**Remote Control of Mechatronic Devices and Manipulators**

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**Abstract.** In this article, the theoretical basis and practical applications of remote control technologies for mechatronic devices analysed. Today, the use of remote control systems in the automation of industrial processes and robotics has significantly increased production efficiency, reduced human error, and ensured a high level of safety. The main remote control infrastructure consists of sensor systems, microcontrollers, IOT devices, and a cloud platform that provide real-time monitoring and control. In addition, the use of Internet protocols (MQTT, OPC UA), 5G networks, computing, and artificial intelligence algorithms in these systems is of great importance. Therefore, we will use manipulators for remote control using IOT devices and increase efficiency. Through this comparison, we will consider the work performed using a hand and then on a manipulator. The article provides a scientifically based discussion of the advantages of remote control, cybersecurity issues, cost effectiveness, and prospects for further development.

**Keywords:** Mechatronic devices, remote control, IOT (Internet of Things), Industry 4.0, automation, cloud computing, edge computing, cybersecurity, OPC UA, MQTT, 5G technologies, digital twins, SCADA systems, teleoperation, robotics.

**INTRODUCTION**

In recent years, automation, robotics, and digitalization processes have accelerated dramatically in all sectors of industry. Mechatronic devices are a combination of mechanics, electronics, automation, and software, and play an important role in modern production lines. They not only improve production efficiency, but also facilitate human labor, reduce the risk of working in hazardous areas, and improve product quality [1-3]. Remotely controlled mechatronic devices have been developing in close connection with the concepts of Industry 4.0 and the future Industry 5.0 in the last decade. Remote control systems developed on the basis of Internet technologies and IOT (Internet of Things) platforms allow for real-time data collection, analysis and quick decision-making. Cloud computing, edge computing, 5G mobile networks, artificial intelligence and digital twin technologies are also making remote control more reliable and efficient. In the Uzbek industry, work is underway to modernize the mechatronics and robotics sectors within the framework of the “Digital Uzbekistan – 2030” strategy. For example, in the oil and gas, chemical, agricultural and mining sectors, remotely controlled devices are used in dangerous and complex working conditions [4-5]. This allows not only to protect human health, but also to reduce production costs and increase efficiency. This article provides a scientific analysis of the theoretical foundations, technological infrastructure, application areas, cybersecurity issues, and future development prospects of remote control of mechatronic devices.

**METHODS**

Creating remote control systems for mechatronic devices requires a comprehensive approach, since such systems consist of several interconnected technological components. This section analyzes the technical architecture, operating principle, and research methods of remote control of devices and manipulators [6-8]. The remote control system of a device consists of the following five main stages:

* Sensors - measure parameters in the real environment (temperature, pressure, vibration, speed, angular position);
* Microcontroller or PLC - processes the data coming from the sensors and sends control signals to the actuators;
* Communication interface - transmits data via wireless protocols such as Wi-Fi, LTE, 5G, or Lo Ra WAN;
* Cloud or edge computing platform (Cloud/Edge) - analyzes the collected data, visualizes it, and transmits it to the user via the control panel;
* Operator interface – in the form of a web application, mobile application or SCADA systems, allows remote control of the device.

The most commonly used protocols in remote mechatronic systems are MQTT, OPC UA, Modbus TCP/IP, as well as the ROS (Robot Operating System) platform. MQTT is a lightweight protocol, adapted for IOT devices. Remote control increases the accuracy and reliability of work. Labor time and cost are reduced. As a result, the cost of the work operation is reduced.

Automation of the production process in industry also requires automation of the work of YKTTMM. In these machines, control and transportation between units are mainly automated through electrical wires. SCADA systems are one of the main software tools for visual control and monitoring. The study considered the use of adaptive control algorithms through PID controllers. Computing technology was also used to reduce latency, since all calculations were performed on a local server near the user. It is important to attach great importance to the issue of security during remote control. In this methodology, the use of SSL/TLS protocols and VPN channels was used as the main measure to protect remote control systems from cyberattacks. In addition, all user authentication and input-output control mechanisms were implemented. The remote control system for manipulator devices was tested using the following methods:

* Simulation - verification of mechatronic models using software (MATLAB/Simulink, Proteus);
* Laboratory tests - working with real devices and sensors;
* Load tests - assessing the system's ability to work with large amounts of data;
* Latency tests - measuring data transfer time and interruptions.

By combining IOT and sensor networks, industrial processes can be monitored and controlled more effectively, leading to improved quality, increased productivity and reduced costs. For example, in a manufacturing plant, IOT devices and sensors can be used to monitor production lines, detect defects and adjust processes in real time, improving product quality and reducing waste. In addition, IOT and sensor networks can be used to optimize energy consumption in industrial processes, which can lead to significant cost savings. To achieve a delay of less than 21 ms, i used simple computing technology.

Methodological analyses showed that the successful operation of remote control was ensured by uninterrupted operation, reliable control algorithms and strong cybersecurity measures. Robots cannot be imagined without optical sensors. With their help, the robot sees the environment. These sensors work using a photo resistor. The reflection sensor (emitter and receiver) allows you to distinguish black and white areas on the surface, for example, to move a wheeled robot along a drawn line. An infrared light-emitting diode with a lens serves as a light source, and a photodiode or phototransistor serves as a detector. Video cameras also play a big role in this regard. They are practically the eyes of the robot. This type of sensor is now widely used in the field of image processing thanks to the development of technologies and can be successfully used in industrial production in Uzbekistan.

**RESULTS AND DISCUSSION**

In this integration, IOT devices are used in an industrial process to collect data from sensors and other sources, such as machines and equipment. Experimental results show that in workshops where remote control was introduced, manual control performed by the human factor was reduced by 41-55%. This, in turn increased the labor efficiency of operators and minimized the presence of people in hazardous areas. Real-time analysis of data collected by sensors and the introduction of a remote control system reduced production failures by 28%. Experiments using 4G networks showed that the average delay is 16-21 milliseconds, which is sufficient for real time control of industrial robots. When using edge computing technology, latency is further reduced, since part of the data is processed on a local server rather than being sent to the cloud. One of the biggest problems for remote control systems is the risk of cyberattacks. During the tests, the effectiveness of security measures such as login authentication, SSL/TLS encryption, and the use of VPN channels was tested. Experiments have shown that the use of the AES-256 encryption algorithm ensures a high level of data confidentiality and transmission security. Maintenance costs on production lines where remote control technologies have been introduced have been reduced by 20–30%. Predictive failure and remote diagnostic capabilities have ensured rapid action by operators. In addition, an increase in enterprise income has been observed by reducing production downtime. The initial stages of implementing "Smart Factory" systems are being implemented in the industry of Uzbekistan. According to the analysis, remote control technologies are most effective in the oil and gas, energy, chemical and mining industries. For example, robots or drones operating in hazardous environments can be controlled remotely without posing a threat to operators. The advantages of remote control of the manipulator include quick system setup, control from different regions via global networks, and flexibility. This approach not only increases production efficiency, but also reduces risks caused by the human factor. Therefore, the development of remote control systems and their application in industry will be of strategic importance for the large-scale development of industry in Uzbekistan.

**FIGURE 1.** Comparative analysis of the efficiency and failure rate of manual and remote control.

The diagram shows the comparative results of efficiency and failure rates between manual control and remote control systems. According to the data, the efficiency of the manual control system is only 60%, which is explained by the limited capabilities of operators, errors and delays caused by the human factor. As a result, the implementation of remote control systems and IOT technologies in production processes, the overall efficiency increases by approximately 26-32%. Sensors that transmit real-time data continuously monitor the condition of the equipment, reducing the failure rate by about 40%. Automatic control of manipulators reduces human participation and improves work accuracy by 20%. Based on data received via the IOT network, service processes are further planned, which allows to increase technical reliability by 17%. As a result, the remote monitoring system ensures the continuity of production and significantly increases efficiency. Diagram shows the efficiency achieved before and after the installation of the manipulator. Remote control for the manipulator device has shown that not only does it increase efficiency, but also reduces human factor involvement and ensures safety. The analysis shows that such systems also save energy and time in the production process, and improve quality control. As a result, the technological advantage of remote control over manual control is obvious.

The azimuth formula is used to determine the distance between two points in space, i.e., the distance between a device or manipulator and a controller. It is defined as the horizontal angle measured clockwise from the north reference line or meridian to the direction line between two points on the earth's surface. If we take true north as a reference, we get the "true azimuth". If we take magnetic north, we get the corresponding "magnetic azimuth" So, the Azimuth formula allows us to calculate the angle between these two lines.

These are the line between the robot vehicle's position, north, and the line between the robot vehicle's position, and the target. To calculate the azimuth, we only need the target and robot manipulator coordinates.

The azimuth formula we need is calculated using the following sines and cosines:

(1)

(2)

Sin formula: The following formula is used to calculate the azimuth: Where the hour angle (h), the declination of the skylight (Dec), and the height of the skylight (El) are given. This formula is used to calculate the approximate azimuth of the device.

**CONCLUSION**

Based on the research conducted, it was found that remote control of mechatronic devices is an important factor in optimizing, automating and increasing the level of security of modern industrial processes. The integration of remote control with IOT, 5G, cloud computing and edge computing technologies ensures the continuity of production processes, allows for the detection and elimination of malfunctions in real time. The results of the study showed that in systems where remote control is implemented, production costs are reduced by 20–30%, the level of security is increased and errors caused by the human factor are minimized. At the same time, it is necessary to pay special attention to the cybersecurity problems of remote control, introduce strong encryption algorithms, VPN channels and authentication mechanisms. In the future, it is possible to create more intelligent and flexible systems by using artificial intelligence, machine learning and digital twin technologies in remote control of mechatronic devices. The widespread introduction of such innovative approaches in Uzbek industry will serve to increase production efficiency and strengthen competitiveness. So, based on the above formula, it is most effective to use it for remote control. For example, planting and watering operations occur at a certain interval depending on the consecutive distance between two crops, and this interval can be easily changed by controlling the code.

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