

Development of Real-Time Pipeline Management System for Prevention of Accidents

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Abstract

Recently the importance of the management technologies for prevention increases. There are many kinds of pipelines under the ground of cities which have pipelines for waterworks, wastewater, oil, gas, electronic power, communications, heat energy, and so on. And these underground pipelines have different roles in supply the essential resources for citizens of cities and will be more important for citizens increasingly. So we call these pipelines as "LifeLine." By the way, these pipelines do not support their core roles to citizens and we can easily see that pipeline accidents have given inconvenient facts or serious man-made disasters to modern citizens as well. For examples, road settlement and sinkholes, waterworks leaks, pollutions by wastewater and oil, explosions by gas, and so on. Nowadays, we live in times using ICT - sensor technologies. So these environments have been advanced and are probably possible to resolve pipeline management problems using them beforehand in real time. Thus, ICT convergences will encourage us to make new technologies and paradigms on the field of pipeline management.

Keywords: *Smart Pipe, Life Line, Pipe Accidents, Real-time Management*

1. Background

A variety of pipeline-related accidents take place in urban areas, which are mostly related to the lack of the pipeline operation and management under the ground. For drainpipe bursts, they cause mainly urban inundation, urban land subsidence, fishkill by river pollution as seen in Figure 1.

Concerning water supply, ruptured pipes bring about different leakage accidents. In particular, gas pipe bursts cause serious explosion accidents. Lastly, oil pipe bursts are also related to severe ground and groundwater pollution issues. These deadly accidents increase serious causalities as well as social overhead costs, directly and indirectly.

Thus, it is considerably required to preemptively spot and settle those issues through the real-time management of underground pipelines as the nation's most critical infrastructures.



Figure 1. Different Accidents Related to Damages of Underground Pipelines

2. Introduction

It is quite difficult to manage pipelines for waterworks, wastewater, oil, electronic power, communications, etc. because they are buried under the ground. However, if it is possible to detect or find out the location of leakage or breakage by smart pipeline system, we are able to reduce social cost from managing pipelines under the ground with ICT sensor technologies which have been increasingly developed. In addition, if these ICT technologies can be utilized to prevent pipeline issues in advance, consumers can be served better and also pipeline operators can give better services to them.

So web programs linking the current pipeline management with the ICT technologies in real-time make it possible to prevent pipeline problems beforehand when carrying out different pipeline constructions.

This management system for prevention requires that some concepts should be defined and included to better understand them, as shown in Figure 2,

- 1) It is required to previously set up more work space for prevention in the infrastructure. The work space should be provided through the current GIS-based management system
- 2) The prevention should be provided by two step processes; construction workers receive a warning both when they enter the work space and when they damage the sensor-embedded warning tape in the work space
- 3) Remote terminal unit (remote sensor) detects damage and traces its location if construction workers damage the tape. This uses a technology created by the multi-smart pipeline system

Location information concerning the damage of the warning tape is sent to a monitoring server, shown by the current GIS mapping system linked with control service

program, and then transmitted to SmartPhone App Software for user to carry out prevention.

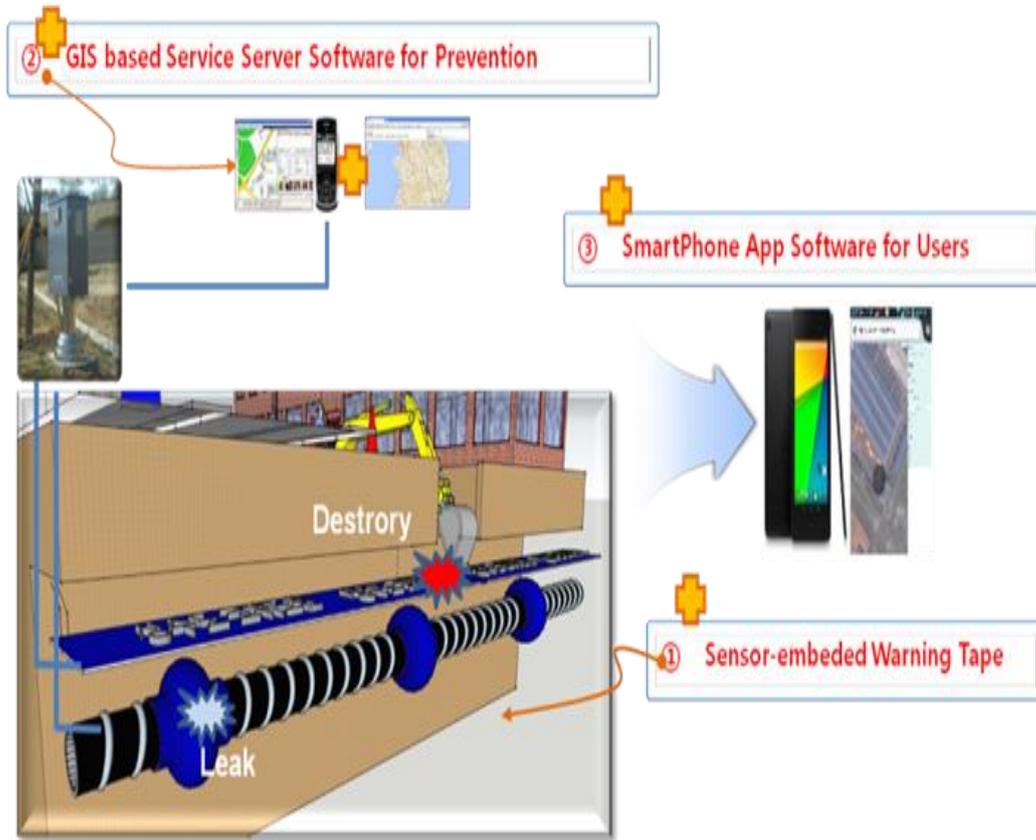


Figure 2. Concepts of Prevention Management System for Underground Pipelines

Currently there are three types of pipeline management technologies for waterworks in Korea (see Figure 3); 1) Point-typed Smart Pipe, 2) Line-typed Smart Pipe, and 3) 3-D Smart Pipe. Firstly, for point-typed smart pipe, it is the most common technology for the follow-up management by installing both hydraulic meters and flow meters. This system divides water networks into block units for better management efficiency.

Secondly, line-typed smart pipe with the follow-up management technology has an advantage of long-distance detection function for water leaks. On the other hand, it has a considerable error bound due to its temperature difference and does not have advanced prevention one.

Lastly, there is the film type system with embedded waterworks pipe sensor cable, the most advanced management system so far. However, this technology failed to commercialize because the film easily comes off. Also, this technology does not have a leakage prevention function.

Therefore, these pipeline management systems for waterworks will be improved much if pipeline leakage issues are prevented in advance and in real time through ICT technology.

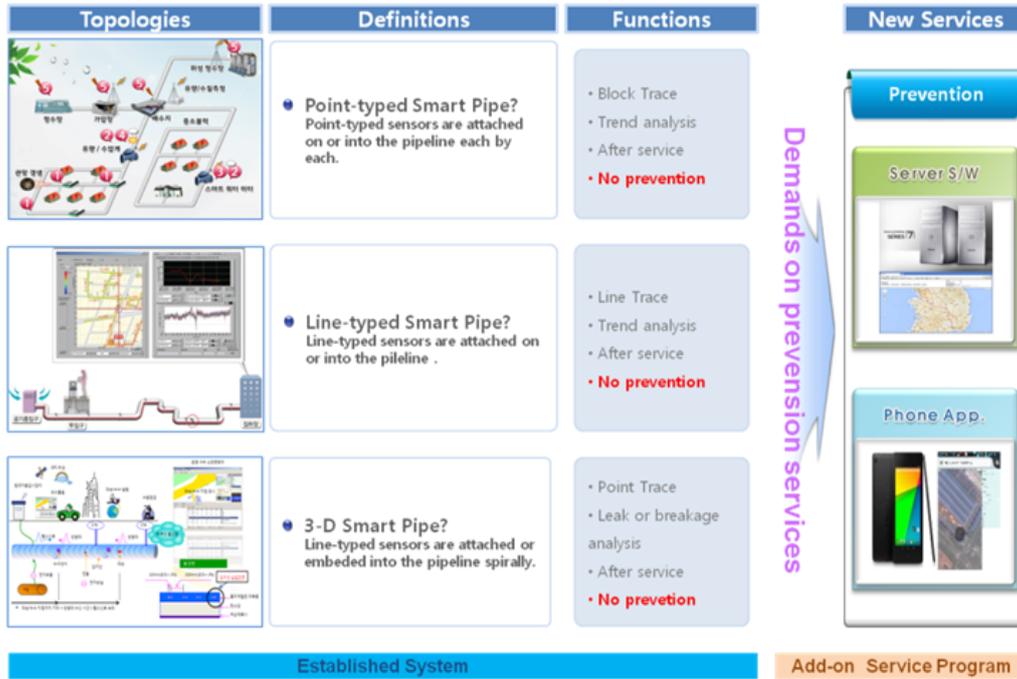
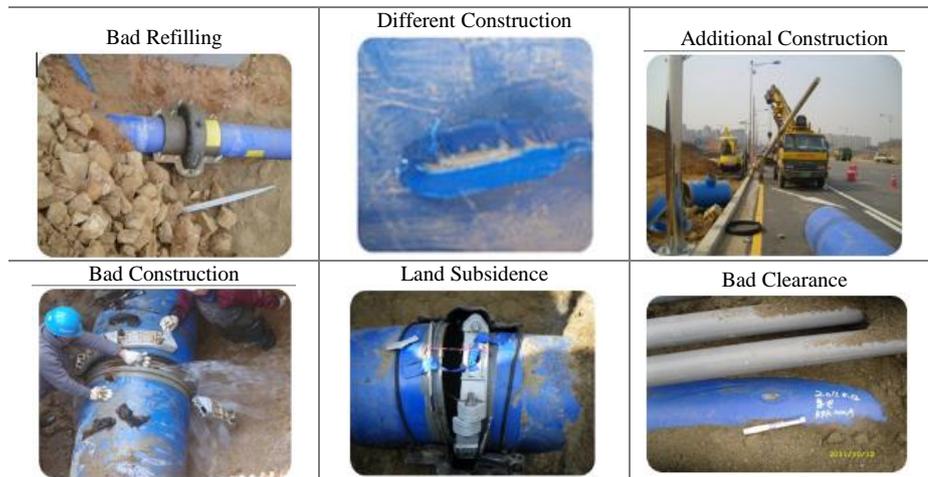


Figure 3. Comparative Analysis of the Current Smart Pipe System

Considering most accidents in terms of pipeline management for waterworks, as seen in Figure 4 and Table 1, pipelines are largely damaged by additional or different constructions around where waterworks pipes are buried and those influences. Also, the pipeline accidents come from lack of the management system for prevention. Based on the figures and table, the current system has not have prevention management technologies yet. Thus, it is more necessary and significant to figure out or detect the circumstance that takes place in advance.



Ratio of Damage for Each Pipe

of Damage by Aging Factor

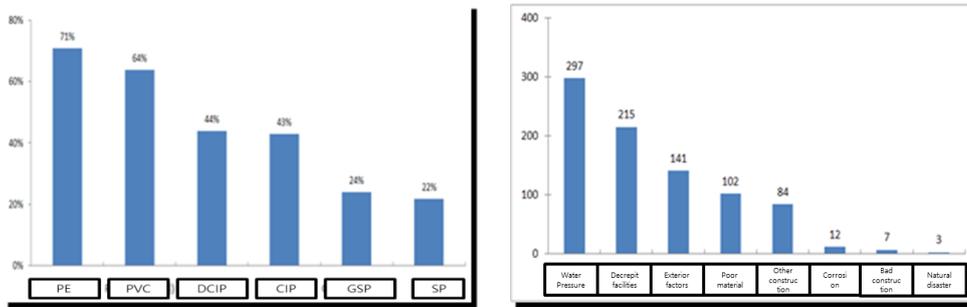


Figure 4. Different Causes of Pipeline Damage

Table 1. Examples of Waterworks Pipe Damage

Area	Caliber	Length	Construction	# of Accident
A	D700A	2,466m	Telephone Pole	1
			Power Cable	2
			Storm Sewer	3
			Telecommunication Cable	2
			Garbage Pipe	1
			Bad Construction	2
			Others	8
Sub-total	-	-	-	19
B	D300A-D700A	1,800m	Gas Pipe	1
			Storm Sewer	3
			Others	3
Sub-total	-	-	-	7
C	D150A-D500A	3,753m	Garbage Pipe	1
			Storm Sewer	1
			Power Cable	3
			Telecommunication Cable	1
			Others	8
Sub-total	-	-	-	14
D	D150A-D600A	7,570m	District Heating Pipe	2
			Power Cable	5
			Storm Sewer	1
			Telecommunication Cable	1
			Others	5
Sub-total	-	-	-	14
Total	-	15,589m	-	54
Average	-	288m/per accident	-	-

Source: Wacon Corporation

3. Conceptual Framework of Real-time Pipeline Management System

3.1. System Operation Flow

Figure 5 shows ‘System Operation Flow’ to provide prevention services in real time. This system operation works in four stages as follows:

- 1) Sensor-embedded warning tape is damaged for different constructions
- 2) The remote terminal unit (remote sensor) detects the damage and sends location information to the monitoring server
- 3) The monitoring server transmits location information into GIS system. The location information is shown on the monitoring screen. Then the server sends the alarm information to operators’ smart phone
- 4) Once operators figure out the location information, they let construction workers suspend operations. After checking underground pipelines for

defects, if they are in good condition, then the operators can progress constructions

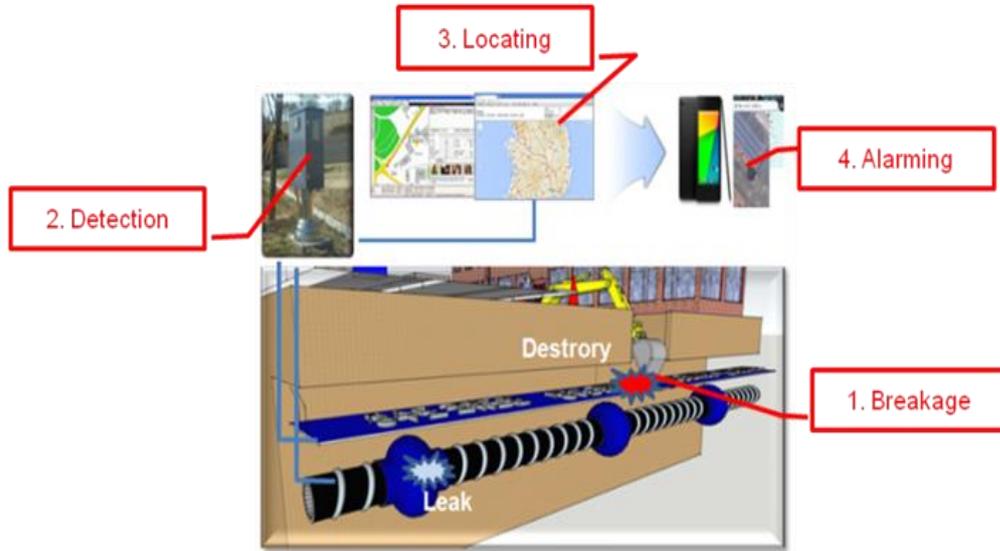


Figure 5. Real-time System Operation Flow

These stages in the mentioned above should be operated based on the following algorithms in Figure 6.

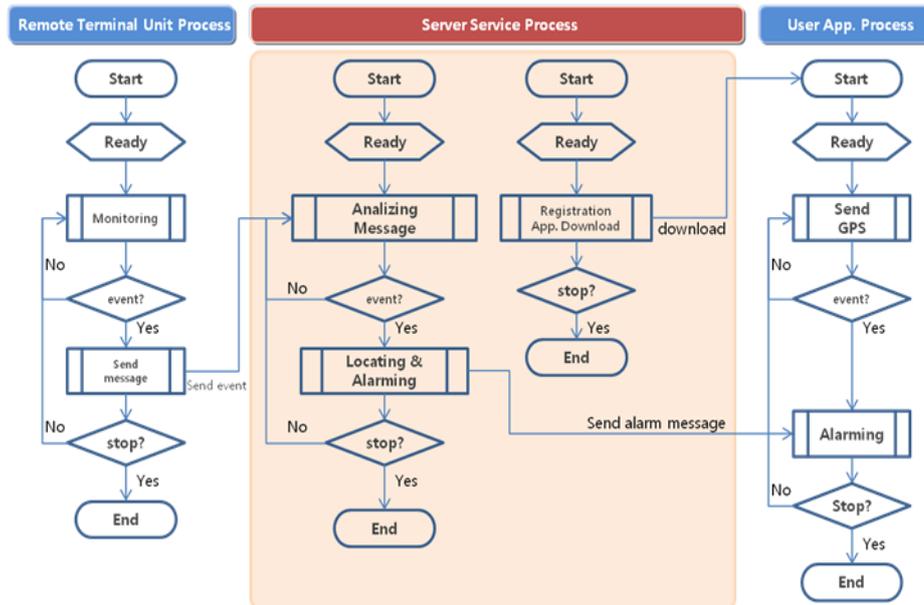


Figure 6. Algorithms for Prevention Service Program

3.2. System Function Design

Major four functions should be clearly defined to carry out prevention services.

- 1) Download: People related to constructions obtain App programs from the web server to install them. This function has two main functions as follows:
 - ① Transmitting the current location information into GPS information

- ② Sending alarm services for prevention, once obtaining from the web server, to related-people like operators and construction workers
- 2) Construction Registration Management: Once workers carry out excavation work, they have to download the app program from the server to register their construction information such as construction date, workers' information, name, contact number (cellphone number), and affiliation
- 3) Location Services and Display: Location information about equipment for construction in all local areas is displayed on the screen of the web server. In addition, this function carries out the real-time monitoring services for prevention and receives workers' location information from their smart phones. This function has four main functions as follows:
 - ① Saving workers' location information, obtained GPS information on the server
 - ② Displaying location information periodically on the GIS map of server; it shows where and what workers are doing
 - ③ Informing daily work situation such as workers' workload, the amount of damaged pipeline, etc.
 - ④ Saving the current work situation with data log hourly and reproducing a situation from the past data
- 4) Location Services and Alarm for Damage: Once damages are sensed by the remote terminal unit (remote sensor) in the work place, this information is sent to the monitoring server program, and then the GPS information, converted from the location information, is displayed on the GIS map. In addition, the information is informed to operators or workers around the work place through smart phone's app program. This function has four main functions as follows:
 - ① Sensing damage from the work space through the remote sensor, and then sending the location information to the web server
 - ② Calculating the length of pipeline with GIS attribute data, transmitted location information from the remote sensor
 - ③ Locating damaged pipeline based on GIS mapping system
 - ④ Displaying the location on the GIS screen, and informing the situation to workers' cellphone

3.3. Server Software Framework Design

As indicated in Figure 7, the prevention system includes 'Substructure,' 'Real-time Prevention Service Program,' and 'User Device.' The substructure consists of 'smart warning tape,' 'smart sensing tape,' 'remote sensing equipment,' 'smart pipe,' 'joint leakage sensor,' and 'joint protection cover.' For the real-time prevention service program, it is broadly composed of 'underground facility information management system,' 'business supporting system for GIS information management,' 'underground pipe management system,' 'service message bus,' and 'database' as below.

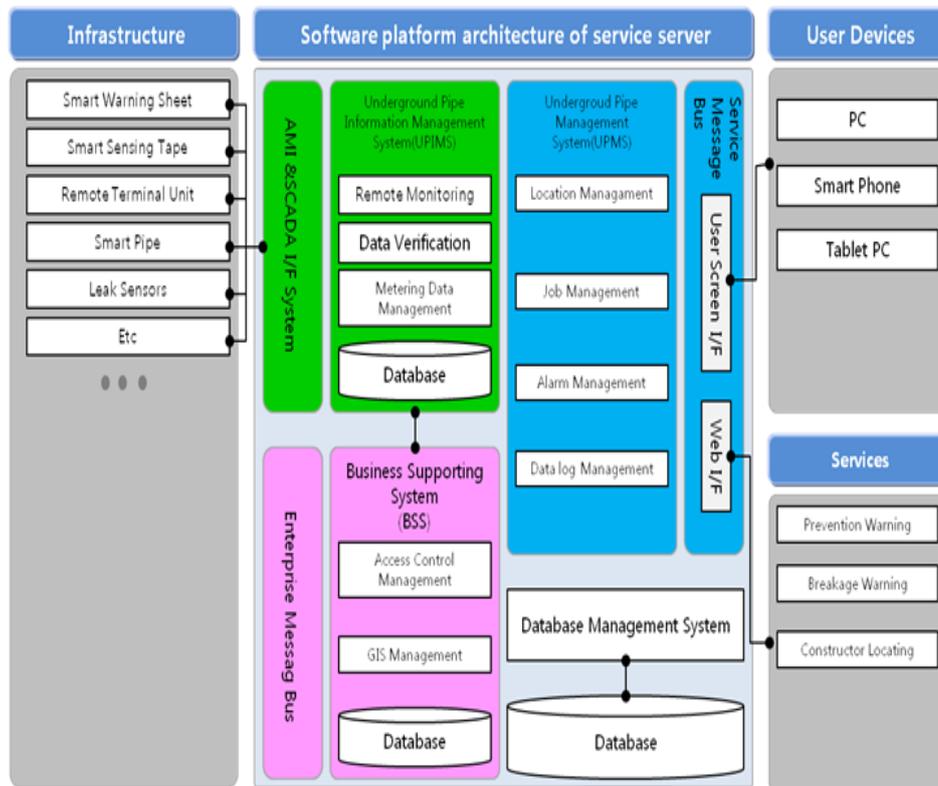


Figure 7. Conceptual Diagram of Prevention Management System for Pipelines

3.4. Smart PhoneApp Software Framework Design

As shown in Figure 8, smart phone app software has the following function:

- 1) Displaying Module for Damaged Location: As app program's module installed in smart phone, if sensor-embedded warning tapes are damaged in a work place, it helps users like operators and workers to recognize the location
- 2) Registration Management System Module for Users: Workers should begin working after registering and reporting to operators. This module covers 'input' for registering information, 'search', 'close', etc.
- 3) Warning Management System Module: This module covers that users receive various interface signals for prevention, such as text, sound, blinking, and vibration
- 4) Data Log System and Database: Recording and Storing work description of smart phone users like operators and workers

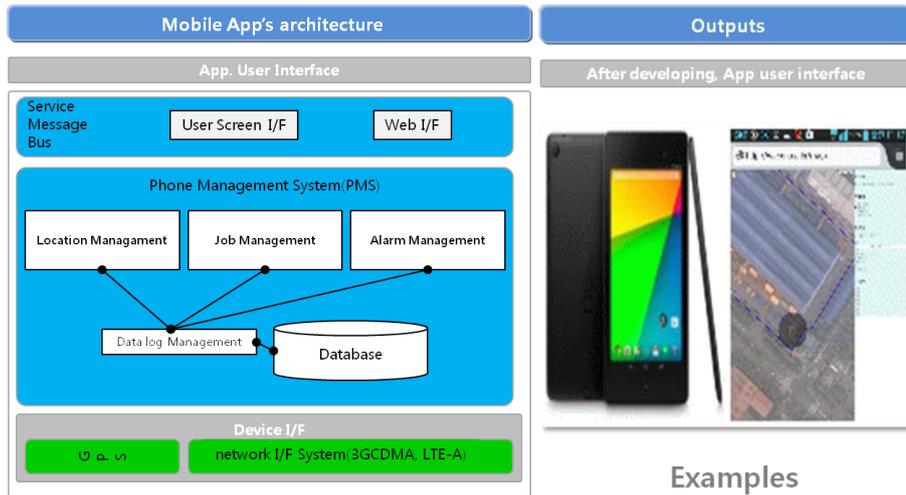


Figure 8. Smart Phone App Program Module Diagram and Its Application Example

3.5. Implementation of Operating Server Program

Web services program has been created, which can be connected anytime and anywhere for user's convenience without any programs. The screen is composed as shown in Figure 9; the register group list is located on the left column, and worker's location information is on the right. This program is available supporting HTML5 (web browser) and WebSocket which makes bidirectional communication possible.

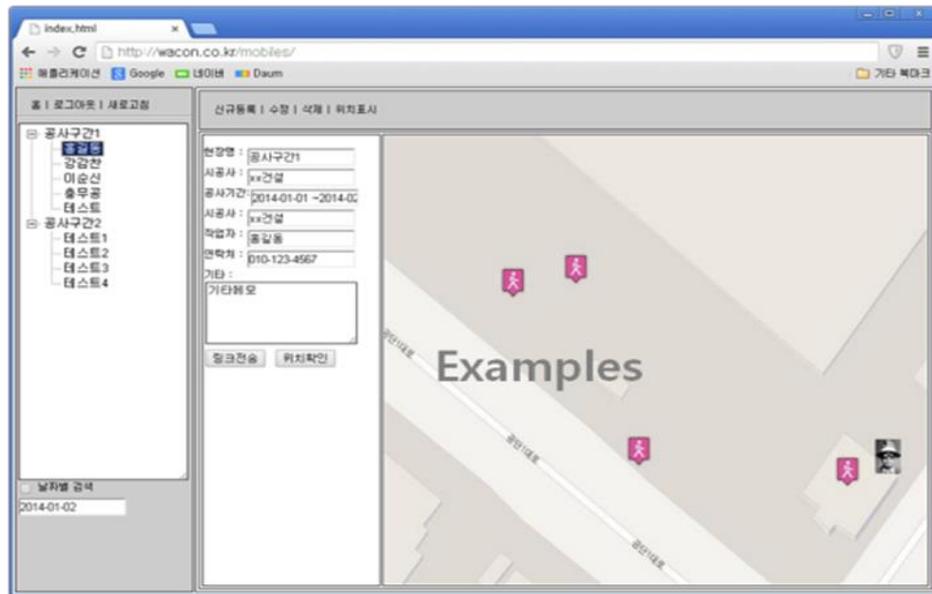


Figure 9. Example of Operating Server Program

3.6. Implementation of Smart Phone App Program

Smart Phone App Program is available with operating system of smart phone which has Gingerbread, Android 2.3 version or subsequent releases and access to GPS and Internet networks. This provides alarm services and registration management options for user's convenience. As seen in Figure 10, the location of

under pipelines is shown in the work area. ‘Eclipse’ has been used as a development tool.



Figure 10. Screen of Smart Phone App Program and Its Description

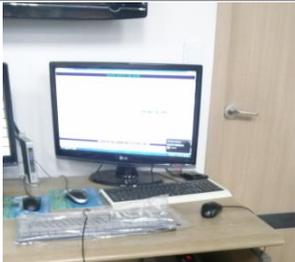
4. Field Application and Data Analysis

4.1. Field Test Application of Real-Time Pipeline Management System for Prevention

The real-time pipeline management system for prevention has been applied in N-City to prevent damage of pipelines for sewage with CDMA (mobile communication network), pipes (600mm of caliber, PE material, and 1.8km of length), one remote terminal unit, one server for operation, and sensor-embedded warning tapes (see Table 2).

This system aims to prevent pollution accidents by wastewater leakage from damaged pipeline under the road nearby rivers. Pipeline is made by PE material to protect it from its corrosion, but it is necessary to prevent damages in advance because PE pipe’s strength, considering PE material, is relatively weaker than that of steel pipe if it is damaged by a digger. Thus, it is required to sense the damage and send warning messages beforehand. This is why the real-time waterworks pipeline system for prevention should be applied.

Table 2. Application of Real-Time Pipeline Management System for Prevention

Type	Length	Server (1)	Remote Sensor (1)	Pipeline
Sewage Pipe	1.8km			

Pipelines



4.2. System Operation Test

Given a situation that pipelines are damaged by a digger, it is necessary to test if the real-time system is accurately operated in real-time. As seen in Figure 11, the test area is divided into two channels, and each channel has four STBs (System Test Box). In addition, each STB are linked with Smart Pipe and Smart Warning Tape 1 through each sensing cable which can be disconnected and again reconnected if necessary. Thus, this test results can tell if the real-time system works properly because a situation, whether or not the warning tape is damaged by a digger in a work area, can be set up by using this sensing cable's attribute, which can be artificially connected and disconnected.

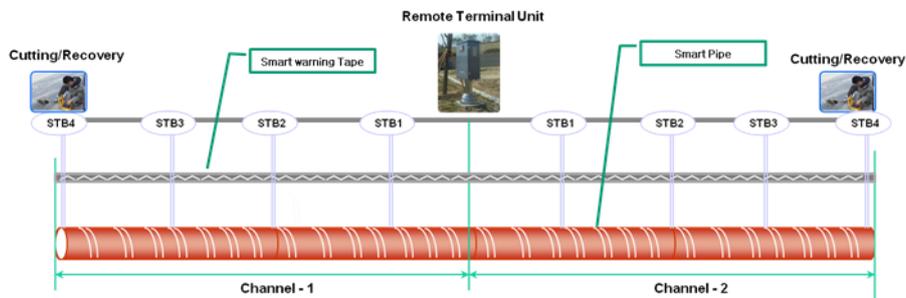


Figure 11. Test for the Real-Time System for Prevention

Because 'Real-Time' is the most important part of this system for prevention, the real-time test has been conducted to confirm whether or not it works correctly in the work area, and then data from this test can be collected in the same way below (see Table 3).

Table 3. Data Collection Method

Test Component					
Area	STB	Remote Terminal Unit	Server	Smart Phone	Real-Time
Two Channels	Cutting/Recovery	Sensor	Sending Warning	Receiving Warning	Differences
Channel 1 (1-4)	Beginning Time	Information Delivery (ex. accident) →		Reception Time	Response Time
Channel 2 (1-4)	Beginning Time	Information Delivery (ex. accident) →		Reception Time	Response Time

¹ Distance between Smart Warning Tape and Smart Pipe is more than 30cm.

4.3. Data Collection and Analysis

Data from the test are gathered by carrying out cutting and recovering those sensing cables randomly and repeatedly over several times in each STB of two channels. Through repetitive tasks, response times are gained by the differences between beginning times and reception times, respectively. So, the real-time response value (time) can be obtained from the average response value (time) of response times (see Table 4 and Figure 12).

Table 4. Collected Data from Test

Date		09/17/2014			
# of Channel	# of STB	Cutting / Recovery	Beginning Time	Reception Time	Response Time (second)
1	1	Cutting	10:00:00 AM	10:01:11 AM	71
		Recovery	11:00:00 AM	11:01:09 AM	69
	2	Cutting	12:00:00 PM	12:00:59 PM	59
		Recovery	1:00:00 PM	1:01:29 PM	89
	3	Cutting	2:00:00 PM	2:01:25 PM	85
		Recovery	3:00:00 PM	3:01:01 PM	61
	4	Cutting	4:00:00 PM	4:01:12 PM	72
		Recovery	5:00:00 PM	5:00:57 PM	57
Average Response Time					70.375

Date		09/20/2014			
# of Channel	# of STB	Cutting / Recovery	Beginning Time	Reception Time	Response Time (second)
2	1	Cutting	10:00:00 AM	10:01:10 AM	70
		Recovery	11:00:00 AM	11:01:32 AM	92
	2	Cutting	12:00:00 PM	12:01:23 PM	83
		Recovery	1:00:00 PM	1:01:10 PM	70
	3	Cutting	2:00:00 PM	2:00:59 PM	59
		Recovery	3:00:00 PM	3:01:08 PM	68
	4	Cutting	4:00:00 PM	4:01:15 PM	75
		Recovery	5:00:00 PM	5:01:13 PM	73
Average Response Time					73.75

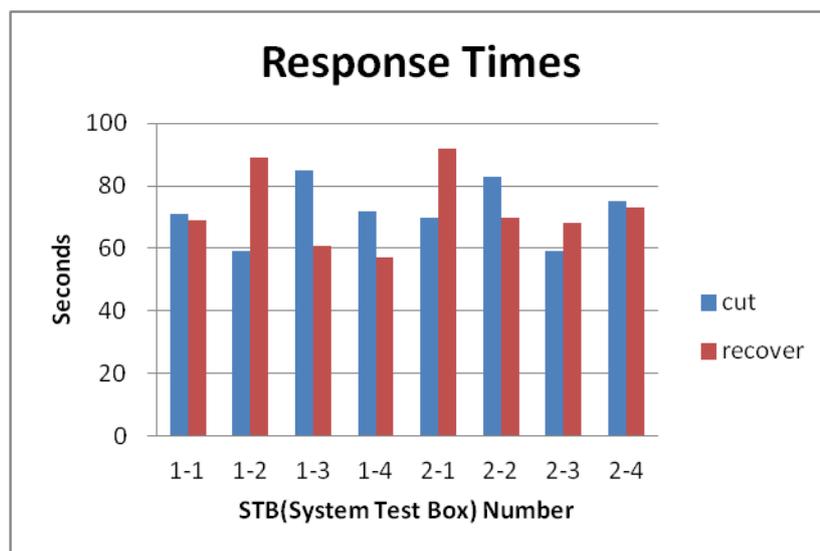


Figure 12. Analysis of Real-Time Response Time

Based on Table 3 and Figure 12, the average response value (time) is about 72 seconds; the fastest response time, 59 seconds and the most delayed time, 92 seconds. The average response time indicates that workers can receive warning (alarming) messages in just 72 seconds or so implying when the warning tape is being damaged by a digger in a work place. Therefore, we can expect that users recognize accidents in advance and prevent pipeline damage by their carelessness and unconsciousness within 72 seconds due to that the warning tape is more than 30cm far from pipelines.

4.4. Application Case

The real-time pipeline (smart) management system for prevention was implemented in practice, related to a Motor Company in Korea. In particular, this system was applied in underground pipelines for industrial wastewater like cleaning sulfuric acid. Pipes (3.3km length) were used with 88mm-caliber, dual combined tube, PE (inner coffin), and steel (outside of pipe). In addition, other equipment were applied, two remote terminal unit (remote sensor), one server, sensor-embedded warning tape (smart warning tape), and pressure sensor for leakage detection.

So far, there have been two leakage issues caused by poor connection between pipes in this area (see Figure 13). However, the real-time management system has played a vital role in detecting the leakage in advance, informing operators and workers on time, and thus preventing a massive loss of citizen's life and property from the spilt dangerous industrial wastewater including sulfuric acid.



Figure 13. Leakage Accident Case and Its Recovery

5. Implications

5.1. Policy Implication

Considering huge social, economic, and environmental damage by underground pipeline accidents, the current pipeline management system is in dire need of a paradigm shift from following-up management (or ex post facto management) to 'smart' management system for prevention, linked with ICT (Information and Communications Technology).

The new management system will become increasingly important because this this prevention management is able to protect a huge loss of citizens' life and property caused by the accidents in advance. In addition, the system's application will be more useful in a policy and institutional perspective because property management appraisal system to evaluate sustainable property value is reviewed for its application in many government agencies with different angles.

5.2. Technological Implication

In order to apply the smart management system at present, advanced technologies for prevention should be prepared, and then support and turn these technologies into policy and institutional implementation. In this sense, the smart management technology can be used in variety of fields and collaborated with other advanced technologies such as SHM (Structural Health Monitoring) and IoT (Internet of Things). For instance, the smart management technology can make 'Real-Time IoT' possible when applied in 'LifeLine,' underground pipelines.

6. Future Research and Conclusion

It is the most important to utilize this program for safety management preventing serious man-made disaster. In particular, underground pipelines in cities as 'LifeLine' are often broken for users' (operators and workers) carelessness or unconsciousness while they are working for city maintenance and urbanization. Therefore, if the real-time system detecting breakage and leakage in advance is applied, we can expect that it would be more efficient for maintenance control for national property. In addition, if the system is applied to different pipelines such as for agricultural water, water supply and sanitation, power, oil, and gas in cities, it can provide much better services to citizens by increasing safety (or security) and reducing social overhead costs.

Acknowledgement

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