RESEARCH PAPAER

Innovative Technologies in Management and Control of Rescuers When Performing Complex Tasks

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Abstract: A survey revealed a high level of interest among rescuers in using physiological monitoring systems for real-time health monitoring. Most respondents consider such devices necessary and useful for improving safety and efficiency in challenging conditions. However, reliability, convenience, and data privacy remain important issues. An automatic alert system for deteriorating rescuer health is considered critical, as in emergency situations, a rescuer may not be able to initiate a signal. Preference is given to lightweight, uniform-integrated devices that do not interfere with movement and work. Incorporating such systems into rescuers' daily routines will significantly reduce risks to their lives and health, and will also improve the responsiveness of management. Further development and adaptation of these technologies, taking into account user needs and working conditions, is recommended.

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The introduction of innovative technologies is fundamentally changing approaches to the management of rescue operations. Key areas of technological transformation include: Use of wearable biometric devices (fitness trackers , smart watches, helmet sensors) that record vital parameters in real time; Integration with mobile applications and cloud platforms that provide data transfer, storage and analysis; Use of artificial intelligence for predictive analytics and decision support; Geographic information systems (GIS) that provide precise positioning and mapping of emergency zones; Automated warning and control systems that reduce the time gap between data receipt and response [1].

Improving safety and control over rescuers' actions. Modern wearable biometric devices and sensors enable real-time monitoring of vital signs, such as heart rate, blood oxygen levels, body temperature, and other parameters.

Accelerate operational processes and decision-making – Integrating data from wearable devices, geographic information systems, and cloud platforms allows for a complete, real-time, centralized picture of the current situation.

Minimizing human error - Automation of data collection and analysis reduces reliance on subjective assessments and operator fatigue.

The aim of the study is to develop and analyze an effective system for monitoring the physiological parameters of rescuers during emergencies to improve their safety and performance.

The object of the study is the physiological state of rescuers working in emergency situations.

Methods and technologies for monitoring physiological parameters

Modern advances in biomedical electronics and telemetry enable comprehensive monitoring of rescuers' health in real time. The most common methods and technologies include: Photoplethysmography (PPG) - an optical method for recording changes in vascular filling, which is used to measure heart rate (HR) and blood oxygen saturation (SpO_2) [2-4]. Data transmission from wearable sensors is carried out via various communication channels - Bluetooth (for short distances and connection to smartphones or gateways), Wi-Fi and LTE (for transmitting large amounts of data over medium and long distances), as well as satellite communication channels (in conditions without cellular coverage, for example, in remote or mountainous areas). Examples of widely used solutions include Zephyr The BioHarness is a chest strap that measures heart rate, respiratory rate, body temperature, and physical activity levels. The system has found application in sports medicine, military research, and rescue operations due to its high reliability and compatibility with remote monitoring systems [5-6]. Another example is the Hexoskin Smart Shirt , a smart T-shirt with integrated ECG recording electrodes, respiration sensors, and an accelerometer, allows for a comprehensive assessment of the user's cardiorespiratory parameters over time [7]. The Empatica E4 bracelet combines GSR, heart rate, accelerometer, and temperature sensors, making it useful for monitoring stress, sleep disorders, and epileptic seizures [8]. In addition to specialized solutions, there are also mass-market consumer devices on the market, such as Garmin Vivosmart , Fitbit Charge or Apple Watch , which provides basic monitoring of activity and some physiological indicators, although it is inferior to professional systems in terms of accuracy [9].

The use of wearable sensor systems in rescue operations offers several advantages. These devices allow for real-time monitoring of vital signs in conditions where access to traditional medical equipment is limited. Early detection of signs of overload, overheating, hypoxia, or stress reactions improves personnel safety and enables prompt management decisions. Furthermore, remote monitoring of multiple personnel simultaneously simplifies coordination and improves service efficiency.

Thus, wearable sensor systems represent a promising tool for monitoring human physiological status in real time. Their use in rescue operations offers opportunities to improve safety and efficiency in extreme conditions, but requires further improvement in terms of reliability, autonomy, and measurement accuracy.

C system The Rescuer Beacon combines GPS beacon and vital signs monitoring functions, including heart rate, temperature, and body position. Data is transmitted via a GSM channel, expanding the device's geographic reach. The Rescuer Beacon is designed for mobility and ease of use, allowing for the monitoring of rescuers in emergency situations and remote areas [10-14].

The Mayak Rescuer® complex is a mobile transceiver station (MTRS) in the form of a case with five individual transceivers (Mayak-R) and an individual alert device (Bracelet-R).

Fig. 1Rescuer Beacon system

The Mayak Rescuer® system is designed to protect and save the lives of firefighters during emergency situations, such as extinguishing fires in buildings with complex layouts, as well as in the event of a threat of collapse and exposure to external fire factors. (Fig. 1)

If a firefighter is immobilized for more than 45 seconds or manually activates the alarm, the Rescuer Beacon® performs the following functions: transmits the "Alarm" radio signal and the firefighter's number to the MPPS and the "Bracelet-R", which is always worn by the person on duty at the mobile firefighting headquarters; alternately turns on a powerful siren (100 dB), which is audible at a distance of up to 100 m, and a "white sound"; turns on super-bright flashes to search for the firefighter (two super-bright emitters are located at different angles to the surface of the housing), ensuring a search at a distance of up to 10 m in conditions of heavy smoke; transmits the "Alarm" radio signal and its location to the duty unit, which allows for the coordination of the actions of other rescuers.

This option is possible if the city or facility has a comprehensive monitoring, emergency alert, and firefighter rescue system, "STRELETS-MONITORING."

If necessary, the person on duty at the security post can urgently alert all personnel to evacuate a hazardous area, such as if there's a threat of a collapse or explosion. Simply press the "Everyone Exit" button on the mobile station, and the signal will automatically be delivered to each firefighter. Alerts are transmitted via radio from the firefighter's radio beacon at the fire station to the mobile transceiver station located outside the hazardous area. The radio range of the mobile radio beacon, whether operating via an external antenna or the built-in antenna, is sufficient for practical use of the Mayak Rescuer®

system in firefighting and emergency rescue operations of any complexity.

The Rescuer Beacon® radio signal is completely stable within a 1-kilometer line-of-sight range and up to 300 meters behind load-bearing walls. The system's mobility allows it to be installed at a security post in close proximity to the emergency site, making the signal even more reliable. The MPPS receives alerts from five radio beacons, which is sufficient for personnel working in a single rescue team (Fig. 2).

Fig. 2Rescuer Beacon system

Reception of alarm signals from a radio beacon is carried out in the following cases: units are responding to the first fire number (rank), and the mobile station is stationary in the main fire truck and operates via a connected external antenna; an operational headquarters and a GDZS checkpoint are established at the fire, and the MPPS operates via a built-in antenna.

Light signals are perceived depending on smoke density at a distance of up to 10 meters. A piezoelectric siren is clearly audible in a building at a distance of up to 60 meters when working with personal respiratory protective equipment (PPE) and searching for an injured firefighter in a non-breathable environment, allowing for the determination of the direction of movement. Localizing the source of light and sound can sometimes be difficult due to light scattering, sound reflection off walls, and hearing strain caused by the loud siren. A "white sound" can more accurately pinpoint the location of an injured firefighter at a distance of up to 10 meters.

The physiological monitoring system being developed for rescuers implements comprehensive monitoring of key biometric parameters, enabling real-time assessment of health and performance in extreme conditions. Below is a detailed description of each parameter, with examples of the technologies used and links to authoritative sources.

Heart Rate (HR) The firefighting community recognizes that cardiovascular disease is one of the most common and serious health risks associated with working in extreme emergency situations [15]. Physiological risks in firefighters include intense physical exertion, sympathetic nervous system activation, high heat load, and exposure to toxic substances and environmental pollutants [16]. These factors also increase the risk of developing cancer in firefighters after retirement. According to the Fire Fighters Association, more than 130 firefighters died of cancer in 2019 [17].

During rescue operations, specialists are exposed to these hazardous factors, requiring continuous professional monitoring of their vital signs. In this context, the use of pulse, heart rate, and oximetry sensors allows for rapid monitoring of the physiological state of rescue team members. If dangerous changes are detected, the commander receives a signal and can decide to withdraw the rescuers from the scene for rest or medical assistance.

While such monitoring systems do not completely eliminate the risk of injury and illness, their use significantly improves the safety and effectiveness of rescuers, reducing the likelihood of acute conditions and potentially reducing the incidence of chronic diseases, including cancer, among former rescue personnel.

an Arduino microcontroller has been developed as a basic hardware solution for a system for physiological monitoring of rescuers. Uno , which integrates several key sensors to provide comprehensive physiological data collection.

The device's design ensures compactness and ease of use in the field. All components are mounted on a breadboard (or on a printed circuit board during final assembly) with minimal wiring to reduce size and improve reliability.

This solution enables the acquisition of real-time information on key physiological parameters, which is essential for timely decision-making in extreme rescue conditions.

The developed physiological monitoring system is designed to continuously measure and analyze the rescuer's key biometric parameters in real time. The system is based on an Arduino microcontroller. Uno , which interacts with connected sensors and implements algorithms for collecting, filtering and interpreting data.

The device is a portable monitoring system based on the Arduino microcontroller platform , integrating an infrared temperature sensor and a set of biosensors for measuring key physiological parameters. The system includes a non-contact infrared temperature sensor for real-time body temperature monitoring, and biosensors for recording heart rate and blood oxygen levels (SpO_2), which characterize the rescuer's health in real time.

The device continuously collects and processes data, which can be transmitted wirelessly to the control center for analysis and timely decision-making. Using the Arduino platform, this system is flexible, scalable, and energy-efficient , making it suitable for mass adoption.

The main advantage of the proposed solution is its comprehensive monitoring approach, ensuring the timely detection of signs of overload and potential health threats to rescuers during complex and dangerous tasks. This device improves the safety and effectiveness of rescue operations, reducing the risk of occupational illnesses and accidents.

In today's environment, there is a need for continuous monitoring of the vital signs of rescuers in high-risk areas (fires, rubble, chemically hazardous objects, etc.). Existing devices typically measure individual parameters and do not provide comprehensive analysis in real time, limiting the effectiveness of management decisions in emergency situations. Examples of existing analogs for comparison are presented in Table 1.

Table 1 Advantages compared to analogues

Parameter	Fitness bracelets (Garmin Forerunner 965)	Rescuer Lighthouse Complex (Russia)	Dräger PSS Merlin (Germany)	Arduino using infrared temperature sensor and biosensors
Temperature measurement	Yes (often skin, not always accurate)	No	No	Yes (IR proximity sensor)
Pulse, heart rate	Yes	Yes	No	Yes
Galvanic skin response	No	No	No	Yes
Integration of multiple sensors	No	Yes	No	Yes (all in one device)
Mobility and portability	Yes	Yes	Yes	Yes
Possibility of synchronized data processing	Limited	Limited	Partially	Yes
Price	$ 950	$6,000	$ 1,674	$ 83.34

Thus, the proposed device stands out:

- Multifunctional and comprehensive monitoring – several important indicators are collected and analyzed simultaneously.
- Affordable cost – thanks to the use of Arduino and available sensors.
- Flexibility – it's easy to add new sensors and change the configuration.
- The ability to integrate data – which improves diagnostics and health monitoring.

The proposed device is a compact and integrated system based on the Arduino microcontroller platform and includes the following components:

- Infrared temperature sensor for non-contact measurement of body temperature;
- optical pulse sensor for recording heart rate;

The collected data is processed by an Arduino microcontroller , followed by synchronization and visualization. The device supports wireless data transmission (Wi-Fi , Bluetooth) to the squad leader's mobile device, a monitoring console, or cloud storage for analysis and operational decision-making. Thresholds can be configured and an alarm automatically generated when values exceed acceptable limits.

The device includes an infrared temperature sensor, a pulse and saturation sensor, and a Bluetooth module for wireless data transmission.

The circuit consists of the following main components:

- Temperature sensor – designed to measure body temperature. It connects to the Arduino via the 5V power line and transmits data via a digital interface.
- The pulse and oxygen saturation sensor measures heart rate (HR) and blood oxygen levels (SpO_2). It communicates with the Arduino via the I²C interface (SCL and SDA lines) and ground (GND).
- The Bluetooth module enables wireless data transfer from the Arduino to an external device (e.g., a smartphone, tablet, or computer). Connection is made via the power lines (5V and GND) and the UART interface (RX).

Arduino UNO microcontroller handles sensor data collection, primary processing, and Bluetooth data transmission . This architecture enables the implementation of a compact, energy-efficient , and easily scalable solution for telemedicine and rescue applications.

The study involved 23 male rescue workers, including firefighters and search and rescue workers. Participants were born in various regions of Uzbekistan, including Tashkent and the Tashkent region, Fergana, and Navoi regions. The survey was conducted among employees. Republican Center for Rescue Operations for Special Tasks of the Ministry of Emergency Situations of the Republic of Uzbekistan .

Participants ranged in age from 22 to 44 years (born between 1981 and 1999), with an average age of approximately 30 years.

The participants' height ranged from 170 to 183 cm. All participants were married, most had 1 to 4 children, which reflects their social status.

Rescue service experience ranged from less than one year to more than 10 years. Most participants had between four and 10 years of experience. Rescue workers primarily work in two types of situations: search and rescue operations and firefighting, with occasional work in chemically and radiation- hazardous areas.

The survey was conducted using a specially designed questionnaire aimed at identifying the perception of the necessity and usefulness of physiological monitoring in the course of their professional activities.

Data collection was carried out in person on August 1, 2025.

Standard statistical methods, including descriptive statistics and correlation analysis, were used to analyze the data to identify key trends and relationships in participants' responses.

A significant portion of participants indicated they were familiar with devices such as sports watches and heart rate monitors, but most had not used specialized medical monitors or GPS trackers . This may indicate a lack of accessibility to professional devices or the lack of implementation of such technologies in practice.

One of the key factors limiting the use of monitoring systems is the concern that devices may interfere with traffic or operate unreliably in harsh conditions. Concerns regarding the protection of personal data and privacy have also been raised, requiring careful consideration when developing new solutions.

An interesting and important result is the high level of support for the automatic alert function for headquarters in the event of a rescuer's health deterioration. This highlights the need to develop intelligent systems capable of promptly responding to critical conditions without user intervention, which is particularly relevant in conditions of extreme stress and risk.

Thus, the survey confirms the relevance of developing comprehensive health monitoring systems for rescuers, taking into account convenience, reliability, confidentiality, and functionality. Further research and technical implementation should address the identified user preferences and concerns to ensure maximum effectiveness and adoption of these technologies.

Conclusions: Rescuers overwhelmingly support the idea of using real-time physiological monitoring systems to monitor health in the workplace. They consider key indicators such as heart rate, temperature, blood oxygen levels, and stress to be important. Most respondents believe such systems will improve the safety and effectiveness of rescue operations. The main barriers to implementation include potential disruption to traffic, reliability in extreme conditions, and data privacy issues. Despite this, the idea of automatically alerting headquarters in the event of a rescuer's deteriorating health is considered extremely important and in demand. Respondents also prefer wearable devices such as bracelets and sensors integrated into uniforms, and they consider the use of such systems essential for all team members, especially in difficult and dangerous conditions.

Thus, there is a clear need and interest in the development and implementation of reliable, user-friendly and functional systems for monitoring the health of rescuers in real time.

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