Data transmission technologies for the development of a drilling rig control and diagnostic system

Irina Rastvorova, Sergei Trufanov
Department of Electronic Systems, Empress Catherine II Saint Petersburg Mining University, Saint Petersburg, Russia

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ABSTRACT

This article examines telecommunication technologies used in automatic control and diagnostics systems and discusses key aspects of using telecommunication solutions for monitoring and controlling the operation processes of the electrical complex of a drilling rig, including remote access, data transmission and real-time information analysis. It provides a comprehensive overview of such communication technologies as Bluetooth, Wi-Fi, ZigBee, global system for mobile communication (GSM), RS-232, RS-422, RS-485, universal serial bus (USB), Ethernet, narrowband Internet of Things (NB-IoT), long range wide area network (LoRaWAN), and power line communication (PLC). Technologies that will be most effective for use in control and diagnostics systems of a drilling rig complex are proposed. The possibility of using machine learning to process a large amount of data obtained during the drilling process to optimize the controlled drilling parameters is investigated.

Corresponding Author:

Sergei Trufanov
Department of Electronic Systems, Empress Catherine II Saint Petersburg Mining University
199106, St. Petersburg, Vasilyevsky Island, 21 line d.2, Saint Petersburg, Russia
Email: sergeitrufanov73@mail.ru

1. INTRODUCTION

In the modern world, the development of technologies and automated systems plays a key role in many industries, including the oil and gas sector. One of the urgent tasks is the analysis and selection of optimal data transmission technologies for automatic control and diagnostics systems of drilling rigs. Analysis of the organization and operation of drilling rigs indicates the need to review and modernize existing approaches. Despite the introduction of advanced technologies and effective management of individual operations, drilling still has significant potential for increasing productivity and improving technical and economic indicators. The main reserves lie in monitoring drilling parameters in real time and in improving the organization of work. In this review article, we will consider telecommunication technologies that are currently used in various control systems and are capable of bringing the drilling process to a new level of efficiency. The purpose of this article is to study existing data transmission technologies, their advantages and disadvantages, as well as to determine the most suitable methods for use in automatic control and diagnostics systems of drilling rigs. We will also consider examples of the successful use of such technologies in practice and possible development prospects in this area.

2. THEORETICAL ANALYSIS

Processes characterized by high technological and operational complexity are ideal candidates for automation using electronic computers (ECM). This approach allows for increased accuracy, reduced human error, and more efficient management of complex operations. The technological complexity of the drilling process is due to a large number of variables, such as "axial load on the bottomhole, rotation frequency of the drilling tool, torque and bottomhole power, vibration parameters of the drilling tool" [1], the values of which to varying degrees affect the efficiency of this process, and a multitude of interactions between them, which requires the application of control actions that are not always obvious. This is especially evident in situations where the correct interpretation of the drilling rig's behavior becomes a key factor for workers to make operational decisions.

In studies [2]–[4], special attention is paid to monitoring the drilling process to optimize its parameters, since "the use of optimal drilling parameters reduces power consumption by almost 75%" [3]. In works [5]–[7] methods for optimizing drilling parameters are developed to increase the efficiency of the electrical complex of the drilling rig. Publications [8], [9] pay special attention to the use of telecommunication technologies for the creation of remote monitoring and diagnostic systems.

Control of even several parameters of a drilling rig becomes extremely difficult in conditions of constantly alternating rocks, which cause continuous changes in technological characteristics. Maintaining an optimal level of operation in such an environment is almost impossible without the use of automated systems that can adapt to rapidly changing conditions and provide precise control of parameters in real time. This is why many researchers strive to optimize drilling operations by implementing monitoring and automatic control systems [9], [10].

Automatic control of the technological process requires constant monitoring, regulation and control actions. Monitoring allows you to track all process parameters in real time, see their dynamics and evaluate the effectiveness of control actions. Regulation involves adjusting the process parameters to achieve specified values or changing them according to developed mathematical models and control methods [8], [11], [12]. Control helps the object function effectively in continuously changing conditions.

For effective management, it is necessary to use various technical solutions [13] and appropriate information support based on the use of “smart” measuring and control devices, as well as autonomous “smart sensors” with self-monitoring and self-calibration functions, capable of connecting to information networks for information exchange using modern digital interfaces, including wireless ones” [11]. In parallel, a database is formed for subsequent statistical analysis and determination of optimal process parameters [14]. Information in automatic control systems must meet the following requirements: i) reliability; ii) timeliness; iii) usefulness; and iv) unambiguity. In areas related to automation and control of production processes, both wired and wireless data transmission methods are actively used. We will consider in more detail the data transmission technologies used in monitoring, diagnostics and control systems of technological processes.

3. METHOD

3.1. Wired interfaces

In modern industrial automation systems and data transmission networks, serial interfaces such as RS-232, RS-422 and RS-485 are widely used. These interfaces ensure reliable data transmission between devices, having various characteristics in terms of range, speed and resistance to interference, which makes them universal solutions for integrating equipment into automated systems [15]. RS-232 was one of the first interfaces developed for exchanging data between data terminal equipment (DTE) devices, such as computers, and data communications equipment (DCE) devices, such as modems and routers. Data is transferred directly, without intermediaries, which ensures fast and efficient communication between devices [16]. This standard allows devices to be connected over relatively short distances and provides basic protection against electrical interference. This makes it especially popular for industrial and automation systems where stability is important.

RS-422 is an interface standard that came to replace the outdated RS-232 interface, defining a symmetrical (differential) data exchange interface using two separate wires for each signal. It allows for higher data rates and minimizes problems associated with different ground potentials, since the ground is no longer used as a reference wire, as in RS-232 [16]. RS-485 is one of the most popular and reliable interfaces for organizing industrial communication, ensuring effective interaction between various devices and systems. Being an extension of the RS-422 standard, it retains such advantages as high data transfer rate and significant communication distances, but has an important difference-the ability to support the connection of a larger number of transmitters and receivers to one line. This makes RS-485 an ideal choice for multi-point systems and complex automated networks [16]. During the analysis of works [15], [16], describing serial interfaces RS-232, RS-422 and RS-485, key parameters were identified that ensure the effective operation of automation systems. In Table 1 are the values of the parameters of data transmission interfaces.

Table 1. Key parameters of RS-232, RS-422, RS-485 interfaces for control systems

Parameter	Data transfer interfaces		
	RS-232	RS-422	RS-485
Method of signal transmission	Single phase	Differential	Differential
Maximum number of receivers	1	10	Up to 256
Maximum cable length, in m.	15	1200	1200
Maximum transfer rate	460 kbps	10 Mbps	10 Mbps
Receiver sensitivity	± 3 V	± 200 mV	± 200 mV

The table shows that:

a. The RS-232 standard transmits information over a shorter distance compared to other interfaces, which does not allow its use in large-scale automatic control systems.
b. RS-422 and RS-485 have higher sensitivity due to the use of differential data transmission, which allows better suppression of noise and interference.
c. RS-422 and RS-485 standards provide a high data transfer rate compared to RS-232, which directly contributes to improving the efficiency of the technological process, allowing a more accurate and timely response to changes and ensuring optimization of production operations.
d. RS-485 has the ability to connect the largest number of receivers, which allows the automation system to transmit more data for further analysis.

Thus, RS-232 is used for connections over short distances, and RS-485-over long distances with higher requirements for data transfer rate [17]. This is why the RS-485 interface is the most common in industrial automation systems.

In addition to the RS-232, RS-422 and RS-485 standards, the universal serial bus (USB) digital interface is often used to transfer data from peripheral devices. The USB connection "is a cable with 4 wires: two of them supply power (5 V, 500 mA) to the device, the other two provide data transfer" [18]. The USB architecture is built on the principle of hierarchy, where the computer acts as the main control device, called the host. The devices connected to it play the role of slave (peripheral) elements of the system.

Having analyzed the information about this interface [18], [19], in the context of automation systems, USB offers a number of advantages and disadvantages that should be taken into account when choosing a data transfer channel. Over the years, the USB standard has evolved, going through versions 1.1, 2.0, 3.0, 3.1, 3.2, and up to the latest version 4.0, which supports transfer rates of up to 40 Gbps [20], making it suitable for transferring large amounts of data, including audio, video, and other multimedia files. It also allows you to power an external device through a power line built into the cable, making it easier to connect and operate. However, it has a huge drawback in that the maximum cable length is 5 meters, which can create problems when connecting devices over long distances.

Ethernet-the most common network standard used to create local area networks and connect devices to the internet. In automation systems, Ethernet is used to combine various devices into a single network, providing high data exchange rates and access to network resources. However, despite its popularity and data transfer rates, Ethernet was not originally developed as a real-time standard. This limitation can cause problems when used in automatic control systems, where minimal latency and predictability of response time are critical. For such tasks, specialized Ethernet-based protocols such as EtherCAT or PROFINET, which are adapted for real-time operation, can be used.

An analysis of publications [21], [22] allows us to look at the Ethernet network standard as an opportunity to create an industrial automation system. The advantages of Ethernet networks, due to their openness and standardization, have made them popular in the office environment. Since industrial networks are based on the same technology as office networks, this simplifies the integration of technical solutions and opens up new opportunities for the prompt analysis of production information, which was previously difficult or impossible.

Modern versions of Ethernet, such as 10 Gigabit Ethernet, allow you to transfer large amounts of data at high speed. It is also easily scalable, allowing you to add new devices and expand the system without significant changes to the infrastructure. Thus, the use of Ethernet as an industrial network has prospects at the present time.

Power line communication (PLC) is a data transmission technology that uses existing power lines or power supplies as a medium for transmitting information. Data is transmitted using high-frequency pulses that modulate signals, providing the ability to simultaneously use the line for both power supply and information exchange [19], [23]. Korotchenko and Natashina state in their article that “the microprocessor controller of the PLC network ensures data transmission in distributed communication systems, in control, monitoring systems, and general applications without additional dedicated communication lines. Using the PLC technology of signal distribution and the organization of network protocols based on the microprocessor, it is possible to organize a reliable network for data exchange of digital devices over the power line, while there is no need to lay additional expensive network cables" [24].

The technology of data transmission over power lines is widely used in "energy (telemechanics, SCADA (APCS), telephony, AMR), automatic and dispatch control systems, centralized energy metering systems, oil, gas and coal mining industries, lighting control and others" [24], [25]. The works [24], [26] emphasize the efficiency of using PLC technology for remote monitoring in the electrical complex of a drilling rig. A comprehensive solution can provide access to measurement points that are difficult to reach.

The main advantage of PLC technology is that there is no need to lay additional wires for communication, but it is possible to use the power wires of the electrical complex, which in turn reduces the cost of work. And also a fairly high data transmission range, reaching tens of kilometers [23]. The disadvantages include low noise immunity and dependence on the quality of power lines or power supply.

3.2. Near-field wireless technologies

The publications [27]–[29] analyze the literature on wireless sensor networks and the Internet of Things using wireless data transmission technologies to create monitoring, control, diagnostics and automation systems. The main goal of the Internet of Things and wireless sensor networks, as a key technology in the internet of things (IoT), is to "simplify processes in various areas, ensure better efficiency of systems (technologies or specific processes) and, finally, improve the quality of life" [30]. For example, real-time production monitoring "will make it possible to increase the efficiency of resource and energy use" [31]. Wireless data transmission technologies allow achieving high operational efficiency, increasing productivity and more effectively managing industrial electrical complexes and processes by customizing products, intelligent applications for monitoring production resources.

Global system for mobile communication (GSM) is an effective solution for transmitting data from metering devices via a cellular network. The basis of this technology is a GSM module-a device that provides information exchange via mobile communication channels. It requires a SIM card to operate, which provides identification in the mobile operator's network. The module's operating area can be considered the areas covered by the operator's cell towers, which makes it a universal tool for remote monitoring and control of various systems. Of course, one GSM module is not enough, a microcontroller is also needed that will interact with the GSM module to receive and issue commands from the user through the GSM module.

The works [32]–[35] provide examples of using GSM networks for monitoring in various areas, such as agriculture, medicine, industry, as well as in smart systems based on the Internet of Things. The main advantages of using a GSM module include wide coverage, ease of use and the ability to control a smartphone. The disadvantages include the SIM card service fee and unstable communication in areas remote from base stations.

Bluetooth, Wi-Fi, and ZigBee are some of the most popular wireless data transmission technologies operating in the 2.4 GHz frequency range. These protocols are widely used in industrial automation systems, providing flexibility in organizing communication between devices. Bluetooth technology, which complies with the IEEE 802.15 standard, has become a pioneer in the creation of wireless personal data networks (WPAN - wireless personal area network). Bluetooth is a short-range wireless communication technology (10-100 m) designed to provide communication between various devices [36]. Due to its versatility and low power consumption, Bluetooth has become widespread in household and industrial applications.

Wi-Fi technology is based on the IEEE 802.11 standard. Devices of this standard can operate at frequencies of 2.4 or 5.0 GHz and with a channel width of 20 to 40 MHz, which allowed "to reduce the amount of interference, but using a 5 GHz frequency reduces the range compared to a 2.4 GHz frequency" [37]. ZigBee technology, based on the IEEE 802.15.4 standard, is designed for building low-speed multipoint networks. It is optimized for applications that require energy efficiency, reliability and stability of communication. ZigBee provides a signal transmission range of up to 90 meters indoors and up to 4 kilometers in open areas with direct visibility between nodes [38].

Based on the analysis of wireless data transmission standards Bluetooth, Wi-Fi and ZigBee in works [39], [40], the following main points can be highlighted:

a. Wi-Fi is designed to transmit large amounts of data, such as streaming video, Hi-Fi audio or voice communication, due to its high speed and broadband capacity. However, its significant drawback is high power consumption, which makes the technology less suitable for use at the level of sensors and actuators in industrial conditions, especially where long-term autonomous operation of devices is required.
b. Bluetooth devices consume less energy and have a shorter range. Due to the short range, Bluetooth can support more devices in one area, which allows better use of the available bandwidth.
c. ZigBee has the lowest power consumption, but at the same time the lowest data transfer rate. At the same time, due to the network formation topology, this technology allows covering fairly large monitoring areas.

3.3 Long-range wireless technologies

In addition to the short-range wireless data transmission standards described above, there are also low-power wide-band networks (LPWAN). It is ideal for IoT systems that only need to transmit small amounts of information over long distances. The most common LPWAN technologies are long range wide area network (LoRaWAN) and SigFox in unlicensed ISM and LTE-M bands and narrowband internet of things (NB-IoT) in licensed ones [41], [42]. The publications [41]–[43] present an analysis of LPWAN technologies for monitoring, which shows that wireless sensor networks based on low-power wide-band networks generally provide increased communication performance.

NB-IoT is a cellular communication standard for telemetry devices with low data volumes. The technology provides a throughput of 200 kHz, a maximum payload size of 1600 bytes and an unlimited number of transmitted packets per day. In terms of power consumption, NB-IoT guarantees a battery life of up to 10 years for its devices [42], [43]. The works [44], [45] present monitoring systems using NB-IoT technologies and cloud storage for real-time data processing.

Long range (LoRa) is a wireless communication technology that operates in the unlicensed range below 1 GHz for long-range communication (up to 15 km) and provides ultra-low power consumption with a battery life of up to 15 years. LoRaWAN is a LoRa-based network communication protocol used for communication between nodes and gateways, where the range is from a few meters to more than 100 km. These technologies have become widespread in the internet of things (IoT) due to their long range and resistance to interference [41], [42], [46]. Studies [47]–[49] examine the possibility of using LoRa and LoRaWAN technologies for real-time environmental telemetry. As a result of the review of the above-mentioned data transmission technologies, an experiment was planned and organized in laboratory conditions to deploy a monitoring system on a prototype drilling rig, which is shown in Figure 1.

Figure 1. Prototype of rotary drilling rig

The following sensors were used to monitor the drilling process: i) Rotation speed sensor (encoder); ii) Vibration sensor (accelerometer); and iii) Temperature sensor (thermocouple). The following technologies were tested: i) ZigBee (XBee S2C); ii) Bluetooth (HC-06); iii) LoRaWAN (RN2483); iv) NB-IoT (BC95).

The sensors were mounted on a prototype drilling rig and transmitted data to a personal computer at a distance of 10-15 meters. First, all sensors were tested in a static mode without interference, then under normal drilling rig operation conditions and at extreme values. As a result of the experiment, all telecommunication technologies successfully coped with their task and demonstrated high resistance to interference from a working laboratory drilling rig and can be recommended for use as data transmission channels at real objects. For short distances, Bluetooth or ZigBee are better suited, and for remote monitoring: LoRaWAN or NB-IoT.

Also, an attempt to transmit data using PLC technology using two BL6810 modems was made on a sample of a load-carrying cable, an analogue of which is used on a drilling rig in the Arctic. There was a PLC controller and a computer on both ends of the cable. During the experiment, it was possible to successfully send and receive a signal via the power cable. In the future, it is planned to conduct tests under interference conditions created by the generator.

4. RESULTS AND DISCUSSION

Each of the above-mentioned technologies has its own unique features and can be used in the electrical complex of a drilling rig depending on the specifics of the tasks. For example, it is possible to deploy a wireless sensor network, take readings from devices of the electrical complex and transmit them to the operator's console using Bluetooth or ZigBee technologies or to a control centre, which can be located far from the drilling rig, using NB-IoT or LoRaWAN technologies. Transmission of information over power lines (PLC) [25] will also be effective, because it is suitable for transmitting data over an existing power grid, and this is "one of the best options for a compromise between costs and benefits when implementing smart grids in industrial settings" [26]. PLC technology can also be used to receive data from a drilling tool, transmitting information over a load-carrying cable. By combining data transmission technologies, it is possible to develop an effective system for monitoring and diagnosing a drilling rig complex, which can be controlled both on-site and remotely. Further studies are planned to test the effectiveness of the standards under additional generator interference and in real-world conditions on an Arctic drilling rig.

In order to process a large volume of data received from various sensors via communication channels and promptly respond to changes occurring during the drilling process, artificial intelligence can be introduced into the system. Thus, the papers [50]–[52] study the introduction of machine learning to improve drilling efficiency. The publication [53] presents a workflow using artificial intelligence, the algorithms of which allow increasing the average penetration rate by 43% and increasing resistance to twisting. The authors [54] also developed an algorithm for "machine learning, which, based on the available "clean" input data associated with specific conditions, could correlate, process and select parameters obtained from the drilling rig and use them for further evaluation of various characteristics of rocks, predicting optimal parameters" [54], and also "to predict disturbances in the well without stopping it" [55], [56]. All this is necessary to create an effective control and diagnostic system in accordance with the criteria of minimizing the costs of time and material resources [57].

5. CONCLUSION

Data transmission plays a key role in automatic control and diagnostics systems, as it ensures reliable and stable operation of equipment and devices. Without a good communication channel, such systems may face various problems, such as data loss, delays in information transmission and a decrease in overall productivity. This article reviewed modern data transmission technologies. The most suitable ones for use in control and diagnostics systems of the electrical complex of a drilling rig were analyzed and proposed. Among them, Bluetooth, ZigBee, NB-IoT, and LoRaWAN stand out, which ideally meet the requirements of reliability and efficiency, especially in difficult drilling conditions. These technologies not only provide stable communication, but also eliminate the need for laying additional wires, which greatly simplifies their implementation. In addition, PLC technology was proposed both for telemetry on the surface, between the nodes of the electrical drilling rig, and for organizing communication with the bottomhole. It is a promising solution for use in drilling systems but requires additional research on the reliability of use in interference conditions. It is also proposed to use machine learning to analyze and process large volumes of data obtained from various devices that control the parameters of the drilling process.

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Irina Rastvorova	✓	✓		✓	✓	✓		✓		✓		✓	✓	
Sergei Trufanov		✓	✓			✓		✓	✓	✓	✓			

C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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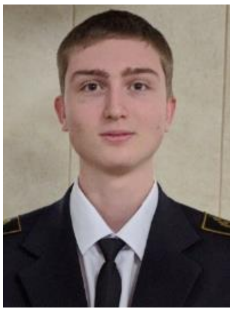
BIOGRAPHIES OF AUTHORS

Irina Rastvorova Saint Petersburg Electrotechnical University "LETI" named after V.I. Ulyanov (Lenin) (ETU "LETI"): 1994-1998 - postgraduate study; 1999-2000 - junior research fellow of the department of electrical engineering and converter technology. State Educational Institution of Higher Professional Education North-West Correspondence Technical University "NWTU": 2000-2008 - associate professor of the department of industrial electronics; 2008-2011 head of the department of industrial electronics. Saint Petersburg Mining University: 2011-2016 - associate professor of the department of electronic systems, deputy head of the department; 2016 - present - head of the department of electronic systems. She can be contacted at email: rastvorova@mail.ru.



Sergey Trufanov is a postgraduate student at the department of electronic systems at Saint Petersburg Mining University. His main areas of research are electronics, electrical engineering and automation systems for electrical engineering complexes. He can be reached at sergeitrufanov73@mail.ru.