A gas pipeline anti-damage early warning monitoring system

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Abstract. This paper introduces a gas pipeline anti-damage early warning monitoring system, which involves the field of pipeline detection technology. Its basic principle is to use vibration detection and sound detection technology, combined with Internet of Things sensing technology, to provide vibration amplitude monitoring and accurate positioning function for pipeline leakage or third-party sabotage occurring in underground pipeline network, and finally transmit alarm information to pipeline maintenance personnel through data analysis platform, so as to achieve the role of pipeline real-time early warning monitoring.

1. Introduction
As the largest single city gas company in China, Beijing Gas Group has a large underground gas transportation network, which is characterized by its large number, wide distribution and difficulty in supervision. When gas pipeline leaks or mistaken excavations by third parties lead to pipeline breakage, pipeline maintenance personnel often fail to detect, locate and solve problems in a timely manner, and insufficient pipeline monitoring leads to inefficient inspections by maintenance personnel, thus creating a safety hazard. Therefore, we need a feasible solution to solve the problem of gas pipeline maintenance and improve the efficiency of pipeline supervision.

Most of the existing gas pipeline monitoring equipment in the market is to monitor the methane gas concentration to determine whether the pipeline is broken or not. Although this way can monitor the amount of leakage, it does not determine the scope of its impact and the time of leakage, thus delaying the subsequent disposal of the pipeline maintenance personnel. The early warning system designed by using sound and vibration detection device is very sensitive to external vibration and can not only judge the magnitude of vibration, but also accurately locate the vibration source, so as to grasp the damage situation of pipeline in real time, which helps pipeline inspection efficiency and greatly reduces the cost of pipeline maintenance.

2. Technical Solution
As shown in Figure 1, the gas pipeline anti-damage early warning monitoring system, including a leakage monitoring terminal, a data middle station and a data analysis platform. The leakage monitoring terminal is an IoT sensor installed in the underground gas pipeline to monitor the current status of the gas pipeline; the data center is mainly used to store the status information of the gas pipeline uploaded by the sensor, including noise environment, vibration frequency, gas concentration and location information; the main role of the data analysis platform is to analyze and process the current information of the gas pipeline, determine the current risk and hidden danger of the pipeline, and The main function of the data analysis platform is to analyze and process the current information of the gas pipeline,
determine the current risks and hazards of the pipeline, and provide the analyzed results to the pipeline maintenance personnel for follow-up decisions.

![Figure 1. A gas pipeline anti-damage early warning monitoring system](image)

2.1. Leakage monitoring terminal
In recent years, China’s gas industry has been developing rapidly while facing huge regulatory problems. Accidents involving broken gas pipes and even explosions have occurred from time to time, resulting in casualties, economic losses and serious social impacts. Therefore, how to prevent the frequent occurrence of such accidents has become a major problem faced by gas companies today, to solve this problem needs to achieve wide monitoring coverage, monitoring without dead ends, timely warning and accurate positioning of several aspects.

The leakage monitoring terminal is developed based on NB-IoT technology, a technology that enables the gas pipeline network to form an entire Internet for data transmission, solving the problem of full monitoring coverage in the first place. Based on this technology, a processor containing alarm module, sound detection module, vibration detection module and gas detection module is added to the data monitoring terminal, which allows online real-time monitoring of multiple states of gas pipelines. When there is noise, vibration or gas leakage in the pipeline, the corresponding module will monitor the abnormal state of the pipeline, and then send an alarm signal through the alarm module, and finally transmit the information to the data middle station through the NB-IoT. In summary, the leakage monitoring terminal can meet the basic requirements of current gas pipeline leakage monitoring and anti-damage. At the same time, it is necessary to consider that the pipeline is in a complex and harsh underground environment, so the basic waterproof, explosion-proof and dust-proof are also necessary conditions.

2.1.1. Leakage monitoring terminal. Sound detection module is actually a noise sensor, the sensor built-in a capacitive electret microphone, sound waves make the microphone electret film vibration, resulting in changes in capacitance, and the corresponding changes in the small voltage, so as to achieve the conversion of optical signals to electrical signals.

Electret microphone front and back electrode opposite, there is a very small air gap in the middle, forming an air gap and electret as an insulating medium, the back electrode and electret metal layer as two electrodes constitute a flat capacitor. There is an output electrode between the two poles of the capacitor. Since the electret film has a free charge distributed on it. When the sound wave causes the electret film to vibrate and produce displacement; it changes the distance between the two electrodes of the capacitor, thus causing the capacity of the capacitor to change, because the number of charges on the electret is always constant, according to the formula: \( Q = CU \) so when \( C \) changes, it will inevitably
cause the change of the voltage \( U \) at both ends of the capacitor, thus outputting the electrical signal and realizing the transformation from sound signal to electrical signal.

2.1.2. Vibration detection module. The vibration detection module is an inertial vibration sensor, consisting of a fixed part, a movable part and a supporting spring part. In order to make the sensor work in the displacement sensor state, the mass of the movable part should be large enough, and the stiffness of the supporting spring should be small enough, which means that the sensor has a low enough inherent frequency. According to the law of electromagnetic induction, the induced electric potential is: 
\[
u = B l x \frac{dx}{dt}
\]
where \( B \) is the magnetic flux density, \( l \) is the effective length of the coil in the magnetic field, and \( \frac{dx}{dt} \) is the relative velocity of the coil in the magnetic field.

In terms of the structure of the sensor, the inertial electric sensor is a displacement sensor. However, since its output electrical signal is generated by electromagnetic induction, according to the law of electromagnetic induction, when the coil is in relative motion in a magnetic field, the electric potential induced is proportional to the speed of the coil cutting the magnetic lines of force. Therefore, as far as the output signal of the sensor is concerned, the induced electric potential is proportional to the measured vibration speed, so it is actually a speed sensor.

2.1.3. Leakage monitoring terminal. The leak detection terminal uses a semiconductor-type gas sensor that collects the concentration of leaking methane gas and sends the data to a data analysis platform for analysis if a gas line is damaged or leaked. This sensor is small, stable, anti-toxic, and can detect low concentrations of gas, and has an important role in combustible gas detection.

2.2. Data Center

The data center, as the memory of terminal data, is developed based on NB-IoT technology and built on cellular network, which can directly not belong to GSM network, UMTS network or LTE network. Compared with broadband, it does not require high performance of equipment, and can greatly reduce cost and realize smooth upgrade for the Internet of everything network with wide coverage requirements.

The leakage monitoring terminal gas pipeline monitoring data requires a network transmission rate of no more than 8kb/s and a network access speed of no more than 56Kbps, so NB-IoT meets the transmission requirements of gas pipeline monitoring data, and at the same time, its low-rate transmission feature can make its loss of battery low and its service life long. Therefore, the leakage monitoring terminal does not add extra maintenance work for pipeline maintenance personnel; on the contrary, the system can replace the traditional mode of manual patrol and improve the efficiency and capability of pipeline maintenance.

2.3. Data Analysis Platform

After receiving the data from the leakage monitoring terminal, the data center will simultaneously transmit the data to the data analysis platform. Based on the received noise data, vibration data and gas detection data, the platform will analyze whether there is leakage in the current state of the gas pipeline, calculate the leakage value, evaluate the leakage level and determine whether it reaches the alarm threshold. Leakage points that reach the alarm conditions will be alerted in the platform to prompt pipeline maintenance personnel to dispose of them, and the platform will give specific leak locations and treatment measures.

If the pipeline is in normal operating condition, the data analysis platform will automatically eliminate the alarm and store the maintenance event in the data center for future gas companies to analyze and summarize the problem.

3. Conclusion

In order to prevent gas pipeline breakage and leakage as well as mis-excavation leading to gas pipeline safety accidents and establish a good gas environment for the public, this paper introduces a gas pipeline anti-damage early warning monitoring system. The system uses vibration detection and sound detection
technologies, combined with IoT sensing NB-IoT technology, which can monitor and warn various abnormal states of gas pipelines online in real time, and finally transmit alarm information to pipeline maintenance personnel through the data analysis platform, thus ensuring the operational safety of gas pipelines.

Sound detection can achieve the monitoring of gas pipeline noise can be derived from the current noise environment in which the pipeline is safe; vibration detection can be sent through the terminal to the data analysis platform through the Internet of Things the amplitude and frequency of the pipeline vibration, and the impact of vibration on the pipeline; finally, gas detection to determine whether the pipeline is leaking, the alarm module can promptly inform the pipeline maintenance personnel to do further processing of alarm information.

In summary, pipeline safety issues need to be solved as soon as possible, especially gas pipelines, once a leakage accident occurs the consequences are unimaginable, gas pipeline release damage early warning monitoring system can effectively protect the safety of gas pipelines, while solving the problem saves manpower, material and financial resources, and has important significance for the development of the gas industry.

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