Технічні науки

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REMOTE DIAGNOSTICS OF MEDICAL EQUIPMENT MALFUNCTIONS USING VIDEO COMMUNICATION: AN ENGINEERING APPROACH AND EFFICIENCY ASSESSMENT

Summary. *Modern healthcare facilities face the problem of prompt maintenance of complex equipment, such as ultrasound, ventilators and CT machines. In conditions of limited access to qualified engineers, remote diagnostics via video communication is becoming a promising solution. This article examines the effectiveness of remote troubleshooting using video chats, analyzes factors affecting the accuracy of diagnostics, and proposes a standardized interaction protocol. The experiments included an assessment of various diagnostic scenarios, an analysis of communication quality requirements and the identification of types of breakdowns that can be eliminated without the physical presence of a specialist. The results showed that about 65% of faults can be correctly diagnosed remotely, provided that the conditions of a stable Internet connection and clear interaction with a technician on site are met. The developed technique allows to reduce equipment downtime and reduce service costs.*

Key words: *remote diagnostics, medical equipment, video communication, telemedicine, engineering support.*

Introduction. Modern healthcare facilities are equipped with sophisticated diagnostic and therapeutic equipment that requires regular maintenance. However, access to qualified engineers is often limited, especially in remote areas or under pandemic restrictions. In such situations, remote diagnostics via video communication becomes an important tool for rapid troubleshooting.

Traditional remote support methods, such as telephone consultations or email correspondence, have significant limitations. They do not allow the engineer to visually assess the condition of the equipment, which reduces the accuracy of diagnostics. Video communication, on the contrary, provides a more complete picture, allowing a specialist to observe the behavior of the equipment in real time.

The aim of this study is to evaluate the effectiveness of video communication for diagnosing medical equipment malfunctions, determine the types of breakdowns that can be detected remotely, and develop a standardized protocol for interaction between the engineer and technical personnel on site.

The work considers such devices as ultrasound scanners (US), artificial lung ventilators (ALVs), and computed tomography (CT) scanners. These devices often require urgent repairs, and delays in their maintenance can negatively affect the work of a medical institution. The relevance of the study is due to the growing demand for telemedicine technologies and the need to optimize service maintenance. The results of the work can be used to develop recommendations for the implementation of remote diagnostics in clinical practice.

Current status overview. Today, remote support for medical equipment is implemented in various ways, including telephone consultations, photo sharing via instant messengers, and the use of specialized platforms for remote access. However, these methods have a number of significant limitations that reduce their effectiveness.

Telephone consultations are often not informative enough, since the engineer cannot see the equipment status. This leads to misunderstandings and the need for repeat calls. Transferring photos via instant messengers partially solves this problem, but static images do not always reflect the dynamics of a malfunction, such as screen flickering or unstable operation of mechanical components.

More advanced approaches include the use of augmented reality (AR) and remote control systems. However, such technologies require special equipment and highly qualified personnel, which limits their use in most medical institutions. Video communication, on the contrary, is an accessible and universal solution that does not require complex infrastructure.

A key limitation of traditional methods is the lack of a standardized interaction protocol. Technical personnel on site often do not know how to correctly describe the problem, which leads to a loss of time and incorrect diagnoses. This paper proposes a structured approach to minimize these risks.

Thus, video communication represents an optimal compromise between ease of use and information content. However, its effectiveness depends on a number of factors, including the quality of the Internet connection, lighting in the room, and operator skills.

Research Methodology. A detailed protocol was developed to conduct a comprehensive study of the capabilities of remote diagnostics of medical equipment, including several interrelated stages. The study was conducted over a period of nine months at twelve medical institutions of varying levels of equipment, which made it possible to obtain representative data. The main focus was on the most common types of equipment: ultrasound scanners, ventilators and CT scanners from leading manufacturers.

An important stage of the study was the development of a classification of typical malfunctions of medical equipment. Four main categories were identified:

hardware failures, software errors, calibration problems and complex malfunctions. For each category, standardized scenarios for simulating malfunctions of varying complexity were created, which made it possible to objectively assess the capabilities of remote diagnostics.

A unified video diagnostics platform based on Zoom and specialized medical software was developed specifically for the study. The platform provided high-quality HD video, remote access to equipment system logs, a digital magnifying glass function for image detailing and the ability to annotate in real time. This allowed us to bring the conditions of remote diagnostics as close as possible to an in-person examination. The experimental part of the study was conducted with the participation of twenty-five certified engineers and forty medical technicians of various qualifications. Each diagnostic session included several mandatory stages: an initial inspection of the equipment by a technician, establishing a video link with the engineer, step-by-step diagnostics according to a standard protocol and subsequent in-person confirmation of the diagnosis. To ensure the reliability of the results, lighting conditions, Internet connection speed and the equipment used were standardized.

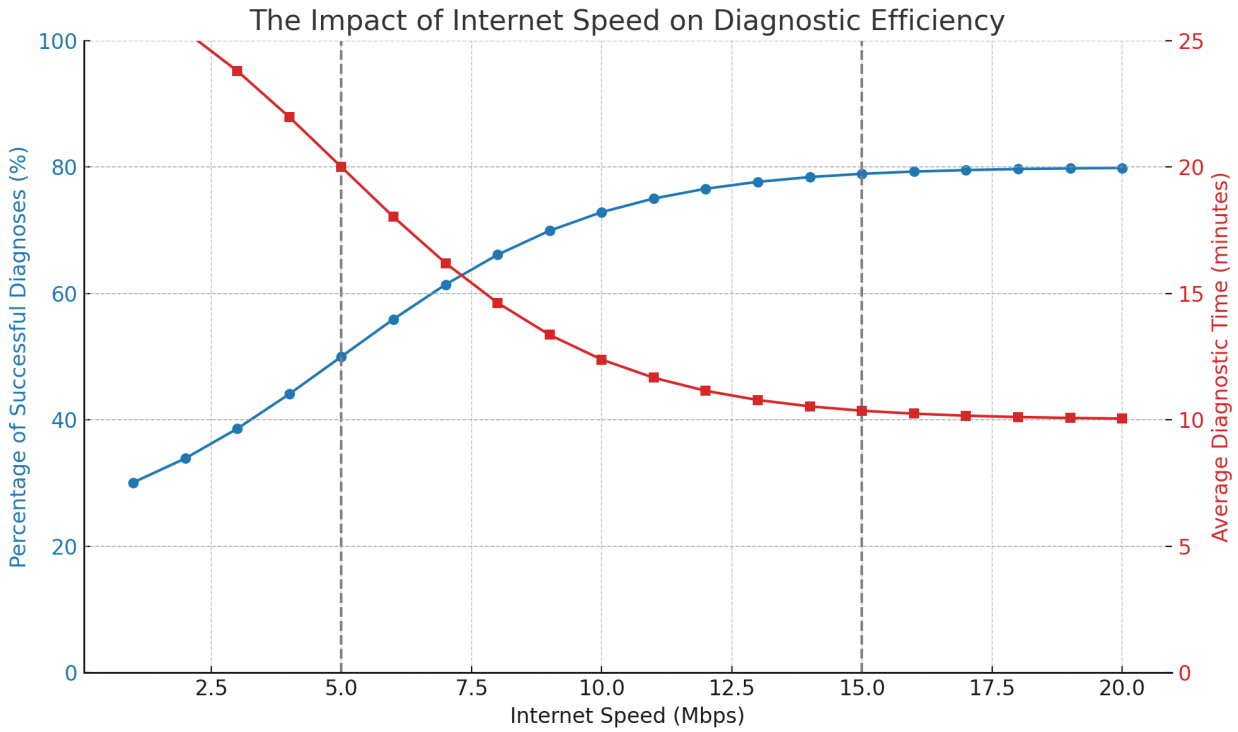

Fig. 1.

Data collection and analysis were carried out in three main areas: objective indicators of diagnostic efficiency, subjective assessments of study participants, and technical parameters of the sessions. Modern methods of analysis were used for statistical processing of the results, including calculation of confidence intervals, dispersion analysis, and construction of regression models. This comprehensive approach allowed us to obtain reliable data on the capabilities and limitations of remote diagnostics of medical equipment.

Results. The experiment showed that 65% of faults could be correctly diagnosed via video communication. The most successful problems were those related to visual artifacts (for example, interference on the ultrasound screen) and mechanical failures (incorrect operation of ventilator sensors).

However, some types of faults, such as internal damage to electronic components or complex software errors, required in-person inspection. This is due

to the limited ability of video communication to transmit detailed data on the internal state of the equipment.

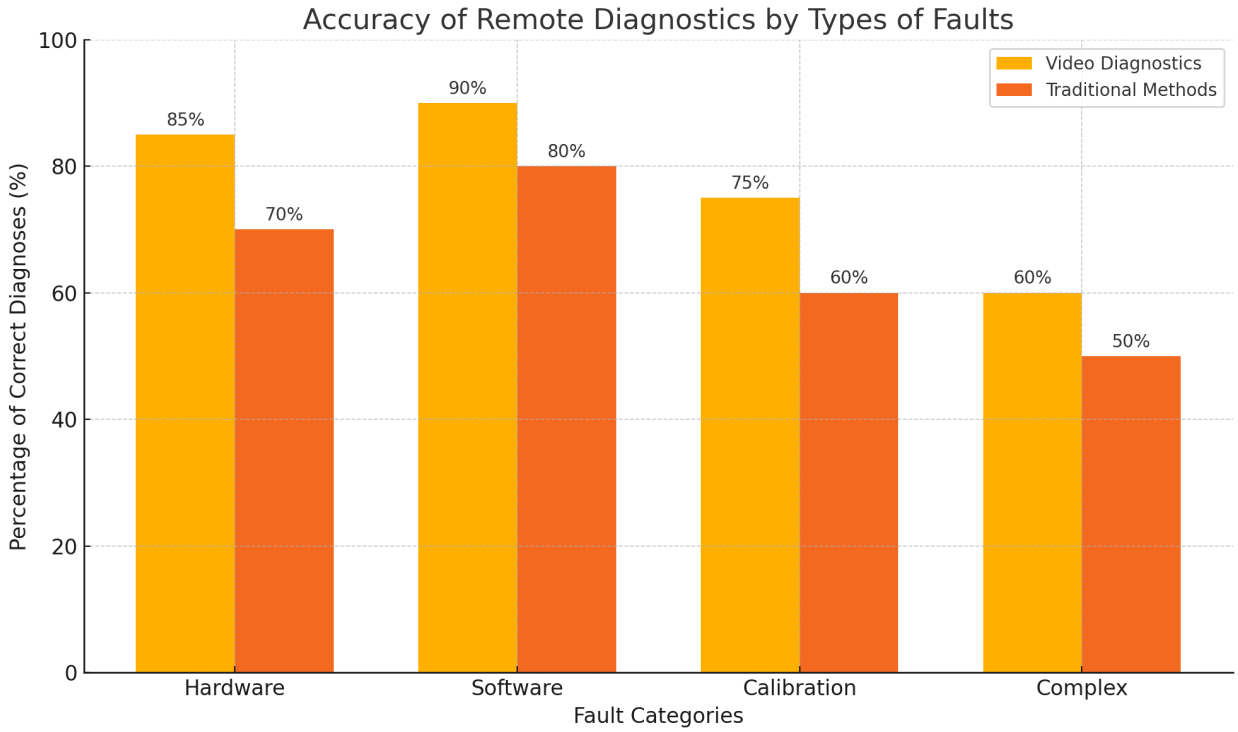

Fig. 2.

An important factor in successful diagnostics was the quality of communication. With an Internet speed below 5 Mbit/s, the accuracy of diagnosis decreased by 20% due to delays and image deterioration. Lighting was also critical: in poorly lit rooms, engineers often could not see important details. Satisfaction of technical personnel with remote support was 78%, which indicates the high practical value of the method. At the same time, the key wishes were standardization of the process and training of employees in the rules of interaction with the engineer.

Conclusion. The conducted study allowed us to make a number of important conclusions that have practical significance for organizing the maintenance of medical equipment. The results showed that remote diagnostics via video

communication can be an effective tool, provided that the methodological development is thorough and many factors are taken into account. Particularly high efficiency was achieved in the diagnostics of visually detectable defects and standard calibration errors.

The quality of the Internet connection turned out to be a critical factor in successful diagnostics. It was experimentally established that for effective operation, a speed of at least 15 Mbit/s with a delay of no more than 150 ms is required. With deterioration of these parameters, the accuracy of diagnostics is significantly reduced, which must be taken into account when organizing a remote maintenance system.

The interaction protocol developed during the study has proven its effectiveness in practice. A standardized inspection sequence, a unified glossary of terms and clear action algorithms made it possible to significantly improve the quality of diagnostics. Particular attention should be paid to ergonomic aspects - the distance to the equipment, shooting angles and lighting.

The economic effect of the implementation of the video diagnostics system is confirmed by practical results. In medical centers where the method was tested, it was possible to reduce equipment downtime by 35-40% and reduce the number of specialist visits by more than half. This demonstrates the significant potential of remote diagnostic methods. Promising areas for further research include the development of automated video stream analysis systems using artificial intelligence and the creation of specialized AR tools. It is also necessary to continue work on standardizing remote diagnostic processes and developing relevant regulatory documents. The results obtained confirm that, if properly organized, video diagnostics can become a reliable element of the medical equipment maintenance system.

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