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Comparatively Testing Concrete Permeability for Wireless Communications of a Pipe-cleaning Robot

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Abstract

Background/Objectives: Comparative experiments with wireless communication sensors were conducted to select a wireless method for the future installation of a smartball for ondol pipe inspection and cleaning.
Methods/Statistical Analysis : A wireless communication device was placed in a concrete specimen polyethylene pipe, and the communication distance was measured while adding test specimens in the horizontal and vertical directions. The electromagnetic wave was shielded using aluminum foil, except for the wall in the direction of the experiment. To measure the receiving distance of the Wi-Fi and Bluetooth sensors, a smartphone was used to check the connection by distance and communication speed. Two radio-frequency (RF) modules were used with the wireless module so that the texts could be sent at a constant speed on one side, and the sent texts were received on the other side to determine the receiving distance.
Findings: Regarding the performance of each module in the general environment, the communication distance of the Wi-Fi, Bluetooth, and RF sensors was 130, 15, and 42 m, respectively. In the horizontal-direction experiment with one 600 mm × 200 mm × 100 mm specimen, the communication distance of the Wi-Fi, Bluetooth, and RF sensors was 7, 3, and 5.5 m, respectively. As a result of adding two specimens of 600 mm × 200 mm × 50 mm, the communication distance of the Wi-Fi, Bluetooth, and RF sensors was 4, 2, and 4.5 m, respectively. In the vertical direction, a total thickness of 25 cm was added using a prepared specimen, and all Wi-Fi, Bluetooth, and RF modules showed communication capabilities.
Improvements/Applications: The RF module was found to be suitable for the wireless communication method to be installed on the smartphone for ondol pipe inspection and cleaning. In future studies, we aim to develop a smartball capable of wireless communication, video shooting, and transmission by conducting research on mapping the actual images taken to the ondol pipe drawing.

Keywords: Bluetooth sensor, concrete, permeability, RF sensor, Wi-Fi sensor, wireless

1. Introduction

Alongside the rapid global industrial and economic growth, physical water, service, sewage, oil, gas, and other types of pipes are increasingly used at industrial sites and in homes worldwide. These pipes generally extend over very long distances, are composed of several branches, and are often buried underground. Currently, at industrial sites, pipe-maintenance work is performed by professional manpower who actually enter the pipes themselves or using tools. In the case of pipes where human access is impossible, a scraper connected to the wire is inserted via excavation or is performed using heavy equipment such as a tractor. Then, a dry rod is inserted to clean-out the inside of the pipe to complete the work [1-2].

Recently, active research and development have been undertaken to use robots to clean said pipes. However, most pipe-cleaning robots currently perform cleaning while navigating inside an opaque pipe [3-5]. The conventional ondol (Korea's traditional underfloor) heating method involves passing hot water or steam from a heater or a boiler through a copper pipe or cross-linked heating pipe buried underneath a room floor. For this purpose, the flexible liquid-filled pipe is installed at regular intervals underneath the concrete to heat a room via solid-floor conduction and airborne convection. Notably, the temperature difference between the floor areas located just above the heating pipes and the other floor locations is significant, resulting in an uneven heat distribution across the concrete. This can lead to future construction problems and difficulties with on-site management and maintenance. Moreover, repairing broken pipes of this nature is very difficult.

In South Korea, no robots exist that can drive smoothly through the vulnerable parts of sewer and water-supply pipes. Thus, there have been little-to-no applications of robots for the inspection and testing of pipe networks in general. Hence, effective maintenance and leakage countermeasures remains problematic [6].

The maintenance and management of ondol pipes are difficult, because their diameters are very small, and their lengths are quite long. Furthermore, they are buried inside concrete. There have been a few studies on permeability tests conducted by inserting a wireless communication sensor into such pipes under concrete. To provide a real-time location system (RTLS) for pipe inspection at a construction site, an study was conducted to check the transmission loss through walls [7]. To overcome the limitations of a robot module for pipe cleaning, a robot was developed that could traverse and clean pipes having an inner diameter of 250–500A. The pipe-cleaning robot was developed to remove foreign matter inside the pipe while minimizing human intervention [8-9]. Current inspection methods require a human operator to observe live video from a camera installed in the robot to visually analyze repair needs. However, this method does not provide numerical data on the location and defect state.

This study is designed to support the future development of a smartball pipe-cleaning robot that collects internal images of pipes taken from an onboard camera so that the internal conditions of the pipe and cleaning status can be checked. The collected data will be transmitted to a monitoring system wirelessly. The current experiment has a narrow scope and assesses the wireless communication capability from inside pipes buried in concrete. An RF wireless transmission/reception module, a Wi-Fi module, and a Bluetooth module were buried in concrete, and the effect on penetration depth of the concrete according to the frequency change was investigated [9,10]. To this end, the specimen was fabricated using standard construction concrete, and the communication distance was measured according to thickness using a wireless communication module installed inside. From this investigation, we present the basic data needed for establishing communications using wireless communication sensors for pipe-cleaning robots.

2. Materials and Methods

This study reports on an experiment that assesses wireless communications from within ondol pipes buried in concrete. When Wi-Fi, Bluetooth, and RF wireless modules are embedded in plain concrete, the communication distance can be measured according to the concrete thickness. The experimental procedure is illustrated in Figure 1.

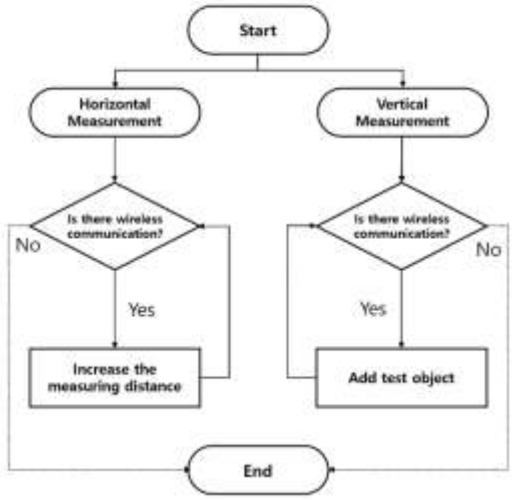


Figure 1. Experimental Procedure

2.1. Variables

In this study, alongside concrete thickness, the direction and intensity of the electromagnetic (EM) waves transmitted by the wireless communication modules are variables used to assess the measurement of EM wave permeability through concrete via Wi-Fi, Bluetooth, and RF. One concrete specimen of 600 mm × 200 mm × 100 mm and five other specimens of 600 mm × 200 mm × 50 mm were fabricated to house a polyethylene (PE-X) pipe with an outer diameter (OD) of 32 mm and internal diameter (ID) of 26.2 mm. For the fabrication, ordinary Portland cement meeting KS F 5021 was used with a specific gravity of 3.15 and fineness of 3341 cm^2/g.

2.2. Equipment for Experiments

The Wi-Fi module used in the experiment is a Samsung ESP8266, which uses the 802.11 b/g/n protocol and Wi-Fi Direct and Soft-AP functions. The module used in the experiment is the Huicheng HC-06 with BLE 2.0, a built-in 2.4-GHz antenna, and a slave module. The RF used in the experiment is the SMG nRF24L01+ with a 2.4-GHz antenna. The specifications of each module are outlined in Table 1.

Table 1. Specifications of wireless communication module

Features	ESP8266	HC-06	nRF24L01+
Module image			
Frequency	2.4 GHz	2.4 GHz	2.4 GHz
Module size	24 mm × 9 mm	37 mm × 15.6 mm	15 mm × 29 mm
Working voltage	3.3 V	3.0–3.6 V	1.9–3.6 V
Transmission range	1500m	10m	250m

2.3 Fabrication of test specimen and measurement of receiving range

The specimens are shown in Figure 2. A communication module was placed in the concrete specimen inside the PE-X tube, and the communication distance in the horizontal and vertical directions was measured while adding specimens in the horizontal and vertical directions. When conducting the experiment in the vertical direction, aluminum foil was used to block EM waves under the floor, through the walls of the specimen, and through the pipe. When conducting the experiment in the horizontal direction, aluminum foil was used in the same fashion except for the wall in the direction of the receiver.

To measure the receiving distance, Wi-Fi and Bluetooth communication speeds and distances were examined using a smartphone (Galaxy Note 20, Samsung); for RF communications, two RF modules were used. Text messages were sent at a constant rate from inside the PE-X and were received outside the concrete.

(a) Specimen with PE-X tube inserted **(b) Normal Specimens**

Figure 2. Specimen made for the experiment

3. Results and Discussion

3.1 Transmission distance and receiving distance

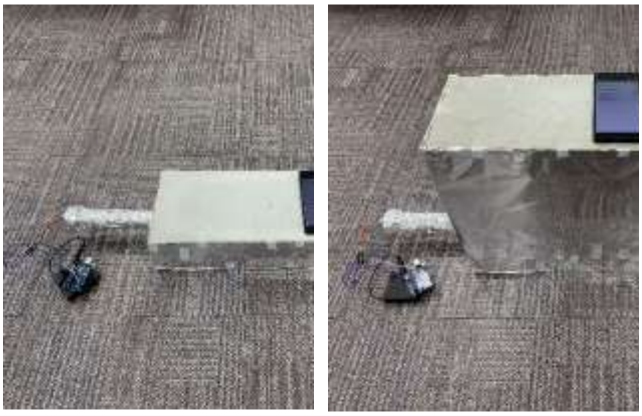
The experiment was conducted inside a corridor of the C university building in an environment similar to the main experiment. The communication module was fixed at the starting point, and the distance was set to 100 m. When the EM wave of each module was received, the communication distance was measured while increasing the concrete thickness by increments of 100 m.

The maximum communication distance of the Wi-Fi, Bluetooth, and RF modules was 130, 15, and 42 m, respectively. In the case of Wi-Fi, the communication distance covered the entire distance from one end of the corridor of the building to the other. Hence, additional measurements were taken outside. As a result, the maximum communication distance of the Wi-Fi module was found to be 130 m.

3.2 Communication distance in vertical and horizontal directions

For the experiment in the vertical direction, the communication module was inserted into the concrete specimen with the PE-X pipe inserted as shown in the figure below. Then, concrete specimens were added one-by-one in the vertical direction and aluminum foil was applied as previously discussed. Experiments were conducted for Wi-Fi, Bluetooth, and RF modules.

For the Wi-Fi and RF modules, with all five concrete specimens added in the vertical direction, power levels of –70 and –65 dBm were captured, respectively, indicating good communication capabilities. In the case of Bluetooth, although the communication speed decreased, the speed for smooth communication was maintained. The vertical-direction experiment started as shown in Figure 3 (a) and proceeded with the addition of specimens, as shown in Figure 3 (b).



(a) Experiment in vertical direction

(b) Experiment in vertical direction with specimen added

Figure 3. Experiment in vertical direction

In the horizontal direction, as shown in Figure 4, the communication module was inserted into the concrete specimen within the PE-X pipe with the aforementioned aluminum-foil configuration. Then, as shown in Figure 5, the module was placed at the starting point, and the communication status was examined by distance. More specimens were added, as shown in Figure 6.

Figure 4. Wall opening for checking

communications in the horizontal direction

Figure 5. Starting point of experiment in the horizontal direction

Figure 6. Experiment in horizontal direction

As shown, specimens were added to increase the thickness of the concrete for additional experiments. The results of the experiment in the horizontal direction are presented in Table 2.

Table 2. Result of experiment in horizontal direction **(Unit : m)**

Features	Wi-Fi	Bluetooth	RF
General environment	130	15	42
One specimen	7	3	5.5
Two specimens	4	2	4.5

Regarding the performance of each module in a general environment, the communication distance of the Wi-Fi, Bluetooth, and RF modules was found to be 130, 15, and 42 m, respectively. In the horizontal direction with one specimen of 600 mm × 200 mm × 100 mm, the communication distance for Wi-Fi, Bluetooth, and RF was 7, 3, and 5.5 m, respectively. With two additional specimens of 600 mm × 200 mm × 50 mm, the communication distance Wi-Fi, Bluetooth, and RF was 4, 2, and 4.5 m, respectively.

3.3 Discussion

This experiment was designed to accumulate basic communication transmission data so that the future smartball pipe inspection and cleaning robot can be developed. Concrete specimens were fabricated ordinary Portland cement. With Wi-Fi, Bluetooth, and RF modules installed inside a PE-X pipe embedded in concrete, distances reflecting communication permeability for each module were measured based on concrete thickness.

The communication distance of the Wi-Fi, Bluetooth, and RF modules was 130, 15, and 42 m, respectively. In the experiment in the horizontal direction, as a result of conducting the experiment with one specimen of 600 mm × 200 mm × 100 mm, the communication distance for Wi-Fi, Bluetooth, and RF was 7, 3, and 5.5 m, respectively. As a result of adding two specimens of 600 mm × 200 mm × 50 mm, the communication distance Wi-Fi, Bluetooth, and RF was 4, 2, and 4.5 m, respectively. In an actual environment, it is necessary to ensure EM wave permeability in concrete and communication distance, and the results of this study indicate that the RF method is more suitable than the Wi-Fi method, because the reduction in communication distance is smaller.

In the experiment in the vertical direction, a total thickness of 25 cm was added using the prepared specimens. Examination of the communication status of each module confirmed the communication capability of all Wi-Fi, Bluetooth, and RF modules. Further research is needed to determine whether the communication was achieved because of the good performance of the wireless communication sensor for communication through the concrete specimen or whether the aluminum foil was not capable of blocking the EM waves.

4. Conclusion

To determine the wireless communication method of a future smartball pipe-cleaning robot equipped to handle inspection and cleaning functions inside ondol pipes buried in concrete, experiments were conducted using different types of wireless modules to assess communication capabilities through a concrete pad. As a result, we found that when the permeability and communication distance were comprehensively considered, the communication quality status was as follows: Wi-Fi > RF > Bluetooth. However, as a result of comparing the communication distance in an environment similar to a more generalized one, Wi-Fi showed the greatest decrease in communication distance, followed by RF and Bluetooth. Considering the experimental results and cost aspects, it was determined that the RF method was most suitable for the wireless communication method to be applied to the future smartball ondol pipe inspection and cleaning robot. In future studies, video capture and transmission capabilities will also be assessed in addition to researching the mapping competency based on pipe-plan drawings.

5. Acknowledgment

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