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Nazarbayev Intellectual School of Physics and Mathematics in Kokshetau

**Sewer Blockage Detection and Prevention System Based on Ultrasonic Technology and AI-analysis.**

**Salavatuly Daniyar, Khairullin Aibek.**

11 grades

**Field and Section:** Applied Science Projects

**Mentor:** Zhangozy Ongarbay, physics teacher

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# **Abstract**

**The purpose of the study:** To develop a system for monitoring sewer pipes using ultrasonic sensors and Arduino to detect blockages and assess pipe conditions without causing damage.

**The hypothesis of the study:** The developed system will enable real-time detection of blockages in sewer pipes by analysing ultrasonic signal reflections. This will allow for early intervention, preventing serious damage and costly repairs. The economic accessibility of the method ensures rapid implementation and widespread use, significantly improving sewer system maintenance efficiency.

**Stages of work on the project:**

* Assessment of the problem of sewer blockages, their relevance, and impact on infrastructure
* Study of the causes of the problem
* Research of existing methods of object detection and their comparative analysis
* Determination of the most effective means of combating the problem
* Work on the creation of the system: design and assembly
* System testing
* Results. Сonclusion.

In the process of work, **the method** of empirical research was used, which includes:

* Study of scientific materials, analytical articles, statistical data;
* Experiment;
* Modeling;
* Analysis of the results of the modelling.

**The novelty of the research** lies in the development of a non-invasive, cost-effective method for monitoring sewer systems. Unlike traditional inspection techniques, the proposed system provides real-time data, allowing for proactive maintenance and reducing environmental and infrastructural risks.

**Results and conclusions:** The developed system successfully detects anomalies in sewer pipes by analysing ultrasonic signal reflections. It provides timely alerts about potential blockages, ensuring proactive maintenance. The simplicity, affordability, and effectiveness of the system make it a practical solution for urban infrastructure management.

**Scope of application:** The system is designed for use by municipal utility services, private companies maintaining sewer systems, and environmental organizations focused on water infrastructure sustainability.

# **Introduction**

**Relevance of the topic:** The rapid urbanization in Kazakhstan is putting significant pressure on sewer systems. Blockages and breakdowns have become a common issue, leading to consequences ranging from emergency situations to serious environmental problems.

**Objectives of the work:** To address this challenge, we propose a monitoring system that combines ultrasonic sensors with artificial intelligence. This system can detect potential blockages in advance, allowing municipal services to eliminate them before they cause major failures.

* Study the problems of sewer blockages, their relevance, and impact on infrastructure and causes of the problem.
* Research of existing methods of object detection and their comparative analysis.
* To determine the most effective means of combating the problem and search of solutions.
* To create the system of detection of blockages in real time: design, assembly and testing them.
* To do a conclusion and identifying its limitations
* To plan the future development of the system.

**Brief methods for solving the tasks:** clogged pipes can lead to leaks, environmental pollution, and increased maintenance costs. By integrating artificial intelligence, we can reduce operational expenses and improve the reliability of wastewater management. Our system collects real-time data and processes it using machine learning algorithms. This approach will enable cities to manage their infrastructure more efficiently, minimizing the risk of failures and extending the lifespan of sewer networks.

# **Research session**

## **Analytical Review**

Traditional maintenance methods rely on manual inspections, CCTV pipe surveys, and hydraulic cleaning. While these methods have certain advantages, they are often ineffective in preventing major failures since they depend on periodic checks rather than continuous monitoring.

Manual inspections require a significant workforce and are prone to human error. CCTV diagnostics, although useful for detecting existing blockages, demand trained specialists and regular maintenance. Pressure and flow monitoring can indicate abnormalities but fail to provide precise information on the exact location of the problem within the pipeline.

Several countries have already implemented advanced technologies to enhance sewer monitoring. For instance, Singapore has integrated Internet of Things (IoT) sensors into its drainage system, allowing real-time tracking of water flow levels and the early detection of anomalies before they escalate into severe issues. In the Netherlands, AI-driven flood prevention systems analyze water movement patterns to optimize drainage efficiency.

However, in many regions, including Kazakhstan, traditional sewer management methods still dominate, despite their limitations. This results in higher maintenance costs, increased environmental risks, and frequent emergency situations.

Given these challenges, implementing artificial intelligence and IoT technologies opens new opportunities for improving sewer monitoring. Real-time data collection via ultrasonic sensors can help detect potential blockages in their early stages, reducing response time and enhancing overall efficiency. AI models can analyze both historical and real-time data, predicting maintenance needs and minimizing the risk of unexpected failures.

Introducing such a system will not only improve operational efficiency but also significantly cut expenses and reduce environmental impact. Therefore, the development of an AI-based sewer monitoring system represents a crucial step toward modernizing urban infrastructure and enhancing public sanitation.

## **Preparation Stage**

Before developing the system, the basics of ultrasonic technology and signal processing were studied. Research was conducted on how ultrasonic sensors work, their principles of operation, and their application in detecting blockages.

Under the guidance of our physics teacher, Zhangozy Ongarbay, we explored the methods of transmitting and receiving ultrasonic signals, as well as analyzing the reflection patterns to detect anomalies in the sewer pipes.

To deepen our understanding and gain practical experience, we studied circuit designs and data processing methods. We used analyzed international journals academic papers on ultrasonic wave propagation, and technical documentation on Arduino and HC-SR04 ultrasonic sensors.

As an initial test, an ultrasonic sensor HC-SR04 was connected to an Arduino Uno, and basic signal transmission and reception experiments were conducted. (Fig. 1) The initial setup allowed us to understand how to measure distances and detect irregularities in pipe conditions.

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| *Fig 1.* An initial test, using ultrasonic sensor HC-SR04 |

The first prototype is shown in Fig 2.

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| *Fig 2.* The first prototype is shown in *Fig 1* and *Fig 2.* |

## **Research on External Factors and System Characteristics**

At this stage, we analyzed the factors influencing the detection accuracy of ultrasonic signals, such as pipe material, water flow, and potential obstructions. One of the key characteristics of the system – the detection range – was determined.

To define the optimal detection distance, we considered various pipe sizes and blockage scenarios. Experimental tests were conducted in controlled environments to determine the sensor’s accuracy in detecting partial and complete blockages.

For the system demonstration, we used Python to process real-time data from the ultrasonic sensor and display results in graphical form. In case of significant deviations from the normal signal pattern, an alert system was activated, indicating potential blockage.

## **Modelling System. Assembling the device**

The developed system consists of:

* **Hardware:** Arduino Uno, ultrasonic sensor HC-SR04, and a power supply.
* **Software:** A Python-based application that collects and processes data, visualizing the results as graphs and triggering alerts when blockages are detected.

The schematic diagram of the system is shown in Figure 1. The ultrasonic sensor sends signals into the pipe, and based on the reflection time, it calculates the distance to any obstruction. This data is then sent to the Python application for real-time monitoring and analysis.

To improve accuracy, multiple sensors were tested in different positions. The optimal configuration was determined through experimental trials, considering factors such as signal interference and reflection angles.

The system operates by continuously measuring the distance between the sensor and the inner surface of the pipe. If a sudden change in distance is detected, it may indicate a blockage or debris buildup. The Python application processes this data and displays it in the form of graphs. If any abnormal values are detected, the system immediately sends an alert, allowing maintenance teams to act before a serious issue occurs.

The **final version of the system** includes the following components:

* **Arduino Uno** – 1 piece
* **Ultrasonic sensor HC-SR04** – 1 piece
* **Power supply (9V battery or adapter)** – 1 piece
* **Jumper wires** – multiple pieces
* **Python-based software for data processing and visualization**

The sensor was positioned at different angles and distances to test its accuracy under various conditions. The system was calibrated to minimize errors caused by signal reflections and external interferences. After multiple tests, it was confirmed that the system effectively detects blockages and provides reliable data for preventive maintenance.

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| *Fig 3. T*he scheme of the first prototype |

## **Testing and Debugging**

The system was tested in various conditions, including different pipe diameters, water levels, and blockage types. The debugging process involved:

* Adjusting sensor positioning to reduce signal distortion
* Calibrating the Python application to accurately interpret ultrasonic data
* Fine-tuning threshold values for blockage detection

By refining the software algorithms, we ensured that false alarms were minimized while maintaining high sensitivity to real obstructions. The final system successfully detected blockages at an early stage, allowing timely maintenance and preventing serious sewer issues.

The results confirmed that the developed model is a cost-effective and efficient solution for sewer monitoring, with potential applications in urban infrastructure management.

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| Изображение выглядит как текст, линия, диаграмма, График  Контент, сгенерированный ИИ, может содержать ошибки. |
| *Fig 4.* Ultrasonic sensor data graph |

In *Fig 4.* is shown the initial length of the pipe (a green line graph); and analyzed pipe with a blockage, the graph that has fallen sharply (a blue line graph)

## **Economic Aspect of the Project**

The escalating challenges in sewer system management and the increasing costs associated with emergency repairs underscore the significant potential for scaling this project. As urban populations expand, municipalities worldwide are incurring higher expenses due to pipeline blockages and failures. Implementing an AI-driven sewer monitoring system offers substantial economic benefits by reducing maintenance costs and extending the lifespan of infrastructure.

To evaluate the economic and investment potential of the system, we conducted market volume research and developed a business plan based on statistical data. According to a report by Verified Market Research, the global sewer cleaning services market was valued at approximately USD 1.51 billion in 2023 and is projected to reach USD 2.50 billion by 2031, growing at a compound annual growth rate (CAGR) of 6.5%.

In the Commonwealth of Independent States (CIS) region, countries like Russia and Kazakhstan have extensive pipeline networks. Russia, for instance, has approximately 259,913 kilometers of pipelines, while Kazakhstan has about 26,963 kilometers.

This extensive infrastructure indicates a substantial market for sewer monitoring and maintenance solutions within the CIS.

Focusing on Kazakhstan, the country's rapid urbanization and industrial growth have led to increased demand for efficient wastewater management. The presence of significant pipeline infrastructure further emphasizes the need for advanced monitoring systems to prevent blockages and failures.

By optimizing maintenance schedules and predicting blockages before they occur, our system can help cities significantly reduce emergency repair costs and environmental risks. Investing in AI and IoT-based infrastructure solutions is a crucial step toward modernizing sewer networks and ensuring their sustainability for years to come.

# **Conclusion**

According to the initial goal, we have developed a detection and warning system based on ultrasonic sensing. Step-by-step work on each stage of the research led to successful results.

The designed system detects potential blockages inside pipes using an ultrasonic sensor and analyzes the data through a Python-based application with AI-algorithms. The system continuously measures the distance to the pipe’s inner surface, identifying any sudden changes that may indicate blockage. If a significant deviation from normal values is detected, the system immediately alerts the user.

The simplicity, affordability, and effectiveness of this technology, along with its potential for wider application, can greatly assist in solving issues related to pipeline maintenance. This system can contribute to environmental protection and public health by preventing serious sewage system failures.

**Key Advantages of the Developed System:**

* Simplicity and accessibility, making the project cost-effective and easy to implement.
* High detection accuracy, regardless of external conditions such as lighting or temperature.
* Early problem detection, allowing for preventive maintenance and reducing the risk of major blockages.
* Environmental and health benefits, as the system helps prevent sewage overflows and contamination.
* Potential for further development, including integration with smart city infrastructure for automated monitoring.

## **Potential Plans for Further Development:**

* Adding new sensors such as infrared emitters to enhance accuracy of detecting blockages.
* Adding a visual alert system for better accessibility.
* Improving the accuracy of blockage detection by refining signal processing techniques.
* Further developing an AI-based model to predict possible pipeline issues before they occur.
* Expanding the system to monitor multiple parameters, such as flow rate and pipe condition.
* The system has shown promising results in detecting blockages efficiently, proving its effectiveness as a practical solution for urban infrastructure maintenance.

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