Efficient talking in underground water pipelines

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Abstract.
Magnetic induction is a prospective candidate for wireless communication in underground water pipelines. It can overcome many challenges of electromagnetic and acoustic methods in the underground environment. However, similar to the other methods, the communication system needs to transfer data efficiently and reliably from underground nodes to above-ground base stations because of energy constraints. Furthermore, difficulties in repairing the underground devices require proper hardware setup to minimise the maintenance. However, the optimal hardware setup and energy efficiency have yet to be studied in a real testbed, leaving a question about the influence of the underground environments on this method. This article presents our work in progress to address the above gaps. In particular, we introduce three questions and corresponding approach methodology in designing a magnetic induction communication, including the procedure to define an optimal hardware setup, the impact of underground conditions and the tradeoff between energy consumption and communication reliability.

Keywords: Magnetic induction, Underground communication, optimal hardware setup.

1 Introduction:

Water main failures leads to many consequences, such as damage to infrastructure, blocking travelling, and waste of water. They need regularly assessing to be replaced before breaking. Pipeline data is required to achieve a correct assessment for efficient replacement. The data are mainly collected by sending a device into a pipeline[1]. However, this method can only be done periodically and hardly raises an in-time alarm. Integrating sensors into underground pipelines to monitor their health has become a novel approach. As illustrated in Fig.1, the sensors regularly collect, process and send the pipeline data to an above-ground base station, where the health is analysed, and an alarm is raised immediately in case of high risk.

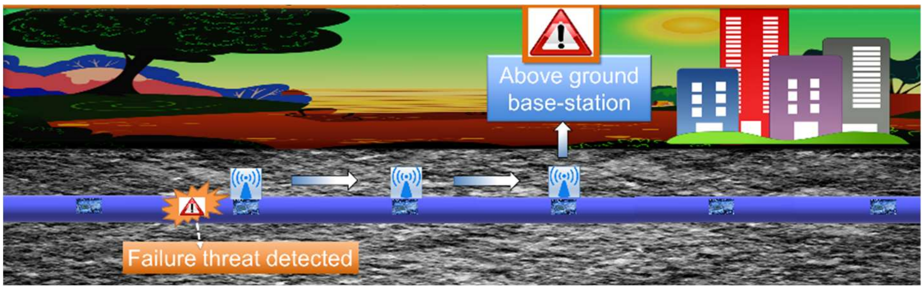

Fig. 1. An overview of underground water pipeline communication for early failure detection

Communication is one of the challenges of the above system. While the wired communication will add complication to the installation, the wireless communication is facing challenges from the underground condition, where the constraint of maintenance ability, energy and the short communication range are the biggest obstacles. Previous studies showed that the magnetic induction (MI) wave is a prospective method for underground pipeline communication [2-4]. The MI setup is simpler than the ultrasonic wave and consumes less energy [5]. Compared with the electromagnetic (EM) wave method, MI has a farther communication range and less influence by the soil wetness in the underground environment [2]. Furthermore, MI is only influenced by the material permeability, which is most similar in different soil moisture [3]. Therefore, MI communication is stable to the soil moisture.

However, to our best knowledge, research has yet to be conducted on the MI communication on the real water pipeline. It leaves a question about the practical result of the impact of the underground conditions. Furthermore, the optimal hardware setup and the trade-off between energy consumption and communication reliability still need to be discovered. Furthermore, the optimal hardware setup and the trade-off between energy consumption and communication reliability still need to be discovered.

In this paper, we present the preparation for the research to investigate the optimal hardware setup and communication strategy to get the most balance between the energy and reliability in MI methods for underground water pipelines. Furthermore, we focus on non-conductive pipes, particularly PVC ones, which are becoming the significant types in drinking water pipelines.

2 Methodology

The MI communication uses a magnetic field radiated through loop antennas to transmit and receive data, as in Fig.2 . Furthermore, the guided wave MI with passive relay coils between the transmitter and receiver can concentrate the wave and enhance the signal strength in non-conductive pipes.

Looking into Fig.2, there are questions about this setting:

Q1: Which hardware setup is optimal for underground PVC water pipeline communication?

From [2] and [3], the coil parameters, including the size, resistance, distance, number of turns, coupling capacitance and distance, influence the path loss. Furthermore, the MI frequency also affects this selection [4]. The procedure for an appropriate selection for the water pipelines has yet to be introduced.

Therefore, we will calculate different setups of MI communication based on the theory in [2] and [4], and do pilot experiments on the ground to give out the procedure to build a proper setup for specific conditions.

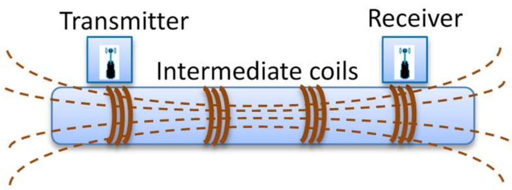

Fig. 2 Magnetic induction communication

Q2: How much does the underground pipeline network influence the MI communication?

The equations in [2] and [3] assume that the environment is homogeneous inside and outside the coils. When applied to the water pipeline, the result in Q1 can be different because of the environmental conductivity of material inside and outside the pipe [3]. For instance, in [4], relay coil distances of 5m are sufficient for a communication range of 20m, and the medium has little influence on the received signal strength. However, from our test on a metal pipe dipped in water, the range is reduced to less than three meters.

Therefore, to answer question Q2, we will investigate the impact of the underground water pipeline conditions on the path loss of the setup calculated in Q1. In particular, the conditions are the soil depth and moisture, temperature, and water flow inside the pipe.

Q3:How much is the trade-off between energy and network reliability?

Energy consumption is one of the crucial factors of underground wireless communication. However, reducing energy consumption can influence network reliability. Therefore, we will investigate the trade-off between energy consumption and network reliability of MI communication in water pipelines. We collect the real experimental data with different scenarios related to hardware setup, then use that data to simulate the network, with throughput and node efficiency.

3 Experiment setup

Fig. 3 describes the desired testbed on that we will conduct the experiments to address questions Q1, Q2, and Q3.

For the tested pipe dimension, we will try two common PVC pipe diameters for potable water mains: 63 mm and 100 mm. Because the practical pipe length is 10 m, and we want to integrate at least one communication node into a pipe, we set the tested pipe length to 10 m.

According to [5], the direct communication range could be up to 10 m. However, the actual range could be decreased depending on the coil setup and environment. Therefore, we will deploy more nodes in between the tested pipe heads. Between nodes, different densities of the passive relay coils will be tested. An electric relay will close or open to enable or disable each coil. Then, we will compare the received signal strength of each coil density. The detail of the setup will be determined when we answer question Q1, where the experiment is conducted on the ground.

To answer questions Q2 and Q3, we will deploy the tested pipe into the testbed in Fig. 3. The pipe is buried at three depths: 0.5, 1, and 1.5 m. Each is connected to a water loop to simulate the water flow. The MI transmitters and receivers are controlled by control boxes and supplied by batteries placed above the ground. In the soil, moisture and temperature sensors are placed nearby the nodes to collect the environmental data.

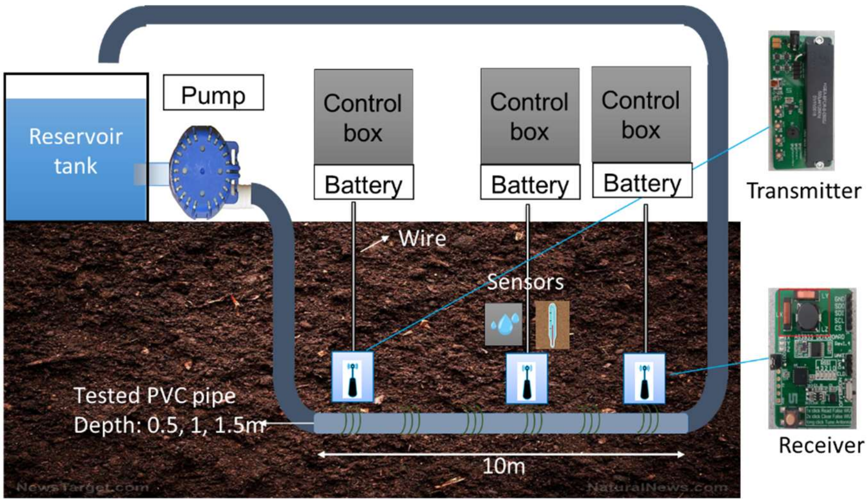

Fig. 3. Testbed for underground water pipeline communication

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