ABSTRACT

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"Development of a distributed autonomous wireless Wi-Fi system for monitoring the technical condition of bridge structures and buildings" thesis, submitted for Doctor of Philosophy (PhD) degree
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The research topicality. With the development of communication and intelligent automation and telecommunication systems and the improvement of analog and digital electronics and measuring systems, additional conditions and opportunities appear for the development of systems for continuous remote monitoring of objects such as bridges or buildings. Improvement of autonomous systems for technical monitoring of load-bearing structures of building objects or bridge structures is associated with the need to use new measuring sensors and devices for wireless transmission of information. Due to the fact that an important basis for the well-being of modern society today is a widespread, safe, high-quality and affordable broadband network, and the development of information and communication infrastructure is one of the most important areas of economic development of the Republic of Kazakhstan, these sensors and system devices should have an increased accuracy, noise immunity and compatibility, and data transmission must be carried out over a large radius at high speed.

An important element of any system of technical diagnostics of building objects or bridge structures is their continuous monitoring, which is based on measuring the stress-strain parameters of load-bearing structures, as well as determining the level of their main parameters. An integral part of technical diagnostics systems is a data collection subsystem, i.e., a subsystem for transmitting measured data to a single information center. A necessary condition for the efficiency of functioning of distributed systems of technical diagnostics with a large number of sensors is the possibility of wireless transmission of the received data.

Evaluating the results of research and development of many domestic and foreign manufacturers and scientists, it can be noted that the existing monitoring systems do not fully meet modern requirements for information transmission subsystems, for example, such as: ", optimization of power consumption of wireless information transmission systems, the presence of algorithms for discrete transmission of streaming data, providing, on the one hand, the requirement for the quality of transmitted information, and, on the other hand, minimization of the size of packet data. In this regard, one of the main tasks in creating an effective distributed monitoring system is the choice of a method and development of a device for wireless transmission of information from measuring sensors to a computer center (server) for data collection.

When choosing a means of data transmission, it is necessary to take into account the fact that the main difference between systems for continuous monitoring of bridge structures and building buildings is the large linear length of the

measurement object, which limits the use of cables connecting the sensors, both for reasons of economy and for technical characteristics. In addition, measuring systems for continuous monitoring of bridge structures and construction buildings must operate in the open air, in conditions of large temperature differences, high humidity, and atmospheric precipitation.

The use of a distributed wireless system will reduce financial costs for carrying out various measures to correct deficiencies by correctly determining the location, angle of inclination, vibration indicators, the effect of temperature and the type of necessary repair measures. In most cases, the measuring devices in these distribution systems are various sensors that measure parameters in strict accordance with data identification and tracking technologies.

Sending data wirelessly will provide the user with the ability to remotely monitor the object under study. In this case, high speed, data transmission integrity and a large radius of coverage for the transmission of measurement results are ensured. As a result, an increase in the service life of the device and an increase in the accuracy, information content and quality of forecasting the state of bridge structures and buildings are achieved. The low cost of the connected devices and their availability of programming does not impair the reliability of the entire system, which increases the advantages of the developed wireless system. The practical implementation of such a distribution system will allow in the future to use it not only in construction, but also in other communication systems, in bridge structures of the railway and highways, "smart" technologies and other areas (for example: agriculture, ecology, energy, health care, meteorology).

The research aim is to develop a distributed autonomous wireless Wi-Fi system for remote monitoring of the technical condition of bridge structures and buildings with a high data rate, long range and support for multiple access with carrier listening and collision avoidance.

The research objectives:

– analysis of research and technical solutions in the field of monitoring the condition of building buildings and bridge structures;

– reasonable selection of the wireless technology standard;

– selection of devices for a distributed wireless Wi-Fi system, their programming and configuration;

– the use of experiment planning technology to study the processes of receiving and transmitting Wi-Fi signals in the system under study;

– ensuring the integrity and reliability of information transmitted data and adapting the system for monitoring in other areas;

– development of a structural, functional diagram of the system, an operation algorithm and a mathematical model of a distributed wireless system;

– development of a computer model of the system to determine the optimal data transfer rate in a wireless system;

– mathematical processing of research results.

The research object – bridge structures and construction buildings.

The research subject – processes of control, diagnostics and remote monitoring of technical condition; processes of collecting, processing and displaying information.

The research methods.

In the course of dissertation research, proven methods for processing and analyzing measurement information, methods for remote identification of measurements, methods for creating software and hardware systems based on microcontrollers and methods of computer modeling were used. In addition, laboratory tests were carried out to monitor the technical condition of building structures during their operation.

The scientific novelty lies in the following provisions and results:

– a new approach is proposed based on the developed data transmission algorithm for remote monitoring of the technical condition of building buildings and bridge structures;

– a new distributed wireless monitoring system has been developed for high-speed data transmission over a long distance with remote technical control of emergency structures;

– new experimental results were obtained and the necessary parameters were selected to obtain optimal data;

– proposed original circuitry and software solutions that ensure the minimum power consumption of the autonomous transmitting part of the systems;

– an original computer model of a wireless channel is proposed, which describes the data transmission rate in the developed distributed system.

The practical significance.

The introduction of new additional units in order to increase the service life of the device and improve the accuracy, information content and quality of the technical condition forecast.

Simple programming of devices and their compatibility of all transmitting and receiving elements.

Relatively low price in comparison with existing similar systems.

Three-step security of access to research results.

A wide range of methods for processing the results obtained.

Thesis provisions to be defended:

– a method for planning experiments based on the theory of mathematical and statistical data processing;

– qualitative characteristics of the wireless Wi-Fi channel to ensure the reliability of the transmitted monitoring results;

– an algorithm for a distributed autonomous wireless Wi-Fi system based on the provisions of the theory of identification measurements and statistical data processing;

– A new approach based on the developed data transmission algorithm for remote monitoring of the technical condition of construction buildings and bridge structures.

– the structure of a distributed autonomous wireless technical condition monitoring system of bridge structures and buildings.

The approbation of results. The main results of the dissertation research were reported and discussed at: the international scientific and practical conference "Kozybayev Readings-2018: Eurasian Potential and New Opportunities for the Development of the Regions of Kazakhstan and Russia in the Context of Global Challenges" (Petropavlovsk, 2018); International scientific and practical conference "Scientific research - 2018" (Karlovy Vary - Moscow, 2018); The International Scientific and Practical Conference "Integration of Science, Education and Industry - the Basis for the Implementation of the Plan of the Nation" (Karaganda, 2019); VIII International Scientific Conferences "Engineering Sciences in Russia and Abroad" (Krasnodar, 2019).

Publications. The main results of the study were reflected in a number of scientific works, including 3 articles published in publications recommended by the Committee for Control in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan, in 1 article - in an international scientific journal with a non-zero impact factor (indexed in Scopus database), in 4 works reflected in the proceedings of international scientific conferences, including 2 in foreign ones, as well as in 1 patent.

The personal contribution of the author.

The main results of theoretical and experimental research were obtained by the author independently. In printed works that are co-authored, the applicant plays a leading role in the generalization and analysis of the results.

The structure of the thesis.

The dissertation has a classical structure: introductory part, main part (four chapters), conclusion, list of sources used. The work is presented on 103 pages of computer text, includes 69 figures, 9 tables and 73 titles of bibliographic sources.

The research results.

The object of research is bridge structures and construction buildings. Based on the results of the review and analysis of monitoring systems, their shortcomings were identified, due to the difficulties of implementation or difficulties in the development, configuration and implementation in the Republic of Kazakhstan. In order to eliminate the identified shortcomings, a new approach has been developed for the development of distributed autonomous wireless technical condition monitoring system, based on an algorithm and a structural diagram. The comparison of existing wireless technologies is made and the choice of the 802.11 standard - Wi-Fi as the main data transmission technology in the distributed autonomous wireless technical condition monitoring system of bridge structures and building buildings is substantiated. The key characteristics of Wi-Fi technology are analyzed to ensure the safety and integrity of the transmitted measurement results.

On the basis of the created mathematical model, a software environment for computer modeling was selected, a computer model was created, which is necessary to establish the optimal parameters of a wireless channel, providing a high data transfer rate with minimal packet loss.

The configuration and programming of all elements of the structural diagram of the distributed autonomous wireless technical condition monitoring system of bridge structures and building buildings was carried out in the Arduino Ide software environment, if it is necessary to expand additional functions, it is possible to change the programming language. The selected sensors, receiving and transmitting modules have a number of virtues, such as ease of programming, obtaining accurate values, small footprint, ease of replacing sensors, remote configuration, and so on.

The practical implementation and approbation of the system was carried out in several stages, in the initial measurements, the wireless channel was checked, the compatibility of the connected sensors with Wi-Fi modules and their connection, the server selected for the dissertation research was configured and the transmitted values were checked at the initial stage of testing. Next, the calculation of the required number of experiments was carried out to check the reliability of the system. After 50 experiments were carried out, the results were exported from the server to Microsoft Excel and the following parameters were calculated: mathematical expectation, variance, confidence interval. According to the results of the calculations, the observed values were determined to compare them with the critical values according to the Fisher distribution. The calculation results proved the reliability of the system and its transmitted data by 98%.

Summing up the results of the research, the following provisions can be highlighted:

– received and systematized the results of studies, operating modes and technical solutions for remote monitoring of the technical condition of building buildings and bridge structures;

– selected, programmed and configured compatible devices when developing a distributed wireless Wi-Fi system;

– the method of planning experiments was chosen and the modeling of the process under study was carried out;

– ensured the integrity and reliability of information transmitted data and created conditions for adapting the system for monitoring in other areas;

– a computer model of the system has been developed, in which the optimal data transfer rate in the wireless system is determined;

– the structural and functional diagram of the system, the algorithm of operation and the mathematical model of the distributed wireless system have been developed.

Works published on the thesis subject.

1. Ивель В.П., Герасимова Ю.В., Калиаскаров Н.Б. Обзор распределенной беспроводной системы сбора и передачи аналоговых данных // Материалы международной научно-практической конференции «Козыбаевские чтения-2018: Евразийский потенциал и новые возможности развития регионов Казахстана и России в условиях глобальных вызовов», – Казахстан: Петропавловск, 2018.– С.243-248..

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мониторинга технического состояния мостов // Материалы IV Международной научно-практической конференций «Scientific research – 2018», – Чехия: Карловы Вары-Россия:Москва, 2018.– С.138-143.

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5. Пат. 3860 РК, МПК E04G 23/00, G01B 11/00. Беспроводное устройство мониторинга состояния трещин и стыков зданий и сооружений / Калиаскаров Н.Б., Герасимова Ю.В., Ивель В.П., Есенжолов У.С., Югай В.В., Мехтиев А.Д.; опубл.08.04.2019, Бюл.№15. – 4 с.

6. Ивель В.П., Разинкин В.П., Калиаскаров Н.Б. Разработка беспроводного устройства мониторинга состояния трещин и стыков зданий и сооружений, и его преимущества. // Вестник КазАТК, Алматы, 2019. – №2, – С.10-17.

7. Калиаскаров Н.Б., Ивель В.П., Герасимова Ю.В., Петров П.А., Югай В.В. Использование технологии WI-FI для сбора и передачи данных температуры и влажности. // Вестник ПГУ. Серия Энергетика, Павлодар, 2020. – №4, – С.215-227.

8. Калиаскаров Н.Б., Ивель В.П., Югай В.В., Петров П.А. Измерение температуры и влажности на основе двухпроцессорной Wi-Fi системы. // Вестник АУЭС, Алматы, 2020. – №4 (51), – С.60-69.

9. Kaliaskarov N.B., Ivel V.P., Yugay V.V., Gerasimova Y.V., Moldakhmetov S.S. Development of a distributed wireless Wi-Fi system for monitoring the technical condition of remote objects // Eastern-European Journal of Enterprise Technologies. – 2020, Vol.5 №9 (107). – P. 36–48.