opportunities.

6. Scientific and Practical Significance

The scientific significance of the study lies in the development of an approach that combines artificial intelligence, computer vision, and inclusive pedagogy for teaching dynamic gestures of a regional sign language. The research contributes to the study of digital methods for recognizing and teaching the Karakalpak Sign Language. The practical significance of the study is reflected in the possibility of using the software in inclusive schools, special education institutions, teacher training programs, and independent learning environments. The system can support students with hearing impairments, teachers, speech and sign language specialists, and researchers working in the field of digital inclusive education.

The proposed software may also be used as a basis for expanding gesture databases, developing mobile applications, and creating multimodal educational platforms. In the future, the system can be improved by adding real-time recognition, voice and text support, visual prompts, and adaptive learning scenarios.

7. Conclusion

The use of artificial intelligence-based software for recognizing dynamic gestures of the Karakalpak Sign Language is an effective direction for improving inclusive education. The proposed system provides technological and pedagogical support for

the formation of gesture communicative competence among learners with hearing impairments. The software analyzes video sequences, extracts spatial and temporal features of gestures, classifies gesture patterns, and provides feedback for correction. Its integration into the educational process increases the objectivity of assessment, supports independent learning, and improves the effectiveness of practical gesture training.

The research confirms that artificial intelligence technologies can significantly enrich the methodology of teaching sign language when they are used as pedagogical support tools. The developed approach helps create a more accessible, interactive, and learner-centered educational environment.

Future research should focus on expanding the database of dynamic gestures of the Karakalpak Sign Language, improving recognition accuracy in real time, adapting the system to different lighting conditions and camera positions, and integrating multimodal feedback mechanisms. These directions will further strengthen the role of intelligent technologies in inclusive education and support the development of digital resources for regional sign languages.

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