CHAPTER 4

Methodological approaches to the intelligent human factor management on an offshore oil and gas platforms

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Abstract

This chapter overviews the problems of increasing the efficiency of safety and health management of shift workers in offshore oil and gas industry through the prism of the human factor. It studies the specific features of the environment, hazards and risks, working conditions and professional activities in the offshore sector. The fields of safety and health management of personnel employed on offshore oil platforms are highlighted. It is shown that, despite the sufficient elaboration of the knowledge base on health hazards and mechanisms for their elimination in the traditional system of occupational safety and health protection, the safety and health issues related directly to the human factor have not explored so far. The state-of-the-art of the problem of personnel safety and health in the context of the human factor is investigated. The concept of a human-centered approach to personnel safety and health management is proposed, implying the inclusion of employees in the control loop as the main component in their contextual environment. This involves continuous remote monitoring of vital health indicators of employees and, at the same time, parameters of the context-dependent environment of each of them, and an expert assessment of the deviation of these parameters from the norm. Based on IoT technologies and e-health solutions, a functional model of a system for continuous remote monitoring of the health of workers during the period of their shift on offshore oil platforms is developed. The architecture and principles of functioning of a distributed intelligent health management system for shift workers in the offshore industry are proposed.

Keywords

Offshore oil and gas industry, human-centered approach, IoT, continuous remote monitoring, expert assessment, intelligent health management system.

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4.1 Introduction

The offshore oil and gas industry is one of the leading sectors in the industry and plays a key role in the global oil and gas supply. The growing demand for oil amongst the depletion of onshore hydrocarbon reserves has contributed to the intensification of work on the exploration of hydrocarbon deposits and their production on sea shelf. Currently, offshore fields produce about 40 % of oil and 30 % of gas. According to the agreed experts' estimates, in the next 20–30 years, the deepwater fields (from 400 m to 1.5 km) and ultra-deepwater (from 1.5 km and more) fields will become the main source of expansion of hydrocarbon production [1]. Oil and gas corporations are interested in the development of such fields. It increases the relevance of the task of implementing deep-water projects for the exploration and production of hydrocarbons on a global scale [2].

Meanwhile, as the depth of production increases, the distance of the offshore structure from the coast, the hardness and thickness of the rock, the exploration and development of new oil and gas fields are becoming more capital-intensive and science-intensive processes. A steady trend towards the development of hydrocarbon resources in more "difficult" conditions requires the use of high-tech equipment, new innovative methods for collecting, transmitting and processing a large amount of information received from geographically distributed offshore objects [3, 4]. The use of Internet of Things (IoT) solutions can contribute to the formation of effective strategies for the development of offshore fields for reducing operating costs and increasing the level of hydrocarbon production. Currently, large oil and gas corporations are beginning to implement IoT for continuous monitoring and control of exploration, production and transportation of hydrocarbons, ensuring the safety of special offshore drilling facilities [5, 6].

However, achieving production efficiency only on the basis of digitalization of various operational processes does not seem realistic. Today, a large number of skilled workers and specialists are involved in many of the operational processes of the oil and gas industry, whose functional duties and work activities are associated with potential hazards and health risks. Therefore, the task of improving the efficiency of management of safety and health of workers is an essential part of the oil and gas industry at all stages of the life cycle of the oil and gas business. At the same time, the problem of health management of workers is becoming especially relevant in the offshore oil and gas industry, which is classified as a segment of increased danger to the health of workers [7, 8].

According to experts, the use of IoT technology is one of the challenges for the future development of the offshore oil and gas industry [5]. Moreover, the concept and tools of Industry 4.0 provide an opportunity for the development of IoT-based cyber-physical systems [9], allowing in the future to partially or completely depersonalize the operational processes implemented in the offshore oil and gas segment (OOGS) of the industry [6]. Moreover, we share the opinion of the authors who believe that a person will be present in the management circuit of the oil and gas industry for a long time, and, in particular, in the OOGS. Therefore, digital transformation, first of all, should be aimed at creating an Ambient intelligence for the professional activities and daily life of oil workers [10, 11].

This chapter explores the problems of managing the safety and health of workers employed on offshore oil platforms, based on modern digital technologies.

4.2 Problem statement

Currently, there is a tendency towards wide digitalization of the oil and gas industry. The digital transformation of the industry is stimulated by the emergence of such technological innovations as communication networks for the machine-to-machine (M2M) data sharing [12], wireless sensor networks (WSN), IoT technologies [13–17], as well as a large number of IoT applications and industrial services (Industrial IoT, IIoT) [18]. Moreover, many types of equipment in the oil and gas industry are already supplied with smart sensors for various purposes, which, at various stages of the development of oil and gas fields, collect large amounts of previously inaccessible information online, share the collected data and transmit it for processing [12–20]. Expanding the capabilities of IoT and its scope through integration with WSN, modern storage tools, analytical processing of a large amount of heterogeneous data (cloud computing, big data, real-time decision support systems) allows data acquisition to support informed decisions [21–25].

Analysis of electronic sources demonstrates a significant increase in the interest of researchers and developers in solving industrial safety problems in the oil and gas industry using the potential of IoT. The growing awareness of oil companies about the wide possibilities of the IoT in supporting industrial safety and decision-making in the processes of search, exploration and development of fields, production activities, asset management and remote monitoring have stimulated large-scale investments in this sector [26–31]. In 2019, total IoT investment and funding in the oil and gas industry accounted for 284 million USD, with a particular focus on the development of IoT analytic platforms and cloud services for oil and gas supply chain applications. According to experts, by 2024 investments in the global IoT in the oil and gas market are estimated to account for 43.48 billion USD, increasing by an average of 21.86 % annually over the period 2019–2024 [32, 33].

However, it should be noted that the development and application of IoT solutions to support the safety and health of workers (personnel) are not discussed sufficiently [34–39]. At the same time, the development of technologies and the emergence of intelligent wearable, body-worn and implant sensors (smart watches, bracelets, bandages, patches, sensors placed under the skin or inside body), Wireless Body Area Networks (WBAN) [40–43], GPS and mobile devices (smartphones, tablets) [44–46] have opened up unprecedented opportunities for remote monitoring of the health status of workers, including those employed in industries with an increased health risk for a long time without restrictions on their professional activity [47–49].

The relevance of the problem is confirmed by statistical data, according to which the workers in the oil and gas industry are 8 times more likely to be injured [50, 51]. Thus, according to the US Bureau of Labor Statistics, in 2016, 300 fatal and more than 410 thousand non-fatal industrial injuries were registered in the private sector of the oil refining industry [52]. According to the statistics from the UK Health and Safety Executive (HSE), in 2016–2017, 19 fatal and 60 thousand non-fatal accidents were registered. Moreover, the total cost of payments accounted for more than 700 million USD [53]. According to the statistics provided by the Centers for Disease Control and Prevention (CDC), from January 2015 to January 2017, oil and gas workers were involved in 602 incidents, 481 hospitalizations and 166 amputations [54]. According to the statistics of the State Oil Company of the Azerbaijan Republic (SOCAR) [55], in 2016–2018, 32 accidents were registered, 12 out of which were fatal.

The above data on incidents (fatal incidents and accidents) confirm the need to develop an effective safety and health management system for human resources in the oil and gas industry [51, 56, 57].

4.3 The human factor in the offshore oil and gas segment

The oil and gas industry is inherently hazardous to the health and safety of workers. OOGS of the industry refers to the objects of increased danger.

Obviously, oil extraction from offshore fields is performed using various types of special oil drilling facilities. These structures represent a complex oil and gas field engineering and technical complex designed for drilling and development of wells, oil and gas production, lying in the depth of the sea, ocean or other water environment. At the same time, one platform can accommodate up to 80 wells and, as a rule, is attached to the bottom with tons of tethered cables. To date, a significant part of offshore oil facilities (hereinafter we will use the term “offshore oil platforms”) are equipped for the residence and work of personnel [58]. The technological cycle of work on offshore oil platforms (OOP), associated with drilling, production, transportation, storage of oil and oil products, repair and maintenance of equipment and pumps, is rather complicated and fire hazardous [59, 60].

4.3.1 Specific features of OOP through the prism of human factor

Offshore development and operation of oil and gas fields takes place in difficult and often extreme working and living conditions. Analysis of literary sources through the prism of the human factor allows to identify the following specific factors:

1. Attracting a significant number of human resources to various operations and production processes at geographically distributed offshore facilities and structures of OOP [34, 60, 61].
2. Complexity of exploration and production of new hydrocarbon reserves in offshore zone, which are implemented in hazardous and hard-to-reach places [7, 8].
3. Exposure of human resources to risk factors of various nature, affecting their physiological state and behavior, increasing the probability of making mistakes and involvement in emergency situations [48, 50, 51].
4. Risks of release of radioactive substances, the presence in crude oil of hazardous contaminants that pose a threat to life and health of human resources employed in offshore oil and gas industry [50, 51].
5. Deterioration of equipment, oil and gas leaks during their development, transportation and processing, endangering the safety and health of workers.
6. Serious consequences of accidents (death and injury of people, damage to environment, etc.), necessitating the need to improve monitoring and control methods for the safety and health of workers [62, 63].

4.3.2 Features of working conditions and professional activities of workers at OOP

The study of the activities of shift workers engaged in offshore development and operation of oil and gas fields, through the prism of the impact of working conditions, daily life and external factors on their health, makes it possible to systematize following features:

1. Work and living in confined spaces and polluted environments that increase the risk of infectious diseases and the danger to the life of workers [64].

2. A twelve-hour shift work schedule during a certain time interval (often two weeks), which is a source of psychosocial risks, stress [65], depression [66].

3. Fatigue of employees as a result of irregular working hours and stressful working conditions, assessed as one of the most dangerous risks of making mistakes and accidents [67–69].

4. Exposure of employees to hazardous and harmful factors (industrial noise, vibration, exposure to oil and its components) that threaten health and life [4, 70].

5. Unfavorable external factors (cold, wind, fog, dust, rain, storm) that affect the physical condition, work capacity and labor productivity [69].

"Unsafe" behavior of offshore workers, which is one of the main causes of emergencies [71].

6. Leading positions in the structure of occupational diseases of oil workers, which are diseases of the cardiovascular system, disorders of the musculoskeletal system, hypertension, diabetes, skin problems, hearing loss due to industrial noise [70, 72–74].

4.3.3 Safety and health management of human resources employed in public health services

The management of safety and health of human resources in the oil and gas industry is implemented in two interrelated and interdependent areas:

1) safety of working conditions, workplaces and the environment associated with the elimination of hazards and risks to the health of personnel;

2) health protection and elimination of dangers of diseases [50, 51]. Likewise, the safety and health issues of shift workers employed by OOP can also be considered in two main ways.

The first area involves reducing the risks to health of employees by:

a) preventing potential hazards and minimizing the risks to life and health of personnel;

b) improving the working conditions and safety of workplaces by tracking the parameters of raw materials and the environment (exceeded temperatures, noise and dust, hazardous chemicals, etc.);

c) developing the methods for increasing the reliability of equipment and safety of traumatic agents (machines, mechanisms, devices, etc.);

d) systematic training of personnel in mastering new technologies, labor safety rules and regulations, etc.

Today, relatively stable knowledge basis has been formed about health hazards in the oil and gas industry, including on the shelf [4, 50, 51, 63, 75].

Traditionally, experienced specialists (experts) are involved in oil and gas production to prevent emergency situations and minimize hazards. However, against the background of a shortage of qualified workers, aging processes and a natural outflow of experienced specialists, the constant complication of technologies, keeping experts at each local site becomes an almost impossible task for companies [76–78]. At the same time, existing rules and standards of labor safety, fixed in regulatory documents, mainly represent the requirements for the safety of workplaces, the environment, and equipment. However, despite the constant improvement of regulatory documents that take into account technological innovations, the number of incidents caused by the human factor remains quite high (more than 70 % of crashes and accidents in the oil and gas industry). This fact, recognized in recent years by large oil and gas companies, prompts those companies to pay more attention to the role of the human component in ensuring safety and health at all stages of the life cycle of industry:

1. Upstream – Exploration and Production.
2. Midstream – Transportation, Storage and Marketing.
3. Downstream – Refining, Sales and Distribution [35, 50, 51, 56, 57, 60].

To date, the issues of the manifestation of the human factor in the system of safety and health of workers of OOGS are not given sufficient attention in the scientific literature. This determines the relevance of the choice and research of the second area.

The second area is directly related to a person who is the most important participant in production processes in the oil and gas complex. The multifaceted nature of the representation of the human factor, the serious and often unforeseen consequences of human erroneous decisions at high-risk facilities, as well as poor knowledge of the nature and causes of this phenomenon predetermine the need to develop new approaches to its study.

Scientific studies [7, 34, 35, 39, 51, 61] do not include unambiguous interpretation of the concept of "human factor". Analysis of the existing definitions of this phrase shows that the content of each of them is attributed to the characteristics of the object under study, the role of a person in hazardous production, the goal and the tasks to be solved.

In this case, the specific *object of research* is shift workers, whose activities are associated with various production processes on OOP, equipped for human living and work. The *task of research* is the development of modern technologies for managing the health and safety of shift workers, allowing to minimize the impact of the human factor. The *human factor* on OOP is referred to the possibility of committing erroneous actions by a person under current circumstances, i.e. making wrong decisions that caused this or that incident.

Let's assume that the probability of making erroneous decisions by any member of the personnel directly depends on the psychophysiological state of its health, which determines its behavior, activity during the shift on OOP. Therefore, the state of health, as the most important characteristic and the main component of human resources, directly affects all its professional activities [79]. Thus, analysis of the causes of accidents on offshore oil platforms shows that most of them are associated with an unforeseen deterioration of the health of employees, loss of consciousness, exhaustion, "unsafe" behavior, inadequate response and making wrong decisions in emergency situations, etc. The deterioration of the health of employees in the period they perform their functional duties and reside on OOP can affect their actions and decisions made, cause a violation of standards of conduct and safety measures, and lead to incidents. Therefore, the preservation and strengthening of health at the workplace, the timely identification of the reasons for the deterioration of the state of health make it possible to successfully cope with physiological, psychological and social stress and improve the functional capabilities of workers [80].

This actualizes the need for systematic remote monitoring of the health and safety of workers in the environment of their work and life. Continuous remote monitoring of the health and safety of workers during the shift, will allow timely identification of the causes of deterioration in health of workers on OOP and elimination of the impact of human factor [40, 81].

Despite the close interaction of the above two areas for ensuring the safety and health of workers, each of them has its own scientific and methodological specifics. However, with the development and implementation of modern intelligent technologies in the processes of ensuring safety and health, and, in particular, the IoT and supporting technologies, there is a gradual integration of these two areas within the concept of a "connected" worker. For example, the introduction of appropriate IoT solutions can provide continuous remote access of OOP personnel (authorized persons, individual employees) to the knowledge and advice of experienced specialists (supervisors, drilling engineers, labor safety inspectors, medical workers, etc.). Moreover, through feedback received from OOP, IoT technology will provide experts with real information about the current situation, specific workplaces, location and health status of workers in various geo-zones of OOP, the dynamics of the development of a particular hazard, etc. Collection and mining of the data continuously generated by sensors installed in wells, equipment and other oil and gas fields can play an important role in improving models for supporting workplace safety. Sensors designed for continuous monitoring of personnel health indicators in their contextual environment, i.e. position of posture, availability of personal protective equipment taking into account the location, will help reduce the risk of accidents and industrial injuries [37, 38, 81].

4.4 Digital transformation of the oil and gas industry as a key factor in improving the safety and health of personnel on OOP

Currently, the work on the implementation of IoT, wireless technologies and intelligent analytical tools in a wide range of production processes and operations of the oil and gas industry and its offshore segment have not been widely implemented yet [82–84]. The main reason for this is the lack of sufficient data, which is associated with barriers of a technological and infrastructural, as well as managerial and financial nature. For example, sensors and measuring instruments that record diagnostic and operational information are connected by cable wires mainly with the dispatch center on OOP. As a result of the lack of the necessary infrastructure, the information recorded by the sensors cannot be transferred to the shore to the situational centers responsible for the safety and health of personnel on OOGS facilities. This is due to both the specificity of the standards of incoming signals and the inability of traditional cable technologies to remote data transmission. Meanwhile, modern infrastructure for collecting, transferring and processing large amounts of data through digital technologies of Industry 4.0 (IoT, cloud computing, artificial intelligence, Big Data, blockchain, etc.) requires significant financial and temporary resources. New data governance models are needed to create effective tools for data handling and generating value from it.

Today, digital transformation is taking place in oil and gas companies located on almost all continents of the world. The portfolio of many leading oil and gas companies has not only strategies or programs, but specific digital services have already been created and are being implemented to solve some production and operational problems of oil and gas. These companies aim at full coverage of all links of the value chain (exploration and production, transportation and storage, processing and marketing) [26–28].

Let's note that the decline in oil prices has contributed to traditionally conservative oil and gas companies to perform more moderate assessment of the possibilities of new digital technologies in increasing the efficiency of basic processes and decision-making. This has led to a significant growth of companies that have recently begun to develop strategies and programs for the development of the industry and carry out reforms in the framework of pilot projects [30, 31, 78, 85–87].

The analysis of electronic sources shows that today the human factor in the system of ensuring the health of workers in the oil and gas industry and, in particular, shift workers on OOP, have been poorly studied. The development of technologies and the complication of production processes determine the multidimensional nature of possible representation of human factor in the emergence of the threat of incidents. This, in turn, causes an urgent need to develop new approaches to prevent or minimize the impact of human factor at high-risk facilities and, in particular, on OOP [31, 88, 89]. From our point of view, continuous remote monitoring of health of OOP personnel through IoT solutions can be an effective solution to minimize the human factor. In this case, remote monitoring of the health of OOP personnel involves (**Fig. 4.1**):

– continuous tracking of vital indicators of the physiological state of workers during the shift on OOP;

– real-time tracking of activity (movement) of individuals, identification of each employee and determination of its exact location (geolocation) on OOP, including in dangerous, obscure and prohibited areas;

– remote control of the use of mandatory personal protective equipment by each employee, as well as continuous monitoring of the state of environment surrounding an individual employee;

– online collection, transmission and operational processing of information about the physical condition (position) of workers (falling, loss of consciousness, etc.), their behavior (actions), ensuring timely decision-making to eliminate dangerous situation;

– systematic collection and accumulation of data on the dynamics of vital indicators of the health of employees, necessary for a systematic analysis of the state of health taking into account the demographic parameters and the prognosis of early symptoms of a particular disease;

– formation of a data base containing retrospective information on the dynamics of vital health indicators of personnel during the shift, data on the results of regular pre-shift examinations and appointments, information on adopted medical and diagnostic decisions, prescribed medications, updated with current data from systematically conducted monitoring, etc.;

– access to data about the health of each employee using electronic health cards, which are regularly updated electronic analogues of the medical history of certain individuals, containing demographic indicators (age, gender, residential information, education, professional skills, etc.) and data collected from all medical organizations that the employee has contacted throughout its life [90–92];

– development of a single digital integration platform, which could:

1) consolidate a set of isolated heterogeneous data characterizing safety and health taking into account the demographic parameters;

2) identify threats and risks of incidents and injuries associated with the human factor;

3) conduct a comprehensive analysis of all monitored data to generate reliable analytics that support operational decisions on the management of safety and health of workers, which track the health status of personnel and their environment during the work shift on OOP.

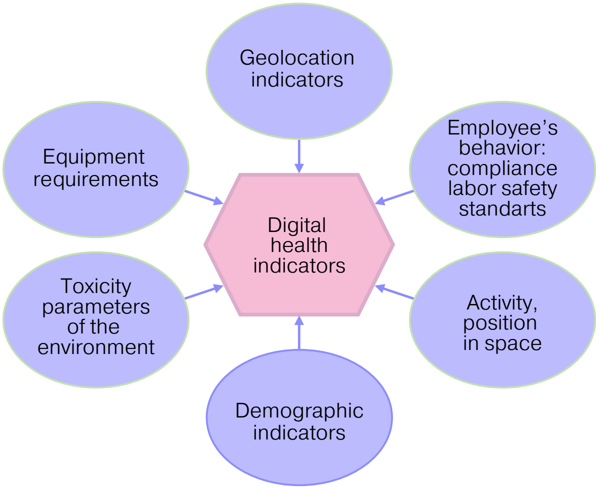

Fig. 4.1 Human-centered approach to health and safety management

The lack of reliable information about the health status of workers in the context-related environment of the latter (geolocation, activity, behavior, level of gas pollution) makes it difficult to make informed expert decisions on taking measures to prevent incidents on OOP adequate to the current situation. The development of IoT solutions for continuous remote monitoring of the health status of personnel and context-dependent parameters and characteristics that directly affect vital health indicators during the shift work on OOP can reduce the risks of emergency situations associated with the human factor.

Taking into account the above, the goal of this study is to develop IoT-based concept and methodological approaches to the synthesis of architecture of an intelligent health management system for shift workers employed in OOGS.

4.5 Conceptual problem statement

The main idea of the proposed concept is a human-centered approach to personnel safety and health management, which implies inclusion of employees themselves as one of the most important components in the management loop. In this case, a human-centered approach to safety and health management involves continuous remote monitoring of vital health indicators of workers and, at the same time, the parameters of context-dependent environment of each of them. Address geolocation coordinates, behavioral models (including those related to the observance of labor safety standards by each employee), activity, state of posture, gas pollution of the environment, etc., can be taken as the parameters of the context-dependent environment. At its core, the IoT platform in the personnel safety and health management system as a tool for continuous remote monitoring of various context-dependent parameters, which directly or indirectly affect the values of vital physiological indicators of workers, provides a "snapshot" of the health status of the latter in their immediate surroundings.

IoT system detects the facts of deviation of certain indicators and parameters from the norm and, in typical situations, automatically develops solutions that exclude human factor. In non-standard situations, all relevant information and real-time solutions offered by IoT system are provided to interested services and their authorized persons (supervisors, doctors, occupational safety specialists, experts), enable the latter to find out the reasons for deviations of indicators from standard values and make appropriate decisions.

The concept of a human-centered approach to the synthesis of an intelligent health management system for shift workers in OOGS involves the development of:

1) methodological approaches to continuous remote monitoring of the physiological state of shift workers based on IoT technologies and e-health solutions, taking into account context-related information;

2) architecture of the intelligent health management system for shift workers;

3) network architecture that supports the processes of remote monitoring and control of the safety and health of personnel during the shift on OOP.

The strategic goal of continuous monitoring of the health and safety of personnel working on OOP is the interaction with each employee, the systematic collection and accumulation of personalized information, the formation of a sufficiently representative and regularly updated database on the dynamics of their health status after a certain time. Embedding this base into the architecture of an intelligent personnel health management system as a module of a dynamic database and joint analytical processing of current and retrospective data will allow to objectively assess the trends of changes in the health status of each employee, make informed and objective decisions to eliminate problems that adversely affect the health of personnel in a short, medium and long term.

IoT technologies, as the basis for a personalized remote monitoring system, will enable to:

1) collect up-to-date information about vital health indicators of personnel and parameters of surrounding environment;

2) identify the deviation of the monitored indicators and parameters from the typical values and standards;

3) create a dynamic database on deviations of health status and context-dependent parameters from norms and standards during the entire shift on OOP;

4) identify the correlation between the state of health, "unsafe" behavior of employee and production factors on the basis of analytical processing of the accumulated information.

Conceptually, a human-centered approach to the management of the health of shift workers on OOP can be divided into three main stages (subtasks) (**Fig. 4.2**).

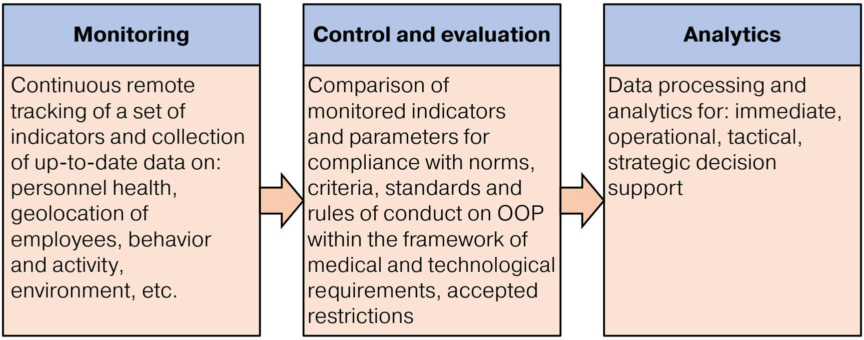

Fig. 4.2 Functional model of health management of OOP personnel

Based on a three-stage functional model of the personnel health management process, the architecture of the "Digital Health" system is developed, which is a multi-level intelligent information system for the health management of OOP personnel.

4.6 Architecture and principles of functioning of intelligent health management system

Before proceeding to the exploration of IoT possibilities in ensuring the safety and health of personnel employed in the oil and gas industry, and in particular in the offshore oil and gas sector, let's briefly outline the essence of the concept of this technology.

4.6.1 IoT architecture

IoT is a network of physical devices with built-in sensors, detectors, electronics, which are uniquely identified, are capable to connect to the network, collect and share data via wired and wireless networks without human intervention [19]. The IoT platform operates on three levels [18, 93–96]:

1. Sensor level represents various objects, extended by embedded systems and smart sensors. The purpose of the sensor level is to collect the necessary data through sensors, process it and transfer it to the network level.

2. Network layer is intended for routing, receives information from sensors and transfers it to IoT devices or applications through data transmission channels without human intervention [18]. Physical objects and devices (things) connect to each other, to the Internet (cloud) through *Gateways* using wireless communication (*Wi-Fi*, *Bluetooth*, *LPWAN*, etc.).

3. Application level (control center) receives data from the network level (from gateways), stores, processes and accumulates it to search for knowledge and then form decisions on its basis. Control Center consists of only two levels, i.e. network and application levels. Technically, application layer is a server with software that analyzes different data sets based on special algorithms for decisions. This level contains many different applications that are activated depending on the tasks assigned [93].

4.6.2 Architecture of shift worker health management system

In accordance with the conceptual approach and functional model described above, the architecture of an intelligent health management system for shift workers in OOGS, which we call "Digital Health", is proposed. The system has a hierarchical structure, in which each of the three levels is geographically distributed, is a target intelligent information system with its own purpose and functions. At the same time, each of the systems is integrated into a single decision process for managing the health of shift workers in OOGS. In this case, OOP personnel acts as a biological object, which is equipped with body-worn and/or wearable devices that generate different data varying for purposes. Body-worn and wearable devices (mono- and multi-functional gadgets in the form of bracelets or watches, bandages, etc.) are personal portable electronic devices (biosensors, trackers) with built-in wireless communication elements that can interact with the environment and the user, record, accumulate, process and transmit data. Smart sensors, RFID-tags (issued to each employee), GPS-trackers built into wearable devices continuously monitor physiological health indicators (temperature, heart rate, blood pressure, etc.), parameters, characteristics and coordinates of geolocation, activity and behavior of each employee. Additionally, special sensors can be attached to the personnel's clothing to detect gas concentration in the air. The use of IoT technology based on wearable technologies and address identification of the necessary parameters allows to actually obtain context-related information about the health status of each employee taking into account the demographic parameters and referring to a specific object, date and time. This information is reliably and securely transmitted in real time to appropriate services, from the position of geographical location and environmental condition (dispatch center on OOP, doctors and security specialists onshore).

The configuration of sensors and settings in IoT platform can be changed and expanded depending on the specific tasks and needs of user. **Table 4.1** shows a set of most informative tracked parameters included in the functionality configuration of Industrial IoT applications. **Table 4.1** presents the types of the most informative monitored parameters.

IoT system is capable of simultaneously transmitting sensed data to various control centers (servers) located both in the horizontal plane (at one level) and hierarchically distributed over many levels.

Table 4.1 Types of monitored parameters

Parameters	Component
Vital health indicators	– temperature; – pulse; – pressure; – heart rate (based on cardiogram recording); – complete blood count; – blood oxygen level; – blood sugar level; – galvanic skin reaction, etc.
Geolocation, activity, behavior	– location determination (using GPS and RFID systems) on platform; – being in a recreation area, incl. rest control; – being in the working area, incl. control of working hours and compliance with labor safety; – monitoring the approach to the energized zone/equipment; – control of going beyond the perimeter and entering prohibited, blind areas (danger of falling overboard), etc.
Condition and posture	– control of the availability of personal protective equipment and the necessary portable equipment; – control of falls/slips (with the provision of automatic signals about an employee's falling); – personal identification; – alarm button; – (SOS); – alarm signaling (warning); – presence of voice communication and instant messages; – video surveillance (photo/video camera) capable to interpret collected indicators for a quick assessment of the general condition

Fig. 4.3 shows the architecture of the intelligent health management system "Digital Health" for shift workers.

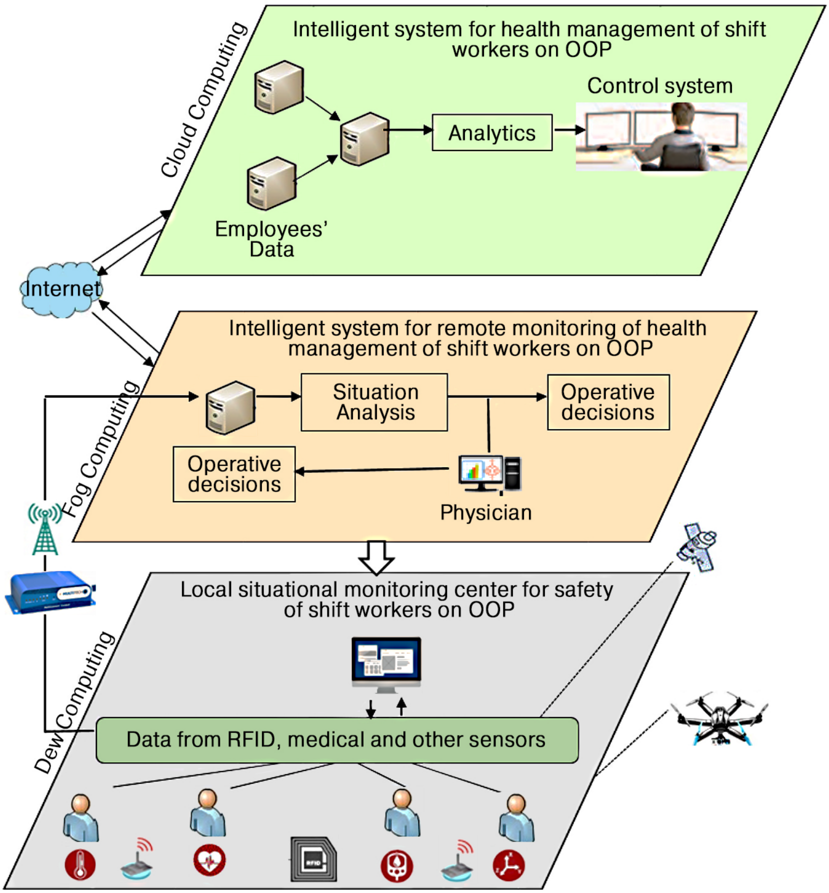

Fig. 4.3 Conceptual model of the "Digital Health" intelligent system

As **the first level** of "Digital Health" system, an IoT solution implemented at the place of residence of the staff, i.e. on OOP, is proposed. When it is possible to include the proposed health management system of shift workers of separate level on OOP into the architecture, we were guided by the consideration that, first of all, urgent decisions related to the elimination of health hazards and the provision of immediate first aid have to be supported at the place of accident. Data collection, processing and analysis is implemented through Dew computing, which provides real-time decision making ensuring low latency in data processing. Targeted data of workers recorded by sensors and RFID through wearable device and smartphone used as a gateway is transmitted via wireless or wired communication to the Local Situation Center for Emergency Response (LSCER) on OOP. LSCER is a computerized workplace of persons responsible for health and safety of workers on OOP. Physically, this is a local computer (Dew data center) designed to receive and analyze incoming data streams on health and safety of workers during the shift. IoT continuously compares the normative (reference), initial (pre-shift) and current (real) values of monitored health indicators and parameters of the contextual environment of workers. As long as all data of workers and their environments is within acceptable limits, nothing is transferred to local computer (Dew data center). As soon as the values of any health indicators and/or coordinates and parameters recorded by sensors go beyond the typical range, these data are sent to local IoT application for processing, analysis and decision-making. IoT application (IIS), equipped with special analytical tools and intelligent algorithms, identifies changes in the health of each employee and deviations of environmental parameters from standards and offers solutions for their elimination.

The second level of the structure of "Digital Health" system supports the remote monitoring management processes in the onshore Specialized Medical Unit through IoT solutions. The need for continuous remote monitoring is due to a number of significant factors. Thus, the personnel work on OOP, which are located at a distance from several hundred meters to several tens of kilometers from specialized medical services. Often, in the event of critical situations related to the health of workers, decision makers responsible for making immediate decisions on OOP do not have sufficient knowledge and qualifications both to interpret and implement the recommendations generated by the IoT system on OOP, and to provide adequate medical assistance to the current situation. Therefore, communication with "onshore" team of medical and safety specialists is a prerequisite for timely qualified medical intervention and taking control actions. However, in this case, medical specialists must have real and reliable information about the dynamics of the vital health indicators of the victims and the circumstances that provoked the deterioration of their condition.

The third level of the architecture of "Digital Health" system is designed to manage the personal health trajectory of shift workers based on IoT solutions. The importance of this module lies in the fact that the results of processing of continuously recorded data on the current state of health of shift workers in long term, systematically accumulated in the database, will make it possible to trace change trends in the state of health of shift workers. The obtained analytical data as an evidence base will make it possible to make informed strategic decisions to improve the management of health, safety and career paths of each employee.

In the proposed architecture of the personnel health management system, all the working functions of the IoT system (data collection, processing, solution synthesis, data storage) are integrated into the following hierarchically distributed computing levels:

1. ***Dew computing*** is intended for continuous data recording by sensors, processing of the latter, and synthesis of local solutions, primarily in the smallest local network (*Dew*), i.e. the data is processed and analyzed offline where it is collected. This allows for data processing with low latency and making urgent decisions (almost in real-time) to ensure the crew safety on OOP (for example, identification of an employee approaching a prohibited zone, fixing a fall, voice communication or a signal to immediately withdraw from a dangerous zone, emergency decisions to eliminate critical situation or provide medical assistance at place). At the same time, it opens up an opportunity for more efficient use of local devices, through which *Dew computing* can provide services and functions on OOP in online and offline modes. *Dew Computing* makes up for the main disadvantage of cloud computing that is the requirement for a stable Internet connection, which is not always possible to ensure on remote OOP. However, in the latter case, the length of time increases during which the cloud will be unavailable and there will be a need to provide qualified medical support and decision-making at a higher level. To overcome this problem, an additional layer – fog computing is introduced, which is a layer between cloud and dew computing [95].

2. ***Fog computing*** is designed for making operational decisions synthesized by an IoT application in specialized data centers and directed both to the lower computing level (*Dew*) to take operational control actions, and to the upper level (*Cloud*) for more detailed analysis. The main advantage of *Fog computing* is data processing without the need to transfer it to large *Cloud* data centers, which reduces the load on the latter. Further, mobility of *Fog* technologies and possibility of geographic location of data centers (*Fog* servers) in the most convenient locations close to the user accelerates the processing and analysis of data from wearable sensors and making operational decisions in accordance with the current situation at *Dew level*. *Fog computing* is often performed on low-power and dispersed computers that do not unnecessarily communicate with cloud. The integration of *Fog computing* into IoT applications contributes to the efficiency of remote health monitoring [96].

3. ***Cloud computing*** intended for a thorough and comprehensive analysis of:

a) data accumulated from the Fog level (IoT gateway), recorded on the fact of deviations of various health indicators, context-related information and decisions made;

b) targeted retrospective, pre-shift, initial and starting medical data of workers;

c) electronic medical records of workers using powerful modern analytical tools (Big Data, ML, Soft computing, etc.).

The purpose of such a comprehensive coverage of employee data for analysis is to increase the validity of decisions made, to reveal hidden dependencies between different indicators for the synthesis of decisions in critical situations. They are delivered to the lower levels of *Fog* and *Dew* computing (for example, making decisions about the urgent evacuation of an injured employee).

4.6.3 Principles of functioning of distributed intelligent system Digital Health

The general principles of functioning of DIS Digital Health in the context of structural layers, proposed in the work, are as follows:

1. All three layers of DIS Digital Health along with many specific applications are equipped with a unique IoT application (software) for each of them. This application is an intelligent information system (IIS) based on a functional model of health management of personnel employed on OOP (**Fig. 4.3**).

2. Modules of IIS database include digitized ranges of changes in normative, edge and critical values of each health indicator (temperature, pulse, pressure, heart rate, etc.), information on standards (reference images) of activity and behavior within the framework of technological requirements and restrictions, authorized and prohibited formats and coordinates of access to hazardous geo-zones (in accordance with the map of drilling rig, working and residential sites, explosive zones on OOP, etc.), permissible limits and level of excess environmental toxicity.

3. IIS knowledge base contains cognitive information linking the expert assessments and decisions with granules of possible values of various indicators and parameters, including critical ones, provoking the emergency situations on OOP.

4. The process of continuous health and safety monitoring of workers employed on OOP generates a huge amount of data, which is problematic to analyze through traditional methods. This leads to the inclusion of high-performance algorithms and analytical tools into the analytical unit of computing platforms DIS Digital Health.

5. IoT monitors in parallel the streams of sensed data of all workers on OOP, compares them with the normative (reference) health status templates, behavioral patterns, geolocation and environmental parameters pre-recorded in IIS databases and knowledge bases, and identifies the deviation rate of a particular indicator and parameter in real time.

6. IoT, instantly analyzing the current situation, reveals the deviation of certain indicators and parameters from the norm and analyzes the current situation. Depending on the criticality of the situation, the degree of its compliance with already known (typical) models, or the identification of new patterns, decision can be made according to two scenarios:

1) automatic formation of a control action by the system;

2) real time data redirecting to emergency response services to make an operational decision.

4.6.4 Scenario for implementing a distributed intelligent system for managing the personnel's health on OOP

An IoT system based on intelligent algorithms automatically (without human intervention) analyzes data and synthesizes a diagnostic solution that can be implemented in accordance with two scenarios (**Fig. 4.3**).

Scenario 1: a decision automatically made by the IoT system as a response to a critical situation instantly acts as a control effect in the local situational center for emergency response (LSCER) on OOP. In this scenario, an IoT system for continuous remote monitoring of the health status of personnel employed on OOP can be considered as a platform that ensures the integration of the real physical world with the virtual world of computing processes, i.e., as a cyber-physical system (CPS), functioning without human intervention in the control loop (human out of loop) [97]. In this case, the connected object is an employee equipped with unique identifiers and sensors to track the health status of the latter in their environment. Sensors interact with the virtual world, i.e., transmit collected data wirelessly online to a computer (Fog and Cloud data centers) for analysis and development of analytics. Automatically made decisions to eliminate health risks based on the analytics results are sent for execution to the LSCER on OOP.

Scenario 2: the decision automatically synthesized by the IoT system is transferred to the responsible clinician (expert) for evaluation and confirmation. The doctor evaluates the results of the data analysis, involving, if necessary, specialists in the field, and makes a final decision, which, within a given period of time, is transferred to OOP for execution. The cyber-physical model of this scenario assumes maintaining a human expert (clinician, supervisor, safety engineer, etc.) in the control loop for remote monitoring of the health and safety of employees on OOP (human in the loop) [12, 98].

Currently, the designed IoT platforms mainly provide the stage of redirecting electronic diagnostic data by a “smart” system to the responsible clinician for a final decision. This is due to the specifics of the monitoring object (person), the high cost of an error (threat to human health and life), as well as the psychological factor. Moreover, the system provides clinicians with the necessary contextual and background information to reduce diagnostic errors and quickly make informed decisions [99]. The results of real-time remote data analysis enable specialists to identify early symptoms of certain pathologies and risks in the nearest onshore Fog data center and warn employees and decision-makers on OOP about this.

4.7 Discussion

The issues of increasing the level of industrial safety, improving working conditions aimed at reducing the rate of accidents, industrial injuries and occupational diseases of employees are the main priorities of companies producing oil and gas onshore and offshore. These issues are associated, first of all, with the complexity of technical devices and technological processes, the danger of oil and gas operations, and the specifics of professional activities on OOP especially in offshore segment. As shown above, when solving the problems of supporting labor safety and health protection of workers on OOP, it is also possible to take into account the physical nature of workers and the multifaceted manifestations of human factor, which in extreme situations can cause incidents. Today, oil and gas companies are experiencing an acute need for technologies that could provide them with real-time complete and correct information about the actual state of safety and health of personnel working on remote OOPs. The availability of such information will allow them to get a holistic picture of the situation on OOP and control it by making timely decisions to eliminate potential threats, including those related to human factor. The digital transformation of the industry, including the offshore segment, allows oil and gas companies to create a fundamentally new IoT-based infrastructure for collecting, remote transmission and processing of heterogeneous data on the safety and health of workers during the shift on OOP. The proposed concept of a person-centered approach to industrial safety, which implies the inclusion of an employee (person) in the control loop as the main component in the environment of its professional and daily activities on OOP, can contribute to improving the management of safety and health of employees. In accordance with the concept, the possibility of making erroneous decisions by an individual employee directly depends on the physiological state of health and determines the behavior and activity of the latter during the shift on OOP. Thus, the deterioration of the health status of workers during the period of their functional duties and residence on OOP can affect their actions and decisions made, cause a violation of standards of behavior and safety measures, and lead to incidents. IoT solutions take into account human nature in hazardous production. Continuous remote tracking of workers' health and context-dependent information, instant advanced analytical processing of a huge stream of consolidated real data provide an opportunity to timely identify changes in the health status of workers, establish the reasons provoking unsafe behavior, make timely informed decisions in emergency situations that eliminate or minimize the human factor.

Based on the proposed concept and functional model of the personnel health management process, we develop architecture and principles of functioning of an intelligent health management system for shift workers in OOGS based on IoT infrastructure and e-health solutions. Geographically distributed over three layers, IoT monitoring system based on wearable devices and smart sensors constantly monitors an individual worker and its surroundings. Moreover, each level in the management hierarchy is an intelligent information decision support system that has its own purpose and functions. At the same time, all three systems are logically integrated into a single decision support process for managing the health of shift workers in OOGS.

4.8 Conclusions

A human being is the most valuable and at the same time the most vulnerable link in the chain of the life cycle of the oil and gas industry, which is fraught with danger to the health and safety of workers. The challenge of continuously improving the efficiency of employee's safety and health management, particularly in offshore industry, is a critical part of the oil and gas industry. The study of the specifics of professional activity shows that offshore development and operation of oil and gas fields occur in difficult and often extreme working and living conditions. This often leads to an unforeseen deterioration of the health of employees, fatigue, "unsafe" behavior and actions that provoke the emergency situations which require the immediate intervention of decision maker. However, the lack of real and reliable information about both the health status of workers and the situation at places, the collection and analysis of which takes some time, makes it difficult to take acceptable measures to prevent an incident.

In this article, as an effective solution to this problem, we proposed conceptual approaches to the development of a system for continuous remote monitoring of the health status of personnel working on OOP in its immediate contextual environment based on IoT and e-health solutions. Immediate analytical processing of constantly generated data on vital health indicators of workers and context-dependent information referred to a specific date and time will reduce the risks of emergency situations associated with the human factor.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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