ABSTRACT

The dissertation by Azhar Toilybaykyzy Tursynova addresses
the topical issue of **«Development of Deep Learning equipped IoT System for Stroke Diagnosis».** The work is submitted for the degree of Doctor of Philosophy (PhD) in the field of «8D07109 - Automation and Internet of Things»

Research Relevance. Ischemic stroke is the most common cerebrovascular disease worldwide, accounting for 87% of all strokes in the United States alone. It occurs when a brain artery is blocked, interrupting blood flow and ultimately killing brain cells. The effectiveness of potential treatments largely depends on the time elapsed since the onset of the stroke. Accurate segmentation of the stroke lesion (i.e., the affected brain area) is a very laborious task, requiring the analysis of several MRI sequences and has low agreement among observers. Stroke can occur anywhere in the brain, with varying sizes, and its characteristics are highly variable. Manual segmentation remains the gold standard, but it is impractical in medical practice.

Despite encouraging data on reducing stroke incidence, globally, population aging and the accumulation of risk factors contribute to an increase in the lifetime risk of stroke. According to the Global Burden of Disease 2016 Lifetime Risk of Stroke Collaborators, the average global lifetime risk of stroke increased from 22.8% in 1990 to 24.9% in 2016, representing a relative increase of 8.9% after accounting for competing risks of death from causes other than stroke. A Mendelian randomization study among nearly 500,000 Chinese individuals showed that genetic markers predicting low-density lipoprotein cholesterol levels were directly associated with ischemic stroke and inversely associated with intracerebral hemorrhage, providing causal evidence of the opposing effects of low-density lipoprotein cholesterol levels on the two most common types of stroke. Among 81,714 women participating in the prospective cohort study Women's Health Initiative, those consuming ≥2 artificially sweetened beverages daily on average had an increased risk of all strokes (adjusted OR 1.23 [95% CI 1.02–1.47]) and ischemic stroke (adjusted OR 1.31 [95% CI 1.06–1.63]) compared to those consuming <1 artificially sweetened beverage per week, after adjusting for demographics, history of CVD, risk factors, body mass index, health behavior, and overall diet quality.

Computed tomography (CT) and magnetic resonance imaging (MRI) are the most common methods used for stroke diagnosis. Although MRI provides higher quality images than CT, the technology required for this procedure is only available in major facilities. Typically, CT is the primary step in stroke diagnosis as it allows determining the extent, type, and severity of the damage. Furthermore, CT is considered the fastest and most cost-effective diagnostic technology for stroke. Therefore, given the need for rapid diagnosis, the paramount importance of decision-support systems that analyze CT images to assist physicians in medical decision-making is undeniable.

The ultimate goal of using visualization methods in the detection of cerebral stroke is to diagnose as quickly as possible and gather accurate data about the state of the intracranial vascular network and cerebral perfusion for treatment decision-making. In the case of acute ischemic stroke, delays in diagnosis and treatment can lead to serious consequences for brain function and an increased risk of death. The justification for medical interventions, such as endovascular treatment, is determined by the location of the lesion in the posterior or anterior circulation and the period since the onset of the disturbance. Most procedures for treating patients with symptoms require the presence of specialist personnel. Consulting medical experts is a labor-intensive process, and these specialists may not always be available in every medical institution. Imaging studies such as CT and MRI are essential for the rapid diagnosis of brain lesions in stroke and determining which areas of the parenchyma are damaged. Automated approaches to assessing brain stroke are necessary to expand the capabilities of early treatment.

Traditional methods for automatic identification and classification of cerebral infarcts were developed using a set of design guidelines provided by algorithm developers after careful analysis of clinical data. Because some aspects of potential brain stroke are hidden and difficult to detect during scanning, traditional methods of automatic stroke classification were hindered by insufficient complexity. On the other hand, deep learning methods allow for the extraction of visual attributes from training samples, unlike conventional machine learning. These methods can simplify the modeling of cerebral infarcts and overcome the limitations of previous deep learning approaches. Convolutional neural networks (CNNs) use convolutional kernels to extract specific features from the input image, as well as to solve various image categorization tasks.

Modern artificial intelligence applications are designed to help people solve a wide range of problems. CNNs, a developing subcategory of deep learning, are currently widely used in neuroimaging. Deep learning methods and the use of CNNs are evaluated as a diagnostic strategy for acute ischemic strokes. Recently, data analytics and deep learning have become the most popular topics within the scientific community, producing remarkable results in robotics, image recognition, and artificial intelligence (AI). Neural networks excel in processing unstructured data, especially images, text, audio, and speech. Convolutional Neural Networks (CNNs) are particularly effective for such unstructured data.

Simultaneously, the growing significance of the Internet of Medical Things (IoMT) has begun to change the healthcare landscape. IoMT, a network of interconnected medical devices capable of interacting with each other over the internet, enables real-time data exchange, remote patient monitoring, and instantaneous delivery of medical services. In the context of stroke treatment, IoMT can revolutionize the ways medical data is collected, shared, and utilized, significantly reducing the time from symptom onset to the start of treatment.

Research into diagnostic methods for stroke using the Internet of Medical Things (IoMT) and deep learning for medical image analysis is highly relevant, considering the high prevalence of strokes as one of the leading causes of mortality and disability globally. Effective early detection of stroke can significantly improve outcomes for patients by minimizing consequences and increasing the chances of successful intervention. In this context, using IoMT to monitor indicators such as blood flow velocity through the carotid arteries provides valuable data for timely diagnosis. Furthermore, the application of deep learning algorithms to the analysis of CT images of the brain significantly enhances the accuracy of diagnostic procedures, allowing for the recognition of complex patterns that may not be obvious to the human eye. Such technologies not only facilitate the development of personalized treatment approaches but can also significantly reduce healthcare costs by decreasing the need for prolonged rehabilitation and care. Thus, the development and integration of advanced technological solutions in the field of stroke diagnostics become a key direction for improving the quality and accessibility of medical care at this stage.

Research Object: CT images of the brain and blood flow in the carotid arteries.

Subject of Research: An ultrasonic sensor for measuring blood flow speed in the carotid arteries, and deep learning algorithms for the classification and segmentation of stroke foci in brain images.

The aim of the study is to develop a comprehensive system for the automatic diagnosis of stroke signs using the Internet of Medical Things (IoMT) and deep learning models in brain images.

Research Methods:

- Modeling in Proteus environment the schematic part of IoMT.
- Image processing methods.
- Deep learning methods.

Novelty:

- An IoMT device has been developed to detect early signs of stroke by measuring blood flow speed in the carotid artery.
- A deep neural network model has been developed for stroke classification with a small dataset.
- A deep learning model based on U-Net has been developed for stroke segmentation in brain images with limited data.

Practical significance lies in the application of a comprehensive system for stroke diagnosis using IoMT devices to detect early stroke signs by the speed of blood flow in the carotid artery and deep learning models for classification and segmentation of brain images. The components of the IoMT device include: a continuous wave (CW) ultrasound sensor, an ADS1115 analog-to-digital converter, and a Raspberry Pi 4 Model B single-board computer. The deep neural network models for classification and segmentation of stroke can work with a small dataset.

Tasks set to achieve the goal of the research:

- Investigate diagnostic methods for stroke using the Internet of Medical Things.
- Analyze blood flow speed in the carotid artery.

- Develop a prototype Internet of Medical Things for stroke diagnosis based on blood flow speed in the carotid artery.

- Analyze deep learning models in tasks of stroke classification and segmentation of stroke foci in brain images.

- Develop deep learning models for classification and segmentation of stroke foci in brain images.

- Evaluate the effectiveness of the deep learning models.

Theses to be defended:

- A comprehensive stroke diagnosis system based on the Internet of Medical Things and deep learning models has been constructed.

- A deep learning model based on CNN for classifying brain images with stroke has been developed.

- A model for segmenting stroke foci in 3D brain images based on a modified U-Net architecture has been developed.

Publications. Eight scientific papers are dedicated to the topic of the dissertation, including five in scientific journals indexed by Scopus and Web of Science, two in proceedings of international conferences, and one patent of the Republic of Kazakhstan.

1. Omarov, B., Tursynova, A., Postolache, O., Gamry, K., Batyrbekov, A., Aldeshov, S., Azhibekova, Z., Nurtas, M.,Aliyeva, A., Shiyapov, K. Modified UNet Model for Brain Stroke Lesion Segmentation on Computed Tomography Images //Computers, Materials & Continua. – 2022. – T. 71. – №. 3. Q1, 79%
2. Tursynova, A., Omarov, B., Tukenova, N., Salgozha, I., Khaaval, O., Ramazanov, R., Ospanov, B. Deep learning-enabled brain stroke classification on computed tomography images //Computers, Materials & Continua. – 2023. – T. 75. – №. 1. – C. 1431-1446. Q1, 79%
3. Tursynova, A., Omarov, B., Sakhipov, A., Tukenova, N. Brain Stroke Lesion Segmentation Using Computed Tomography Images based on Modified U-Net Model with ResNet Blocks //International Journal of Online & Biomedical Engineering. – 2022. – T. 18. – №. 13. Q2, 61%
4. Omarov B., Tursynova A., Uzak M. Deep Learning Enhanced Internet of Medical Things to Analyze Brain Computed Tomography Images of Stroke Patients //International Journal of Advanced Computer Science and Applications. – 2023. – T. 14. – №. 8. Q3, 44%
5. Tursynova, A.T., Omarov, B.S., Postolache, O.A., Sakypbekova, M.Zh. Convolutional deep learning neural network for stroke image recognition //Journal of Mathematics, Mechanics and Computer Science. – 2021. – T. 112. – №. 4.
6. Tursynova, A., Omarov, B., Shuketayeva, K., Smagul, M. Artificial Intelligence in Stroke Imaging //2021 11th International Conference on Cloud Computing, Data Science & Engineering (Confluence). – IEEE, 2021. – C. 41-45.

7. Tursynova A., Omarov B. 3D U-Net for brain stroke lesion segmentation on ISLES 2018 dataset //2021 16th International Conference on Electronics Computer and Computation (ICECCO). – IEEE, 2021. – C. 1-4.
8. Patent No. 8655 for a Utility Model. "Comprehensive Stroke Diagnostic System Based on the Internet of Things and Deep Learning." Date of issue: November 24, 2023.

The first chapter is dedicated to a review of the literature sources for stroke diagnosis and the analysis of modern approaches to predicting strokes using artificial intelligence and the Internet of Medical Things. It also discusses the types and pathophysiology of strokes.

The second chapter describes the approaches and decision support systems for stroke diagnosis. It provides reviews of machine learning and deep learning methods. Three types of stroke diagnostics are discussed: identification, classification, and segmentation.

The third chapter examines the materials used and methods applied for stroke diagnosis. It proposes models and architectures for solving classification and segmentation tasks of strokes using brain imaging, focusing on the main methods to enhance the quality and performance of the models. The data for working with the models are defined, as well as the IoMT equipment, its functional schematic, and operating principle.

The fourth chapter is devoted to the results of the research. Experimental results are presented on the use of the Internet of Medical Things for stroke diagnosis, outcomes of the model for classifying brain strokes using deep learning, and results of the experiment with a deep neural network model based on UNet and UNet with ResNet blocks for segmenting brain images. The effectiveness of the developed deep learning models is assessed.