



DEVELOPMENT OF AN INFORMATION SYSTEM FOR REAL-TIME MONITORING OF RAILWAY INFRASTRUCTURE BASED ON IOT AND SENSOR NETWORKS.

*Islomov Diyorbek Zafar o'g'li, teacher, Orcid ID: 0009-0009-2982-8630,
diyorbekshaxrisabz@gmail.com,*

Botirova Zarnigor, Muhammadiyev Dilshod, Hasanov Eldor,

Usmonov Arobiddin, students,

University of Economics and Pedagogy, Karshi, Uzbekistan

Annotation. *This article investigates the architecture, components, and effectiveness of a real-time railway infrastructure monitoring information system based on IoT sensor networks. The study proposes a sensor network for monitoring rail condition, bridge vibrations, switch positions, and environmental parameters using the Karshi—Termez section of the Uzbekistan railway system as a case study. The system architecture consists of three layers: sensor layer (LoRaWAN and NB-IoT), Edge Computing layer, and cloud analytics layer. Experimental results demonstrate that the proposed system can detect faults an average of 72 hours earlier than traditional inspection methods. The economic efficiency of the system is projected to reduce maintenance costs by 34%.*

Keywords: *IoT, sensor networks, railway infrastructure, real-time monitoring, predictive maintenance, Edge Computing, LoRaWAN, NB-IoT, Uzbekistan railways.*

Аннотация. *В данной статье исследуются архитектура, компоненты и эффективность информационной системы мониторинга железнодорожной инфраструктуры в режиме реального времени на основе сенсорных сетей IoT. В исследовании предлагается сенсорная сеть для мониторинга состояния рельсов, вибраций мостов, положения стрелок и параметров окружающей среды на примере участка Карши—Термез узбекской железной дороги. Архитектура системы состоит из трех уровней: сенсорного уровня*



(LoRaWAN и NB-IoT), уровня граничных вычислений и уровня облачной аналитики. Экспериментальные результаты показывают, что предложенная система может обнаруживать неисправности в среднем на 72 часа раньше, чем традиционные методы инспекции. Прогнозируется, что экономическая эффективность системы позволит снизить затраты на техническое обслуживание на 34%.

Ключевые слова: IoT, сенсорные сети, железнодорожная инфраструктура, мониторинг в режиме реального времени, предиктивное техническое обслуживание, граничные вычисления, LoRaWAN, NB-IoT, узбекская железная дорога.

Annotatsiya. Ushbu maqolada temiryo'l infratuzilmasini IoT (Internet of Things) sensorlar tarmog'i asosida real vaqtda monitoring qilish axborot tizimining arxitekturasi, komponentlari va samaradorligi tadqiq etilgan. Tadqiqotda O'zbekiston temiryo'l tizimining Qarshi—Termiz uchastkasi misolida rels holati, ko'priklar vibratsiyalari, strelka pozitsiyalari va atrof-muhit parametrlarini kuzatuvchi sensorlar tarmog'i taklif etilgan. Tizim arxitekturasi uch qatlamdan iborat: sensorlar qatlami (LoRaWAN va NB-IoT), chegaraviy hisoblash (Edge Computing) qatlami va bulutli analitika qatlami. Tajriba natijalari shuni ko'rsatdiki, taklif etilgan tizim nosozliklarni an'anaviy tekshirish usullariga nisbatan o'rtacha 72 soat oldin aniqlash imkonini beradi. Tizimning iqtisodiy samaradorligi ta'mirlash xarajatlarini 34% ga kamaytirishi prognoz qilingan.

Kalit so'zlar: IoT, sensorlar tarmog'i, temiryo'l infratuzilmasi, real vaqtda monitoring, predictive maintenance, Edge Computing, LoRaWAN, NB-IoT, O'zbekiston temir yo'llari.

INTRODUCTION

Reliable and safe operation of railway infrastructure is a key condition for ensuring the stability of the transport system. The railway network of Uzbekistan is more than 6700 km long and is located in various climatic conditions (desert, mountainous, plain). Infrastructure elements — rails, sleepers, bridges, tunnels, switches and signaling systems — require constant monitoring [1, 2].



Traditional infrastructure inspection methods (visual inspection, periodic measurement, laboratory diagnostics) have a number of disadvantages: failure to detect faults that occur between inspections in a timely manner, high labor costs and the use of technical means. Therefore, railway companies around the world are implementing continuous monitoring systems based on IoT sensors [3, 4].

Network Rail (Great Britain) has successfully implemented a system for early detection of rail, signal and contact network faults by integrating IoT sensors with artificial intelligence [5]. Union Pacific (USA) has prevented derailments by monitoring locomotive engines and wheel bearings using smart sensors and AI [5]. SNCF (France) has launched a system for inspecting roads, bridges, and tunnels using drones and AI cameras [5].

The Uzbek railway system is undergoing rapid digitalization: an intelligent information system for identifying wagon and container numbers through smart video surveillance has been introduced, and an online train movement monitoring system has been created [6]. However, a system for continuous monitoring of infrastructure elements based on IoT sensors has not yet been fully developed.

Development of an information system architecture based on an IoT sensor network for real-time monitoring of the railway infrastructure of Uzbekistan and experimental evaluation of its effectiveness.

Research objectives: (1) design a sensor system for monitoring the railway infrastructure; (2) development of an architecture for data collection, transmission and analysis; (3) proposal of predictive maintenance algorithms and evaluation of their effectiveness.

Research object and territorial scope. The Karshi-Termez section of the Uzbek railway network (length 325 km) was selected as the research object. The reasons for choosing this section are: difficult geographical conditions (plain and mountainous areas), the presence of 3 bridges and 2 tunnels, a mixture of electrified and non-electrified sections, and active traffic of freight and passenger trains.

System architecture. The proposed monitoring system is based on a three-layer architecture:



Table 1. Layers of the monitoring system architecture

T/r	Layer Name	Main Components	Function
1	Sensor layer (Perception Layer)	Accelerometers, deformation sensors, temperature sensors, GPS modules, humidity sensors	Measurement of physical parameters of infrastructure elements and conversion into digital signals
2	Edge computing layer (Edge Layer)	Edge gateway devices, LoRaWAN/NB-IoT modems, local server.	Initial data processing, filtering, rapid detection of anomalies and transmission to the cloud
3	Cloud analytics layer (Cloud Layer).	Cloud server, ML models, DBMS, dashboard, warning system.	Data storage, deep analysis, forecasting, reporting and real-time information delivery to dispatchers.

Sensor system. Five types of sensors were used in the study:

Table 2. Sensors used in the monitoring system

T/r	Sensor type	Measured parameter	Installation	Measurement frequency
1	Accelerometer (S)	vibration amplitude.	Rails, bridges	100 Hz
2	Strain Gauge	Rail elongation, bending	Rail base	10 Hz
3	DS18B20	Rail temperature, ambient temperature	Rail head, element	1 Hz
4	Tilt Sensor	Tilt sensor	Pointer mechanism	5 Hz



5	DHT22	Soil moisture, air ty.	Bridge tion, tunnel	0,1 Hz
---	-------	------------------------	---------------------	--------

Sensors are installed at a point every 500 meters, and a total of 650 sensor nodes are designed. Each node consists of a microcontroller (ESP32 or STM32), sensor modules, LoRaWAN/NB-IoT modem and a solar panel power source. The sensor network uses a star topology architecture as a network topology.

Data transmission technologies. Two wireless technologies are used in parallel to transmit data from sensors to the edge server: LoRaWAN (Long Range Wide Area Network) - for low power consumption and long range (up to 15 km), used to transmit environmental and slowly changing parameters; NB-IoT (Narrowband IoT) - for faster and more reliable transmission over the cellular network, used for fast data such as vibration and deformation.

Predictive maintenance algorithm. The predictive maintenance algorithm works in two stages. The first stage is anomaly detection: The Isolation Forest algorithm detects abnormal changes in sensor data in real time. The second stage is failure prediction: The trained Gradient Boosting Regressor model predicts the time of failure based on the detected anomalies. The model is trained on historical failure data collected during 2022-2023 (478 recorded failure cases).

Evaluation methodology. A 6-month experimental period (July 2024 - December 2024) was set to evaluate the system's effectiveness. The following indicators were measured: early failure detection time (hours earlier than the traditional method), false positive rate, system reliability (uptime), energy consumption, and economic efficiency (change in repair costs).

RESULTS

Early Failure Detection Results

During the 6-month pilot period, the system detected a total of 47 infrastructure failures. Of these, 41 (87.2%) were confirmed as true failures, while 6 (12.8%) were found to be false positives.

Table 3. Fault detection results by infrastructure type



Infrastructure type	Number of failures.	Average. Early detection (hours).	Earliest detection (hours).	False positive
Rail crack/deformation	18	84	142	2
Bridge vibration anomaly	7	96	168	1
Point failure.	11	48	96	2
Temperature-dependent expansion	5	36	72	1
Total / Average	41	72	168	6

As can be seen from Table 3, the system detected faults on average 72 hours (3 days) in advance. The highest early detection rate was observed for bridge vibration anomalies — 168 hours (7 days), which is explained by the gradual development of changes in the bridge structure.

System reliability and energy consumption

Table 4. System specifications.

Indicator	Value
System reliability (Uptime)	98,7%
Data transmission success rate	96,3%
Average battery life of the sensor node	14 oy (with solar panel)
Average data latency	2,4 seconds (LoRaWAN), 0,8 seconds (NB-IoT)
Daily data volume (650 nodes)	1,2 GB
Anomaly detection accuracy (Precision)	87,2%



False positive rate	12,8%
---------------------	-------

Economic efficiency. Out of 41 faults detected early during the trial period, 28 were eliminated during planned repairs, which reduced the need for emergency repairs by 68%. Considering that emergency repairs are on average 3.2 times more expensive than planned repairs, the economic efficiency of the system allowed to reduce repair costs by 34%. In addition, the time of train traffic downtime was reduced by 41%.

DISCUSSION

The results of the study confirm the high efficiency of the IoT sensor network in monitoring the railway infrastructure. The average fault detection rate of 72 hours in advance is consistent with international experience - the Network Rail system allows for early detection in the range of 48–96 hours, and Union Pacific in the range of 72–120 hours [5].

The parallel use of LoRaWAN and NB-IoT technologies significantly increased the reliability of the system. While LoRaWAN was effective for long-range, low-power transmission, NB-IoT was advantageous for fast and important data transmission. The hybrid approach ensured stable operation of the system under various conditions.

Deformation sensors made it possible to detect internal rail cracks up to 0.3 mm - these are micro-defects that are almost impossible to detect by visual inspection. Bridge vibration monitoring was the most effective in detecting structural problems at the earliest stage (up to 7 days in advance).

Practical significance. The proposed system can be integrated into the Unified Dispatch Center of Uzbekistan Railways and expand the “Situation Center” system. When used in conjunction with the SCADA remote control system, the system significantly increases infrastructure safety and train movement stability.

Limitations. The study is limited to one section (Karshi-Termez). In the future, it is advisable to expand the system to other sections, in particular the Angren-Pop tunnel and the high-speed Tashkent-Samarkand route. It is also expected that the



introduction of 5G technology will further increase the speed and volume of data transmission.

CONCLUSION

1. The monitoring system based on the IoT sensor network made it possible to detect faults in the railway infrastructure on average 72 hours (3 days) earlier than traditional inspection methods. The highest indicator was recorded in bridge vibration monitoring - 168 hours (7 days).

2. The hybrid application of LoRaWAN and NB-IoT technologies increased the system reliability to 98.7%. Solar panel power supply ensured autonomous operation of sensor nodes for up to 14 months.

3. The predictive maintenance algorithm (Isolation Forest + Gradient Boosting) predicted faults with an accuracy of 87.2%. The false positive rate was 12.8%, and there is a possibility of further reducing this indicator in the future.

4. The economic efficiency of the system was significant: the need for emergency repairs was reduced by 68%, total repair costs by 34%, and train downtime was reduced by 41%.

5. The proposed system can serve to digitize and increase the safety of Uzbekistan's railway infrastructure within the framework of the "Digital Uzbekistan - 2030" strategy.

REFERENCES

1. Ghofrani F. et al. Recent Applications of Big Data Analytics in Railway Transportation Systems: A Survey // Transportation Research Part C. – 2018. – Vol. 90. – P. 226–246.
2. Fumeo E. et al. Condition Monitoring of Railway Infrastructure and Rolling Stock: A Literature Review // Expert Systems with Applications. – 2015. – Vol. 42(20). – P. 7199–7214.
3. GAO Tek Inc. Railway and Infrastructure Monitoring — Predictive Maintenance IoT. – gaotek.com, 2024.
4. Neuroject. IoT in Railway: Comprehensive Guide 2024. – neuroject.com, 2024.



5. VLink Info. AI in Railways: Predictive Analytics for Maintenance. – vlinkinfo.com, 2025.
6. “O’zbekiston temir yo’llari” AJ. Raqamlashtirish va zamonaviy axborot texnologiyalarini joriy etish. – railway.uz, 2024.
7. Hatch Digital. The Future of Railway Maintenance: Optimizing Condition Monitoring and Assessment. – hatch.com, 2024.
8. MDPI. Rail Maintenance, Sensor Systems and Digitalization: A Comprehensive Review // Vehicles. – 2025. – Vol. 5(3). – P. 83.
9. OxMaint. Predictive Maintenance for Railways Infrastructure (IoT + AI). – oxmaint.com, 2026.
10. O’zbekiston Respublikasi Prezidentining 2020 yil 5 oktyabrdagi PF-6079-son Farmoni. “Raqamli O’zbekiston – 2030” strategiyasi. – lex.uz.
11. O’zbekiston temir yo’llari tarixi va rivojlanishi. – railway.uz/istoriya, 2024.
12. Бобомуродов Б. С., Исломов Д. З. ИНФОРМАЦИОННАЯ СИСТЕМА СБОРА И ВИЗУАЛИЗАЦИИ ДАННЫХ С ГЕОРАСПРЕДЕЛЁННЫХ ДАТЧИКОВ //Modern education and development. – 2026. – Т. 45. – №. 2. – С. 263-273.
13. Бобомуродов Б. С., Исломов Д. З. СИСТЕМА МОНИТОРИНГА КАЧЕСТВА ВОЗДУХА НА ОСНОВЕ РАСПРЕДЕЛЁННОЙ СЕТИ IoT-ДАТЧИКОВ AIR QUALITY MONITORING SYSTEM BASED ON A DISTRIBUTED IoT SENSOR NETWORK //Modern education and development. – 2026. – Т. 45. – №. 2. – С. 251-262.
14. Islomov D. Z. ARGO UML DASTURI YORDAMIDA AXBOROT TIZIMINI LOYIHALASHTIRISH USULLARI //Экономика и социум. – 2024. – №. 12-2 (127). – С. 367-372.
15. Zafar o'g'li I. D. et al. WEBASSEMBLY (WASM): BRAUZERDA YUQORI UNUMDORLIKKA ERISHISH VA NATIVE TEZLIKDA ISHLAYOTGAN VEB-ILOVALARNI QURISH IMKONIYATLARI //Modern education and development. – 2026. – Т. 47. – №. 4. – С. 11-18.



16. Zafar o'g'li I. D. et al. DIFFERENSIAL TENGLAMALARNI SONLI YECHISH: RUNGE-KUTTA METODLARINING TAQQOSLAMA TAHLILI VA AMALIY QO'LLANILISHI //Modern education and development. – 2026. – T. 47. – №. 4. – C. 3-10.
17. Zafar o'g'li I. D. et al. KVANT HISOBLASH VA KRIPTOGRAFIYAGA TA'SIRI: POST-KVANT KRIPTOGRAFIYASI VA MAVJUD ALGORITMLAR XAVFSIZLIGI //Ta'lim innovatsiyasi va integratsiyasi. – 2026. – T. 66. – №. 3. – C. 331-334.
18. Zafar o'g'li I. D. et al. EDGE COMPUTING VA IOT INTEGRATSIYASI: REAL-TIME MA'LUMOTLAR QAYTA ISHLASH //Ta'lim innovatsiyasi va integratsiyasi. – 2026. – T. 66. – №. 3. – C. 326-330.