ABSTRACT

of the dissertation for the degree of Doctor of Philosophy (PhD)
in the educational program 8D06101 – “Information systems (by indusry)”

AKERKE TANKIBAYEVA

INFORMATION TECHNOLOGY FOR DETECTING ANATOMICAL STRUCTURES ON MAGNETIC RESONANCE TOMOGRAPHY IMAGE

The main idea of the research: The dissertation is devoted to the development of an information technology framework for the automated analysis of knee MRI with the aim of improving the accuracy of meniscal injury diagnosis. The study seeks to create an integrated system that combines texture-based image processing techniques with state-of-the-art deep learning models (YOLOv8-x, RT-DETR), enabling robust delineation of anatomical structures and automatic detection of meniscal tears even in low-contrast or diagnostically challenging images.

The dissertation proposes and substantiates the following contributions:

An algorithmic approach to texture analysis of meniscal MRI, involving the transformation of raw images into an informative digital representation based on inter-pixel characteristics. This approach enhances the sensitivity of structural delineation and enables a more objective interpretation of imaging data.

A unified MRI preprocessing pipeline that integrates multiple filtering and image-quality enhancement techniques. Experimental metrics demonstrate that the proposed combination of procedures achieves an optimal balance between noise suppression and preservation of anatomical contours.

A conceptual architecture of an intelligent diagnostic platform that integrates classical analytical methods with modern neural-network models for automatic detection of meniscal injuries. The system incorporates modules for image preprocessing, analysis, and visualization, forming a complete technological workflow for computer-assisted clinical decision support.

The developed methods were validated on a clinical MRI dataset comprising images acquired on different scanners and under varying acquisition protocols. Experimental results show improved accuracy in anatomical structure delineation and increased reliability in identifying meniscal tears compared to traditional approaches. Integrating the proposed texture-based diagnostic methods with deep learning models enhanced the robustness of the algorithms to image-quality variability and substantially reduced both diagnostic errors and false-positive findings.

Keywords: magnetic resonance imaging (MRI), meniscal tear, texture-based diagnosis, object detection, deep learning, medical image processing, YOLOv8, RT-DETR, intelligent diagnostic system.

The relevance of the research. In the context of Kazakhstan’s ongoing digital transformation and the rapid introduction of artificial intelligence

technologies, the development of intelligent systems for medical diagnostics is acquiring particular importance. Disorders of the musculoskeletal system—especially meniscal injuries of the knee joint—constitute a significant share of clinical cases and require high-precision imaging. Although magnetic resonance imaging is considered the gold standard for diagnosing such conditions, the interpretation of MRI scans remains subjective and highly dependent on the clinician's expertise.

In this regard, the development of automated MRI analysis methods aimed at improving the specificity and sensitivity of meniscal tear detection represents a highly relevant scientific and practical challenge. Intelligent technologies based on computer vision and deep learning can reduce diagnostic errors, decrease the workload on medical specialists, and expand access to high-quality diagnostics, particularly in regions with a shortage of radiologists.

Thus, the creation of an information technology framework for anatomical structure extraction from MRI images holds significant scientific and social value, as it contributes to the advancement of digital healthcare tools and enhances the effectiveness of medical services.

This dissertation research was conducted within the framework of the 2024–2026 grant funding program for scientific and/or scientific-technical projects of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Project IRN AP23486396: "Models and methods for recognizing anatomical structures in MRI images for computer-aided diagnostics").

The object of the research is the process of detecting meniscal tears on knee MRI images.

The subject of the research comprises the models and the image-processing and analysis methods used for the recognition and localization of meniscal injuries on knee MRI scans.

The research goal is to develop an information technology framework for MRI image analysis that enables the extraction of anatomical structures and improves the reliability of pathology diagnosis, using knee joint abnormalities as a representative case.

Research objectives:

1. To analyze and systematize the existing approaches and methods used for automating the extraction and analysis of anatomical structures in magnetic resonance images.
2. To construct a dedicated dataset of clinical knee MRI images that ensures sufficient representativeness for training and testing diagnostic models.
3. To develop a method of information-texture diagnosis of meniscal injuries based on the analysis of inter-pixel intensity variations and tissue density characteristics.
4. To develop a preprocessing methodology for MRI images that incorporates filtering, contrast enhancement, and sharpness improvement in order to increase data quality for neural-network analysis.

5. To conduct experimental studies, including the training and testing of the YOLOv8x and RT-DETR models, and to perform a comparative analysis of their performance and efficiency in the task of automatic detection of meniscal tears.

6. To develop the architecture of an intelligent diagnostic system for detecting meniscal injuries, integrating modules for preprocessing, data analysis, and visualization.

The main research methods are image processing and analysis techniques, pattern recognition approaches, and deep learning models.

Provisions to be defended:

– a texture-based diagnostic method for detecting meniscal injuries of the knee joint, founded on an information–texture transformation of MRI images, which enables a transition from the visually analog representation of MRI slices to their formalized digital interpretation;

– a combined MRI preprocessing method, incorporating a comparative analysis of several filtering approaches and selecting the optimal technique based on objective image-quality metrics;

– the architecture of an intelligent diagnostic system for identifying meniscal tears, integrating a texture-based diagnostic module with a pathology-detection module built upon deep learning models.

The scientific novelty of the work lies in the fact that, for the first time, an approach based on the YOLOv8-x architecture is proposed for the automatic recognition of meniscal tears on knee MRI images, incorporating a custom clinical dataset and a combined MRI preprocessing method.

Publications. A total of **11** papers have been issued on the topic of the dissertation, including: **3** papers in journals recommended by the Committee; **2** papers in international peer-reviewed journals indexed in the Scopus database with CiteScore percentile and/or indexed in the Web of Science Core Collection (Clarivate Analytics) and/or having a non-zero impact factor; **5** papers in the proceedings of international conferences; 1 publication in other scientific outlets; and 1 certificate of state registration of copyright.

The contribution to the preparation of each publication consisted in the analysis of data from open literature sources on the research topic, in the development and testing of models, in obtaining and describing experimental results, in preparing and discussing conclusions, as well as in presenting and discussing scientific results at seminars and conferences.

The main results of the dissertation work were reported and discussed at 6 international conferences:

1) XI International Scientific and Technical Conference of Students, Master's Students, and Young Scientists "Creativity of Youth for the Innovative Development of Kazakhstan," April 10–15, 2025, Ust-Kamenogorsk, Kazakhstan;

2) XIX International Asian School–Seminar "Problems of Optimization of Complex Systems," August 14–22, 2023, Novosibirsk, Russia;

3) International Conference "Computational and Information Technologies in Science, Engineering and Education (CITech-2023)," October 2, 2023, Ust-Kamenogorsk, Kazakhstan;

4) International Conference “Science, Education, and Practices of Implementing BIM and GIS Technologies,” June 20–21, 2023, Ust-Kamenogorsk, Kazakhstan;

5) IX International Scientific and Technical Conference of Students, Master’s Students, and Young Scientists “Creativity of Youth for the Innovative Development of Kazakhstan,” dedicated to the 65th anniversary of the university, April 3–14, 2023, Ust-Kamenogorsk, Kazakhstan.

The main scientific results proved in the dissertation, as well as in articles on the research topic, include:

1. A texture-based diagnostic method for detecting meniscal injuries, grounded in an information–texture transformation of MRI images. For the first time, a formalized approach is proposed that enables the transition from the visually analog representation of MRI slices to their digital interpretation based on inter-pixel intensity increments and structural tissue characteristics, thereby increasing the sensitivity of anatomical boundary delineation.

2. A combined MRI preprocessing method that includes a comparative analysis of several filtering approaches and the selection of an optimal technique for contrast enhancement and noise suppression. It is demonstrated that the proposed combination of methods provides higher visualization quality of soft-tissue structures compared with traditional solutions.

3. The application of modern deep learning models (YOLOv8-x, RT-DETR) for the automatic detection of meniscal tears in MRI images. Experimental studies confirm improvements in detection accuracy, robustness, and processing speed relative to classical recognition methods.

4. An architecture of an intelligent diagnostic system for meniscal injury detection, integrating a texture-based diagnostic module and a pathology-detection module based on neural network models. A software framework has been developed that enables automated interpretation of MRI images, data storage, and user interaction.

The dissertation has practical significance: the results of the dissertation have been implemented in the form of software for magnetic resonance imaging–based diagnosis of knee joint pathologies at the National Scientific Centre of Traumatology and Orthopedics named after Academician N.D. Batpenov, Department of Arthroscopy and Sports Trauma, Astana, November 2025.

For implementation into practice, it is proposed: Certificate of entry into the State Register of Rights to Copyright-Protected Objects No. 61988 dated 09.09.2025. Type of object: computer software. Title of the object: “Software for Magnetic Resonance Imaging of Knee Joint Pathologies”. Author: A.K. Tankibayeva.

The structure and scope of the dissertation. The dissertation consists of an introduction, 4 chapters, conclusions, a general conclusion, and a list of 144 references. The dissertation is presented on 122 pages of computer text, includes 56 figures, 10 tables, and 3 appendices.