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A Wireless Sensor Network (WSN) application for irrigation facilities management based on Information and Communication Technologies (ICTs)

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ABSTRACT

Irrigation facilities that supply agricultural water are distributed at low density across areas with water demand and require efficient operation and maintenance. Traditional manual irrigation facilities management faces critical limitations, such as delays/losses resulting from data handling errors, and facility misidentification. Therefore, an information system for irrigation facilities management could be more efficient if it includes a wireless sensor network (WSN) that uses information and communication technologies (ICTs). We propose a wireless sensor network application for irrigation facilities management based on radio frequency identification (RFID) and quick response (QR) codes. The system was installed in a pilot site in the I-dong irrigation districts in Gyeonggi, South Korea, and was determined to be beneficial for the inspection of agricultural irrigation facilities in the irrigation districts. Real-time information downloading, collecting field data, and updating the condition of the irrigation facilities in terms of operational conditions and maintenance requirements can improve management. The operation results demonstrated the applicability of the ICTs and WSN to agricultural water management and that it provided good portability, recognition, and information gathering abilities in the field.

1. Introduction

An agricultural water management system is defined as the supply of the appropriate quantity of irrigation water at the appropriate time to maximize crop yield, and efficient operation and maintenance are required to make the system effective. It is desirable to deliver the required quantity of water to enhance crop cultivation using irrigation facilities and canals in the irrigated area (Meijer et al., 2006; Ghumman et al., 2009; Aly et al., 2013; Ticlavilca et al., 2013). Approximately 70,000 irrigation facilities, including reservoirs, pumping and draining stations, weirs, and tube wells have been installed in Korea to enable the efficient management of agricultural water (Nam and Choi, 2014; Nam et al., 2015). One major problem faced by irrigation facilities management is that these facilities are spread over an irrigated area at a low density and are difficult to access (Nam et al., 2011; Hong et al., 2016a). In addition, the operation and management of irrigation facilities suffers from low water use efficiency and the inequitable distribution of water (Phengphaengsy and Okudaira, 2008; Parsinejad et al., 2013; Yang and Chen, 2013). The total length of irrigation and drainage canals, important components of agricultural water supply planning, is 184,000 km. Irrigation facilities and irrigation canals face problems during operation, such as collapses and leaks. These problems require regular maintenance by the facilities manager during periods of irrigation. Because of the reduction and aging of the agricultural population and lack of facilities managers, irrigation facilities are often managed nonprofessionally by local residents. To overcome this lack of management resources, efficient agricultural water management requires the development of improved management methods.

The above concerns have resulted in the development of various monitoring and management methods that use Information Technology (IT) to guide the rational allocation of water resources and water conservation (Verdoodt and Ranst, 2006; Quinn, 2011; Zia et al., 2013).

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The strength of IT is that user can be obtaining useful predictions outcomes for decision making, and this result data can be presented to managers in real time (Thysen, 2000; Vougioukas et al., 2013; Gandomi and Haider, 2015; Lopez et al., 2015). In recent years, the agricultural sector has become increasingly information-dependent, requiring a wide range of scientific and technical information to enable effective decision-making (Cash, 2001; Nam et al., 2012, 2016; Navarro-Hellin et al., 2015). Some researchers have developed reservoir monitoring and management systems that automatically measure water levels and flow rates based on code division multiple access (CDMA) and Zigbee technologies (Nolz et al., 2013; Aqeel-ur-Rehman et al., 2014). An automatic operation and control system for agricultural water management based on tele-monitoring and tele-control (TM/TC) was installed in some irrigation facilities in South Korea, such as reservoirs and pumping stations (MIFAFF, 2004; Hong et al., 2016b; Kim et al., 2016; Nam et al., 2016). However, agricultural water management based on automated control systems has been applied to a limited number of irrigation facilities and not yet to irrigation canals. These systems are not connected to any online monitoring system that provides central information management; therefore, facilities managers cannot obtain real-time data in the field. Irrigation facilities managers operate under considerable uncertainty due to lack of real-time current information, as most irrigation water management processes still rely on handwritten reports. An effective operation and management system should accumulate reliable data that reflects the current data and can be used to determine the operating status of facilities in the field.

Irrigation water losses commonly occur in the water supply and distribution process through irrigation canals from reservoirs to irrigated districts because of facilities aging, construction defects, management neglect, and natural decay or damage. The effectiveness of the water management system depends on appropriate maintenance, including the early identification of warning signs in irrigation canals. Traditional manual irrigation facilities management has faced critical limitations, such as delays and losses in data handling and facilities misidentification. Additional limitations include the identification of the exact location of irrigation facilities with canal leaks in the event of an emergency, lack of knowledge regarding the operating history, and an inability to transmit real-time management instructions. Agricultural water use information and the operating status of irrigation facilities must also enable real-time information to be rapidly obtained in the field. Therefore, it could be more efficient to manage irrigation facilities using an integrated information system consisting of a wireless sensor network (WSN) and information and communication technologies (ICTs) to obtain the information required for the on-site operation of irrigation facilities. The application of radio frequency identification (RFID) and quick response (QR) codes to irrigation facilities management has vast potential for improving the ability of these systems to solve problems.

In the present study, we examine the impact of improved availability of information technology on agricultural water management and irrigation facilities management. An efficient agricultural monitoring system can be used to monitor the real-time status of irrigation facilities on a regional scale. The primary purpose of this study is to develop an information system platform using ICTs and WSN technology based on RFID and QR codes that improves the operation and management of irrigation facilities. We propose appropriate methods for agricultural facilities management based on RFID and QR codes that can obtain real-time information about the status of irrigation facilities in the field. In addition, our newly designed integrated management code identifies facilities in agricultural plains by supplementing the current facilities standard code. The installation employs a methodology for guiding the development and deployment of RFID and QR code applications in agricultural water and irrigation facilities management. It thereby enables real-time communication between data collection and data management using the ICTs and WSN. The system was installed in the I-dong irrigation districts in Gyeonggi Province, South Korea. The results demonstrate the applicability of the WSN for agricultural water and irrigation facilities management can be used by experts to make decisions, such as those concerning irrigation policy.

2. Review of agricultural utilization of ICTs and WSNs

ICTs and WSNs play an important role in improving the precision of agricultural technologies, such as real-time monitoring of crop, weather, and soil moisture (Blonquist et al., 2006; Pierce and Elliott, 2008; Diaz et al., 2011; Kim et al., 2011, 2014; Fernandes et al., 2013; Watras et al., 2014; Nikolidakis et al., 2015; Ojha et al., 2015). Meanwhile, over the past few decades, many researchers have dealt with the problem of the allocation of a limited water supply for irrigation, including studies of wireless sensor network to optimize irrigation water management (Kim and Evans, 2009; Ali and Kumar, 2011; Dong et al., 2013; Lea-Cox et al., 2013; van Iersel et al., 2013; Sesma et al., 2015). Therefore, ICTs and WSNs technology have been widely adopted in water management, providing numerous opportunities for applying wireless communications in agricultural systems (Kim et al., 2008; Vellidis et al., 2008; Chappell et al., 2013) and supporting the effectiveness and efficiency of irrigation facilities management.

Irrigation facilities management typically involves manual identification methodologies. As manual identification is costly, time consuming, and error prone, researchers have attempted to address these drawbacks in recent years. The most promising technology seems to be tag-based identification methods, such as RFID tags and QR codes, because they require less manual intervention and offer a wide range of novel possibilities due to the ease with which they can interface with additional devices (Ilie-Zudor et al., 2011). Several tag-based identification technologies exist, including barcodes, visual tags, and RFID tags (Cunha et al., 2010; Badia-Melis et al., 2014). In our efforts to build WSN systems for irrigation facilities management, we focus on the capabilities of RFID and QR codes to enable identification while facilitating information sharing.

RFID technology is a wireless sensor technology which is based on the detection of electromagnetic signals and the form of automatic identification (Domdouzis et al., 2007). RFID have been widely applied to traceability control and various monitoring, tracking management processes because of its ability to identify many types of objects, categorize, manage the flow of goods including manufactured goods, animals, people, and total product life cycle management (Ruiz-Garcia et al., 2009; Gebbers and Adamchuk, 2010; Voulodimos et al., 2010; Ruiz-Garcia and Lunadei, 2011; Zhu et al., 2012; Badia-Melis et al., 2015). It uses magnetic fields at radio frequencies for identification, location, and automatic data acquisition and transmission, including those in real-time for enhancing management (Morais et al., 2008; Sabbaghi and Vaidyanathan, 2008). The potential benefits of RFID are as follows: (1) it eliminates or improves the performance of routine manual tasks at reduced costs, and (2) it provides real-time information for better planning and execution (Kim et al., 2010). As shown in Fig. 1, the basic structure of the RFID system consists of four major parts: the RFID tag contains the wirelessly connected sensor nodes, which are located on the object to be identified; the RFID reader performs the identification; the middleware utilizes the information; and the server performs data collection and management. RFID tags are attached to the tracked item and have data (an identification number) stored in their memory, and can be used to gather data at any point in time about their immediate surroundings and the object to which they are attached (Finkenzaeller, 2003; van der Togt et al., 2011). Readers are the devices that read data from tags and they depend on the antenna, transceiver, and decoder (Jedermann et al., 2009; Mejjaouli and Babiceanu, 2015). In general, RFID systems include specifications on the communication between tags and readers. The system is supported by middleware and networking services.

The QR code open-source solution provides a simple and inexpensive method of encoding text information that is easily read using

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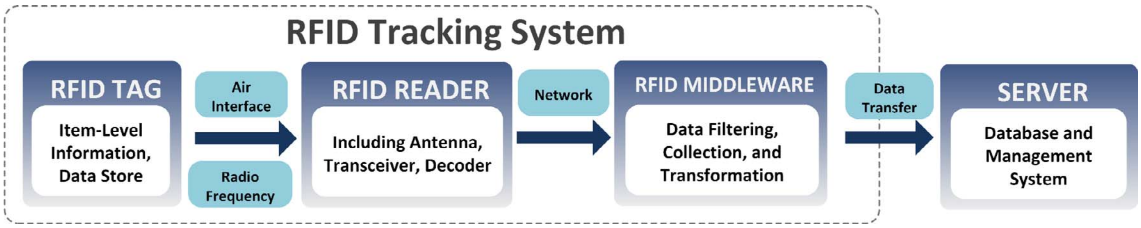

Fig. 1. RFID system architecture (Voulodimos et al., 2010; Ruiz-Garcia and Lunadei, 2011).

electronic readers. Because of the speed of data reading, accuracy, and functional characteristics, QR code technology and processing provide a fast and accurate tool for data entry; they can store a large amount of data in a small area to support information detection (Cunha et al., 2010; Querini et al., 2011). This study reports the construction of WSN systems for irrigation facilities management using the information stored by RFID and QR code technologies.

3. Materials and methods

3.1. Integrated identification code for irrigation facilities management

Irrigation facilities management requires quantitative standards for the accurate identification of the status of facilities, including categories, location and operating time. Unique identification codes are required to effectively manage irrigation facilities. In South Korea, agricultural irrigation facilities, such as reservoirs and pumping and drainage stations, are managed by the Korea Rural Community Corporation using the Rural Infrastructure Management System (RIMS) (Nam et al., 2011). The RIMS agricultural irrigation facilities management system is defined with standard identification codes, such as ten-digit codes that include location codes, facilities codes, and serial numbers. However, irrigation facilities on plains, such as irrigation canals, bridges, and regulation gates, are difficult to manage because they are not encoded for integrated management. In this study, before codes are provided for irrigation canal facilities, a standard code must be developed to uniquely identify facilities. Integrated identification codes have been developed for irrigation facilities for WSN applications based on RFID and QR codes. The integrated identification codes of agricultural facilities management were designed as the combination of the existing standard code and extended codes to create a systematic management database that can be utilized in the search for the integration and utilization of existing systems. For this study, integrated identification codes for embedded RFID tags and QR codes were designed, an application of ICT technology was developed to enable the collection of field data.

3.2. Design of identification functions

The identification process to identify objects can be automatically performed by electronic devices to facilitate identification. Fig. 2 depicts an overview of the proposed identification functions between the tags and readers. In this study, two types of devices are used to perform code identification: an RFID reader on a personal digital assistant (PDA) and a QR code reader on a mobile device. The identification methodologies are designed with three approaches to the detecting of irrigation facility information, such as RFID tags using RFID technology, image recognition using QR codes, and location coordinates using GPS. The first method, which uses widely available RFID technology, relies on automatic nonvisual reading that recognizes the facilities code. The second method, which uses the QR code based on the scanned image processing, reads the identification codes attached to facilities using the camera of the mobile device. The third method, which uses GPS for a location-based search, involves obtaining the position of the current location coordinates and then selecting an appropriate irrigation facility after searching for the surrounding facilities.

The process of identification by mobile technology involves obtaining an identification code attached to objects using RFID tag and QR code decoding, or using location coordinates from GPS. The RFID tag provides a unique identification code. The QR code optically scanned an identification code. After the code is decoded or the GPS coordinates are received, the identification system verifies the existence of the scanned facility from the management server. If the identification code does not exist, for example, in the case of new facilities, a specific code is generated to access the management server to register the facility. After searching and selecting among nearby irrigation facilities, the information on the selected facilities is available on the mobile device and the current status can be checked.

The information management technology is designed to enable a facilities search function; a display function to present information, such as the location, a photograph of it, the real-time/historical water level, and a recording function to perform a condition survey using mobile technologies, as shown in Fig. 3(a). The information search function obtains the basic information using identification functions, such as RFID, QR code, and GPS technology. The facility information stored in the management server can be displayed on mobile devices through map-type, photo-type, and graph-type information, such as the real-time water levels of irrigation canals, as shown in Fig. 3(b)–(d).

3.3. Design of information system for irrigation facilities management

In this study, the WSN system is intended to collect and communicate a variety of status and state information relevant to the management of plains irrigation facilities without the constraints of time and place using ICT technology to enable real-time data exchange. The wireless communication protocol was selected with consideration of distance, data rate, compatibility, and cost. Long-range communication with CDMA technology, medium-range communication with Zigbee technology used by adopting a water level monitoring network, and local wireless sensor networks used by combining RFID and QR codes were constructed to form an integrated management system, as shown in Fig. 4. The typical sensor network for automatic water gauging of irrigation canals and reservoirs consists of automatic sensors, a data logger, and a local server. Using CDMA and Zigbee technology, the data integration, collection, and management were performed, as shown in Fig. 4(a). For this study, a WSN based on RFID and QR codes was developed, as previously discussed. In addition, a database management system was developed for agricultural water management of operational conditions and maintenance requirements (Nam et al., 2011), as shown in Fig. 4(b). The sensor network was designed to wirelessly collect sensor data, and transfer it to the connected local server, and then to send requests generated by the decision support system. As shown in Fig. 4(c), the integrated management server is a configured database and management system; each database is used through the interconnection among devices from the local server. The management server must communicate with the sensor networks to update and collect data by obtaining the history information, facility real-time status, and operation information.

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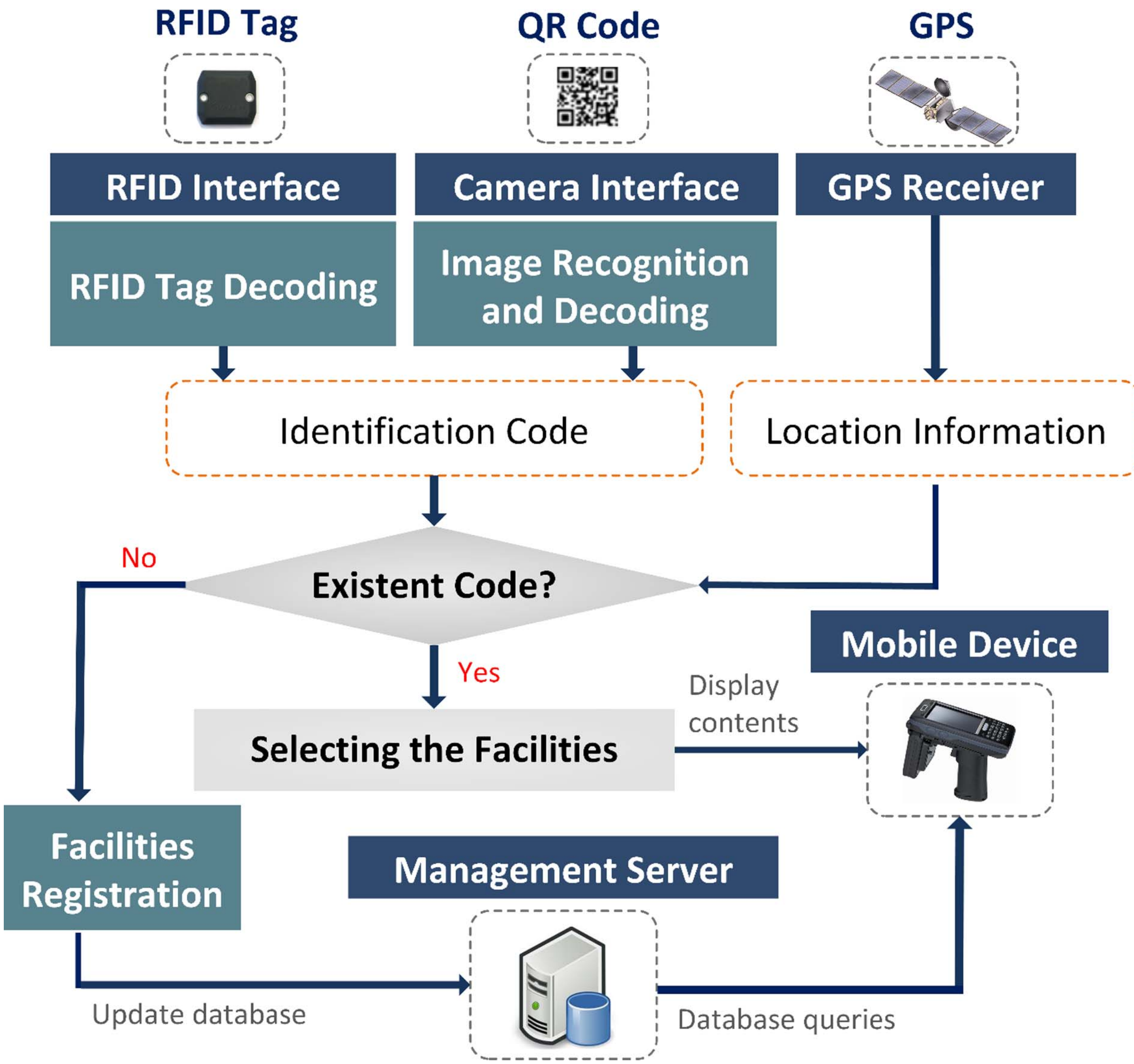

Fig. 2. Functional overview of the mobile technology application process.

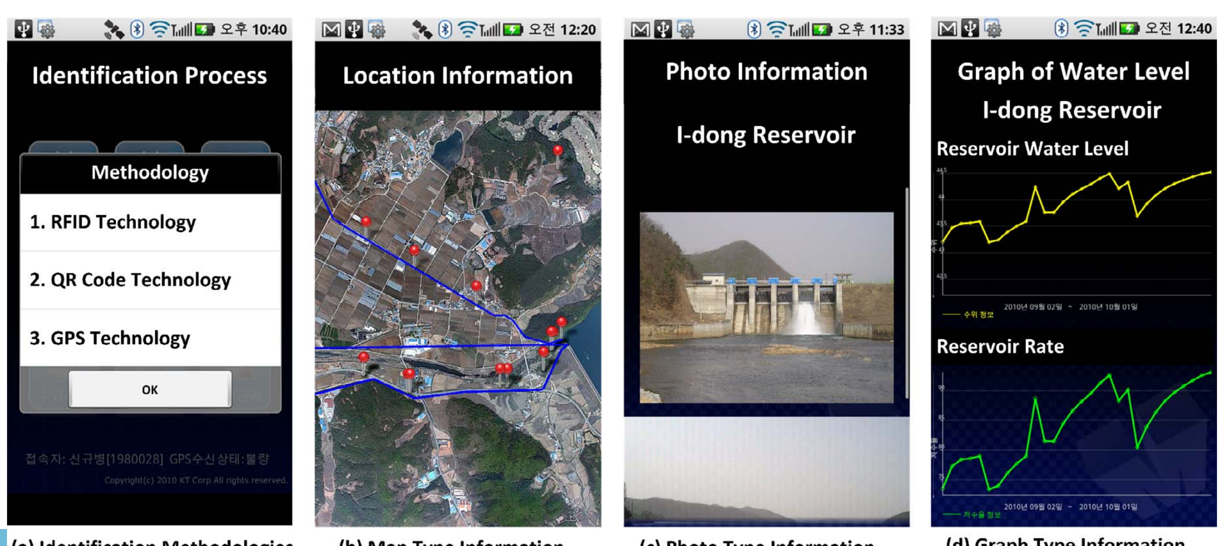

Fig. 3. Feature design for obtaining real-time information via mobile techniques.

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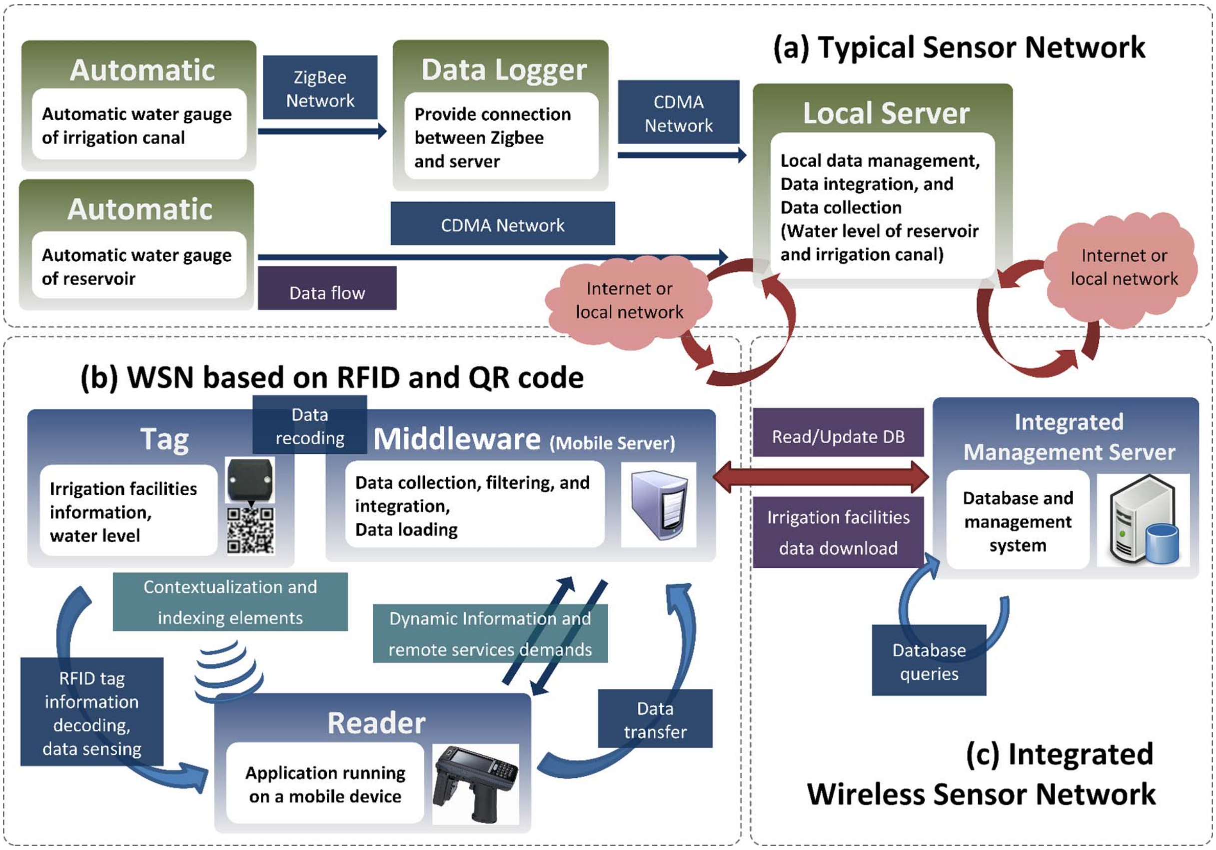

Fig. 4. Data communication diagram of the wireless sensor network (Nam et al., 2011).

3.4. Installation of the pilot site using ICTs and WSNs

This research presents the design of an integrated WSN system for the real-time information management of irrigation facilities using ICT technology. The WSN system is comprised of RFID technology and QR codes and includes one CDMA module and three Zigbee modules. The system was installed in the I-dong irrigation districts in Gyeonggi, South Korea, for the purpose of implementing a decision support system for irrigation facilities management (Nam et al., 2011). Mobile technologies are used for irrigation facility identification and on-site verification for 32 major irrigation facilities. These technologies include the installation of RFID and QR codes at irrigation canals approximately 3.2 km from the start of the I-dong reservoir to the Won-am pumping station, as shown in Fig. 5. The distance between each irrigation facility is approximately 50 m, and an integrated identification code was assigned to each irrigation facility. The CDMA module was installed in the reservoir to communicate with the management server, and the Zigbee modules were installed in the water gauge sensor to collect the real-time water level.

The RFID and QR codes were installed in 21 facilities, for example, the water gauge, gauging staff, irrigation canals, regulation gate, closed conduit, and diversion structure to identify functions, as shown in Fig. 6 and Table 1. Plains irrigation facilities, such as irrigation canals, water gauges, and gauging staffs, are difficult to intuitively recognize on-site because of their relatively small size compared to facility structures, such as reservoirs and pumping stations. The installed types are either panel-attached or directly attached, depending on the type of irrigation facilities. The irrigation canal and regulating gate tags were installed as panel attachments to withstand any damage, as shown in Fig. 6(a) and (d); others, such as the water gauge and gauging staff, were installed as direct attachments, as shown in Fig. 6(b) and (c). The installed height and distance for recognizing the tags was approximately 0.2–2 m. The signs were placed to enable their observation by walking around the facility without disturbing it, and care was taken to avoid damaging the iron near the waterways.

4. Results and discussion

4.1. Assessment of mobile technology operability

Measuring mobile technology operability requires processes and a performance measure for each method. The identification methods, which use RFID tags and QR code readers, are possible to implement by walking or driving, depending on the distance. Using the RFID identification method characterized by non-directional communication enables the facility manager to access the identification regardless of the direction of facilities. However, it is difficult to physically distinguish the given facility when a number of facilities are concentrated. While the QR code, which uses a camera to obtain the facilities identification codes, does not involve this redundancy selection, it is limited by the possibility of damage to the bar code and by the difficulty of night-time identification. The GPS module includes use of intuitive identification features because of its search for nearby facilities around the current location of the inspector; however, it identifies a large diversity of facilities depending on the wide range of relative errors. Finally, the identification method that uses a name search function can exactly identify the facility location if its name is known; however, it is not easy to input text in devices and remember many facilities names.

The previously described methods require comparisons of their identification of recognized distance, inspection speed, and recognition rate. To this end, the facilities identification codes were used to build a database, and field tests were performed for evaluating the applicability and operability of each method. Table 2 summarizes the characteristics and the comparison results of each specific identification method. In the case of short-range wireless communication using RFID technology, the recognition distance of approximately 1.5 m was investigated to

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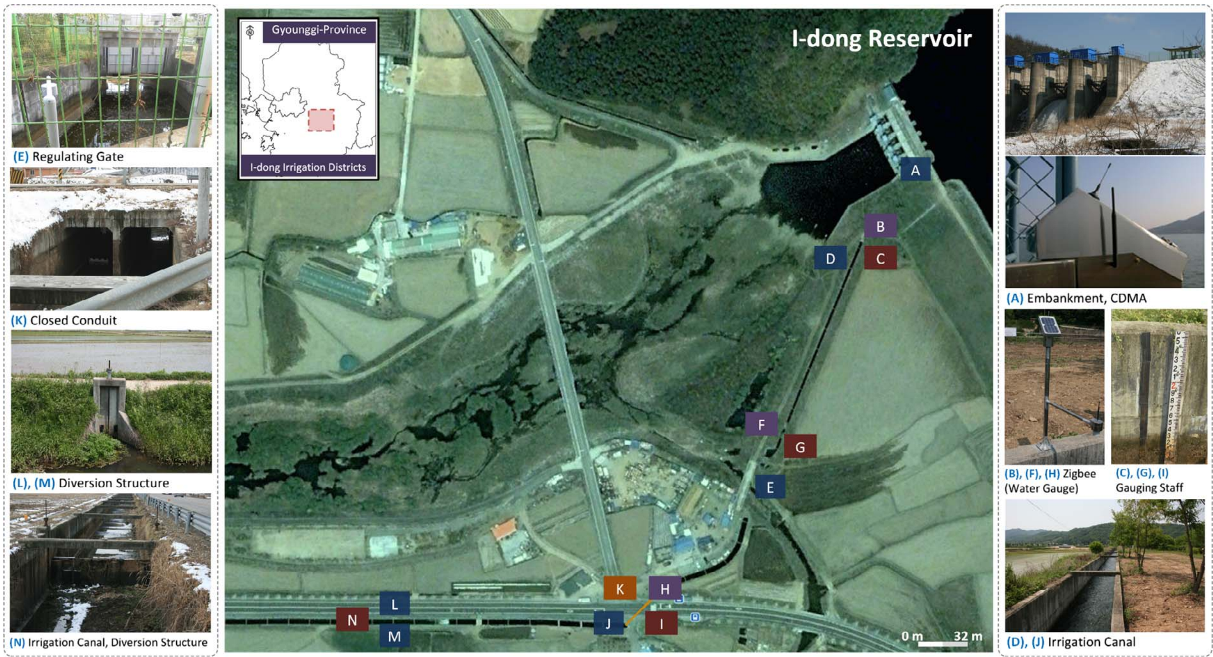

Fig. 5. Pilot site for wireless sensor network testing (map image from Google).

identify the facilities. The inspection speed of turning on the reader within approximately 1 s was recognized regardless of the facility installation height and directional detection. QR codes were verified by an installation of 10 × 10 cm, and the recognition distance was approximately 20 cm. The camera module-focused QR codes were recognized within less than 1 s of turning on the reader. QR codes have a rapid recognition speed; however, they have the disadvantage of using directional detection for recoding and a short inspection distance. The GPS location-based identification modules provided in mobile devices search around the facilities based on current location information from the modules. Based on the evaluation of a resulting verification error, the error for detecting facilities in a flat region occurred at 30 m, while an error appeared at approximately 100 m in mountainous areas. Although the GPS error occurred, the total count of detected facilities was 5.5 items per one trial, which seems more aligned with the degree of identification depending on the wide distribution of agricultural facilities. Searching the name of the facility through mobile devices is a function that searches facilities information regardless of the distance in the field. The process of entering the facilities name in mobile devices is time-intensive and an inconvenient method; moreover, it is not easy to distinguish the irrigation facility based on the name. This method does not have in-field limitations; therefore, it can be used when the other three types of identification methods cannot locate the facilities.

Table 1
Installation status of RFID and QR codes.

Irrigation facilities	Counts	Installed types	Installed height	Approach distance
Irrigation canal	12	Panel attach	0.2–0.5 m	0.5 m
Gauging staff	4	Direct attach	−0.2 m	2 m
Water gauge	2	Direct attach	1.5 m	2 m
Regulating gate	2	Panel attach	1.5 m	0.5 m
Facility (pumping station)	1	Direct attach	1.5 m	0.2 m

4.2. Inspection guidelines using a wireless sensor network and mobile technology

The information system using ICTs for irrigation facilities management enables users to monitor current facilities information collected from the WSN sensors via mobile devices anywhere in real time. The motivation for inspection guidelines is to show the workflow for the development of a WSN and mobile technology built over this approach. In this exploration of this application of RFID and QR codes using ICTs, we consider the operation processes involved in the irrigation facilities management process.

Fig. 6. Attachment of RFID and QR codes to irrigation facilities.

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Table 2
Comparison of experimental results of feature identification (mean of more than two trials).

Classifications	RFID	QR code	GPS	Name search
Distance	1.5 m	0.2 m	50 m	–
Inspection speed	1 s	1 s	10 s	20 s
Reliability	95.2%	90.5%	100%	100%
Total detection count	44 (2.2 items per trial)	19 (A single item per trial)	176 (5.5 items per trial)	116 (3.6 items per trial)
Advantage	Rapid found, Non-directional detection	Rapid found	Long inspection distance	Clear/definite inspection
Disadvantage	Influence of obstacles	Short inspection distance, Directional detection, Influence of weather conditions	Long boot time, Large error range	Name input, Inconvenient input method

Fig. 7 depicts the communication protocol of the identification process using ICTs. The inspection guidelines are primarily comprised of tag, reader, middleware, and server. RFID is used with the concept of storing facilities identification information on chips, placing these chips on tags, and then placing these tags on objects to enable their unique identification. The RFID reader and mobile devices that use decoding or tag sensing processes detect or otherwise obtain the information of irrigation facilities from the tags, such as RFID tags and QR codes. In terms of the detailed operation process, the reader collects current situation information and sends the collecting data to the middleware; the middleware then analyzes the received collecting data to transfer in the server database. In addition, when a manager requests historical data, such as record or repair information, the middleware is used to support the query from the database using ICTs. After the association request is successfully performed, the manager can receive notifications of current and past facilities conditions in real time. The WSN technology for management of irrigation facilities enables access to a variety of accumulated information in the field by the middleware and server via the integrated identification code and mobile devices using ICTs. Moreover, the target of facilities management can be more quickly and accurately recognized in real-time and thereby decrease more errors than past handwritten management methods.

5. Conclusions

In this paper, we described the installation, application, and evaluation of an information system of irrigation facilities management using WSN that utilizes RFID and QR code technology. The introduction of ICTs added a new dimension to the delivery of advanced information to the irrigation facilities manager. The operational results demonstrated the applicability of the ICTs for agricultural water management, good portability, proper recognition, and appropriate information gathering in the field. In conclusion, the enhancement of the platform with identification technologies for irrigation facilities management and access to information system using RFID and QR code provide extended capability for agricultural water management and effective decision-making. The various real-time information obtained from the RFID tags and QR codes deployed in the irrigation canals and facilities can be used by decision maker for irrigation policy. In addition, this system can be connected to online monitoring system that provides central information management; therefore, facilities managers can obtain/access real-time data in the field using ICTs and WSNs.

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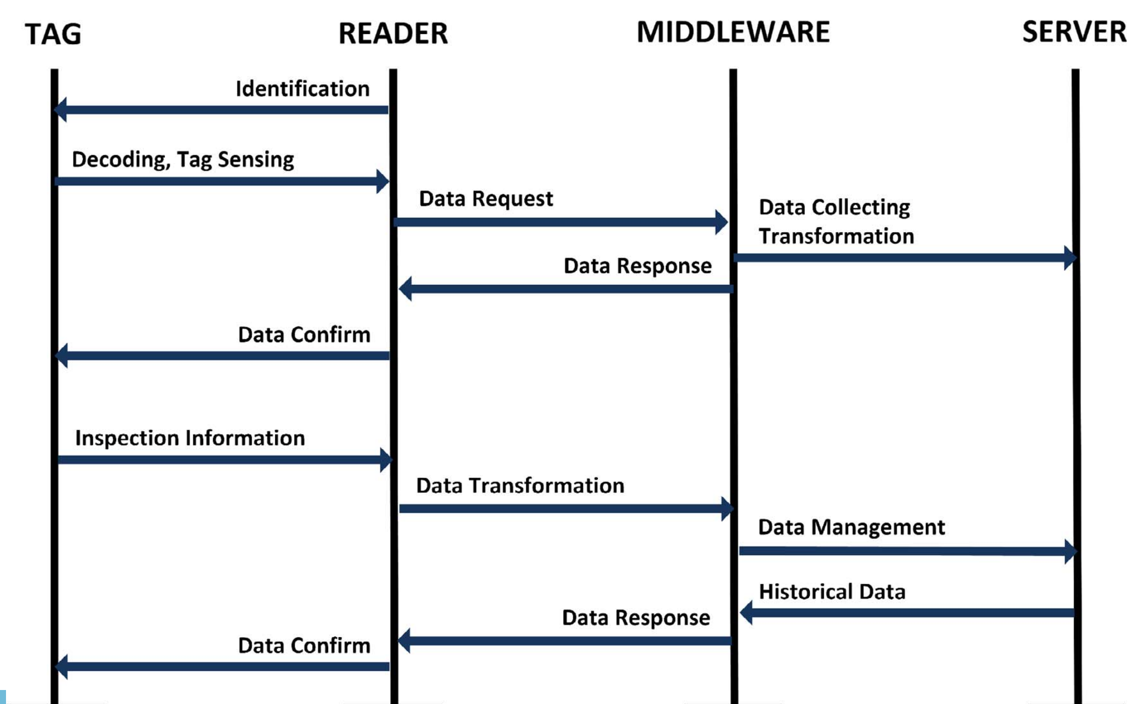

Fig. 7. Data flow of the identification process.

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