Journal of Sustainable Tourism
Vol. 17, No. 3, May 2009, 397–406

Protecting cultural heritage tourism sites with the ubiquitous sensor network

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(*Received 30 May 2008; final version received 22 October 2008*)

Cultural heritage tourism resources are vulnerable to natural and human disasters: once damaged or destroyed, it is hard to restore them to their original condition. This study examines an online and real-time early fire detection system, using advanced information technology and a ubiquitous sensor network to protect cultural heritage tourism resources. It notes the danger of accidental and deliberate fires being started by cultural site visitors, as well as natural fires from lightning strike or nearby forest fires. The system architecture, sensor and network design, and software design of the fire detection system are presented, based on experimental work at the Bulguksa temple in South Korea, a UNESCO World Heritage Site. Lessons learned from building and operating the Ubiquitous(U)-Bulguksa system are presented to provide guidelines for applying ubiquitous sensor networks to protect other cultural heritage tourism resources.

Keywords: cultural heritage tourism resources; Bulguksa temple; fire detection; ubiquitous sensor network

Introduction

With the advent of information technologies, there is an increasing demand for ubiquitous computing in the area of cultural heritage tourism resources. These technologies have been applied to create cultural heritage resources such as virtualized architectural heritage (Virtual Heritage, 2007). Web-based tourism information also provides cultural heritage information about historical and artistic attractions and landscapes, and individual tourists can schedule travel to cultural heritage sites through the use of a ubiquitous cultural Web application (Garzotto et al., 2004).

Many tangible cultural assets are preserved as important national or world heritage resources. Unfortunately, many cultural heritage sites have been damaged, destroyed or transformed by natural or human causes. If cultural tourism resources are destroyed, restoring them to their original condition is difficult and costly. Most of the national building treasures of Korea, including those designated as World Heritage sites by UNESCO, are constructed of wood, so they are very vulnerable to fire. Recently, Namdaemun (or Sungnyemun), designated as National Treasure No. 1 in South Korea, was set on fire by an arsonist. Despite the efforts of more than 360 firefighters, the huge fire finally destroyed this national heritage structure, costing US$21 million to rebuild (Wikipedia, 2008). Wooden cultural

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ISSN 0966-9582 print / ISSN 1747-7646 online

DOI: 10.1080/09669580802582498
http://www.informaworld.com

heritage buildings are particularly vulnerable to fire because of the dangers of cigarettes discarded by visitors, and problems linked to kitchens providing food for visitors in associated hospitality facilities. And wooden heritage buildings are not peculiar to Korea: many historic wooden buildings exist worldwide, especially in Asia and Scandinavia.

Advanced information technology (IT) including ubiquitous computing (Tarasewich & Warkentin, 2002) can be efficiently and effectively applied to protecting these heritage assets. RFID (radio frequency identification)[1] and USN (ubiquitous sensor network)[2] systems are good alternatives for real-time, online monitoring of cultural heritage structures. Both RFID and USN are types of remote automated data collection technologies that operate without a direct line of sight (Ngai, Cheng, Au, & Lai, 2007; Zang & Wang, 2006). The USN uses active sensors, while the RFID is passive in the sense that RFID tags send information on the item that is then identified by an RFID reader. In contrast, the USN collects information on the surroundings or context of an item, as well as the item itself, processes this information and communicates with other devices. Smarter and more intelligent systems using USN can actively respond to the requirements of the item under surveillance. Thus, the USN system is more suitable for the management of cultural heritage sites than the RFID system.

USNs have a variety of application areas. Typical examples are environmental monitoring, military applications, logistical support and health care (Akyildiz, Melodia, & Chowdhury, 2007; Yick, Mukherjee, & Ghosal, 2008). Recently, most of the applications of USNs sponsored by the Korean Ministry of Information and Communication (KMIC) have been introduced by the public sector. Since 2007, USNs have been developed and used for controlling city infrastructures, monitoring the safety of bridge structures, managing cultural heritage sites and monitoring water quality, ocean and weather conditions.

Analog and offline monitoring systems for cultural heritage sites have some disadvantages and difficulties in capturing data in an environment that either requires real-time information or restricts human access. This paper is based on a project, sponsored by the KMIC, regarding an intelligent management system using USNs for cultural heritage resources in the Bulguksa temple known as the Ubiquitous (U)-Bulguksa project.

Bulguksa is a Buddhist temple located in the city of Geongju, in Gyeongsang province in South Korea. The city of Geongju, the former capital of the ancient Silla Kingdom, is a center of cultural heritage possessing numerous ancient relics and national treasures; it is sometimes called the “museum without walls”. The Bulguksa temple also contains many national treasures such as the Dabotap and Seokgatap stone pagodas. The Bulguksa temple, along with the Sokkuram Grotto in the city, was added to the UNESCO World Heritage list in December 1995. Protecting this cultural heritage resource is one of the major issues for the Bulguksa temple. This study describes ways to protect cultural heritage tourism resources by applying ubiquitous sensor networks for capturing and detecting early fire information in a real-time and online wireless sensor network.

Requirements of cultural heritage management systems

Tangible cultural heritage resources are especially vulnerable to being damaged and transformed through time. Figure 1 depicts a cause-and-effect diagram for damage to tangible cultural assets, which is used to explore all the potential or real causes that result in a single effect. As shown in Figure 1, there are various causes such as air, human actions, accidents and natural disasters, through which tangible cultural assets are damaged or destroyed. Human causes include fire, theft and war. Conservation science aims at preserving

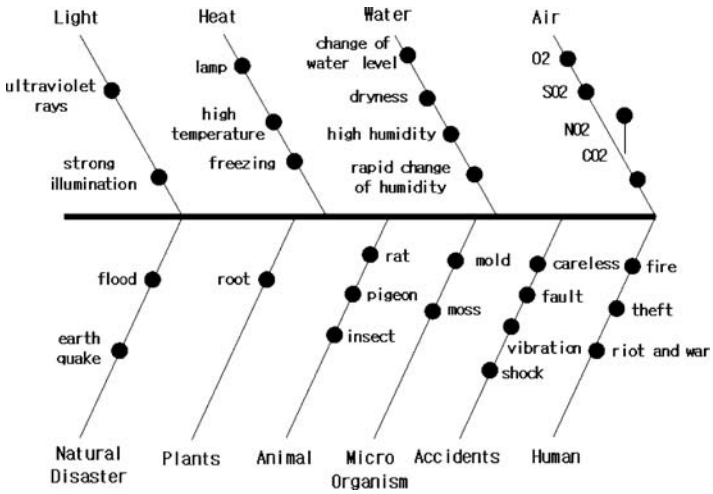

Figure 1. Cause and effect diagram for damage or transformation of cultural properties.

the original structures of cultural properties. Conservation scientists collaborating with information analysts need online and real-time information for the effective management of these cultural resources. Conservation scientists employ data captured from cultural assets for their conservation and restoration.

Figure 2 presents a context diagram including conservation scientists, system managers, information analyzers, knowledge engineers and actors such as firefighters or restoration experts.

There are several requirements that should be considered when designing cultural heritage management systems based on USN:

- What data can be captured through sensors to effectively analyze factors affecting tangible cultural assets? Potential damage or transformation of cultural properties

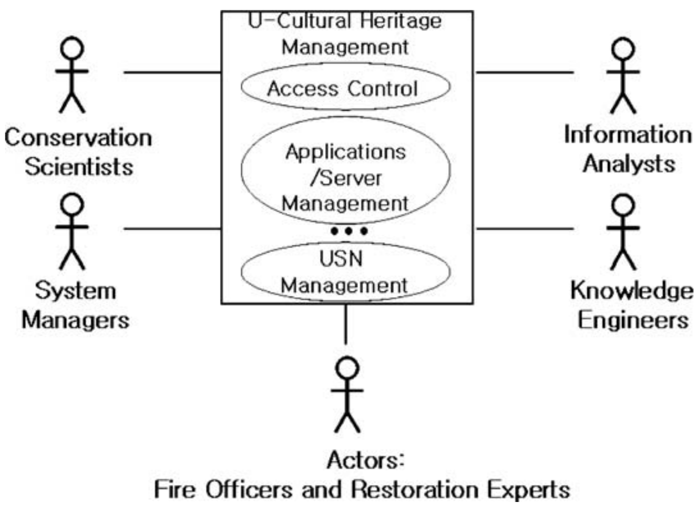

Figure 2. Context diagram of U-cultural heritage management.

depends on the nature of the objects, such as whether they are made of stone, wood or paper. Fire (see Figure 1) is a critical threat to paper cultural properties. Effective fire detection requires a variety of data such as temperature, humidity, pressure, CO, flame, smoke and real-time visual monitoring.

- What are the technological limitation factors? Sensor devices are constrained in terms of battery, communication distance and their accuracy of sensing data (Akyildiz et al., 2007). The issue of low energy consumption is a very important concern in USNs. There are two different methods of solving the power issue for sensor nodes: to reduce energy consumption, or to harvest or extract energy from the environment where the sensor itself is positioned. The former includes such methods as dynamic optimization of the voltage and clock rate, wake-up procedures to keep the devices active at times and efficient routing protocol design (Renyi & Guozheng, 2006). The latter includes technologies to generate background radio signals, thermoelectric conversion and solar or wind power. Solar cell and wake-up procedures applied to the U-Bulguksa project are introduced in the next section. The range of communication is highly dependent on the frequency band employed in the system. The communication range of the sensor node with a 900 MHz band is usually 40–100 m. The max range of the sensor node using ZigBee/IEEE 802.15.4 standard with 2.4 GHz band is 75–100 m (Baronti et al., 2007). However, the range depends on the surrounding environment where the sensor node is located. In the case of the U-Bulguksa project, it was determined that the range of a sensor node is about 50–70 m through testing in the real-world field, because of the many trees around the wall of the temple. Standardization trends or de facto standards of the protocol, middleware and applications should be considered and analyzed in designing the system based on USN. The technology standard is important in terms of interoperability and scalability. ZigBee (2005) is a specification for a suite of high-level communication protocols using small, low-power digital radios as a communication protocol standard for typical wireless personal area networks (WPANs). Middleware lies between applications and operation systems to facilitate developing adaptive USN applications by allowing developers to develop, maintain, deploy and execute various applications independently. There are a variety of middleware approaches for the USN, such as virtual machine-based, modular programming-based, application driven and message-oriented middleware (Hadim & Mohamed, 2006). Because USN is at an early stage of development, it does not yet have available de facto middleware.
- What are the environmental limitation factors? In particular, environmental analysis of natural phenomena such as typhoons and lightning is important, especially if cultural assets are located in the areas where human access is restricted. The impact of a USN on scenic beauty is also important. In the U-Bulguksa project, the temple is located on Tohamsan mountain, and a fire occurring on the mountain would immediately destroy the temple. Therefore, it was decided to build wireless sensor networks around the outer wall of the temple, which is surrounded by many trees. The sensor nodes must be durable and securely sealed, as they are located in the open and exposed to snow and rain. Because many tourists visit the temple, the size of the sensor nodes is important, to avoid compromising the scenic view.

U-Bulguksa: early fire detection systems

Over 70% of the Korean cultural heritage treasures are Buddhist properties, and most Buddhist property is stored in Buddhist temples. In Korea, most temples are located in mountains and are surrounded by forest, making them especially vulnerable to fire because most are wooden buildings; indeed, recently, several temples were completely destroyed by fire. An early fire detection system based on the USN system forms the first part of the U-Bulguksa project.

Service model and system architecture

Figure 3 presents a service model of early fire detection systems. The right-hand side of Figure 3 describes wireless sensor networks with video cameras for sensing fire data. Sensor nodes are placed at key locations inside and outside the temple. The upper left side of Figure 3 shows a control room where duty officers monitor and manage the system. The collected information is sent online in real time to firefighting stations and heritage officers via Web services and short message service (SMS).

Figure 4 presents the system architecture for the service model. The wireless sensor network consists of 27 sensor nodes and one video network camera. The network for the outdoor fire detection system includes 25 sensor nodes installed around the outer wall of the temple, utilizing the 900 MHz band. Twelve sensor nodes are connected to base station 2 (BS2) and 13 sensor nodes are linked to base station 3 (BS3) through a wireless personal area network with low energy consumption. Two base stations send the sensed data to the server with the database systems via CDMA (code division multiple access) communication as illustrated in Figure 4. The surveillance camera and video server are installed at relatively high locations around the temple. Two indoor sensor nodes installed in the wooden main house of the temple send the sensed data to base station 1 (BS1) via the 2.4 GHz band. The server triggered by a fire event forwards the signal to a video camera server to enable duty officers to monitor the specified area.

Design of the system

The fire detection system consists of three important components: sensor nodes, networks and software. A sensor node consists of a hardware layer, which includes a processor with ATmega128L, sensor modules, RF module, and serial interfaces and a software layer.

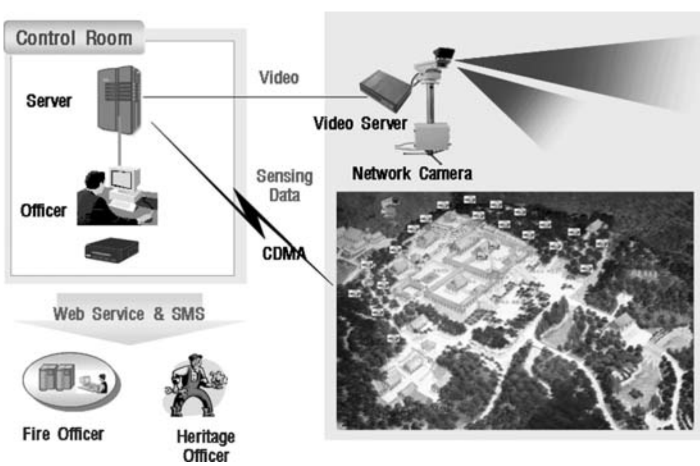

Figure 3. Service model.

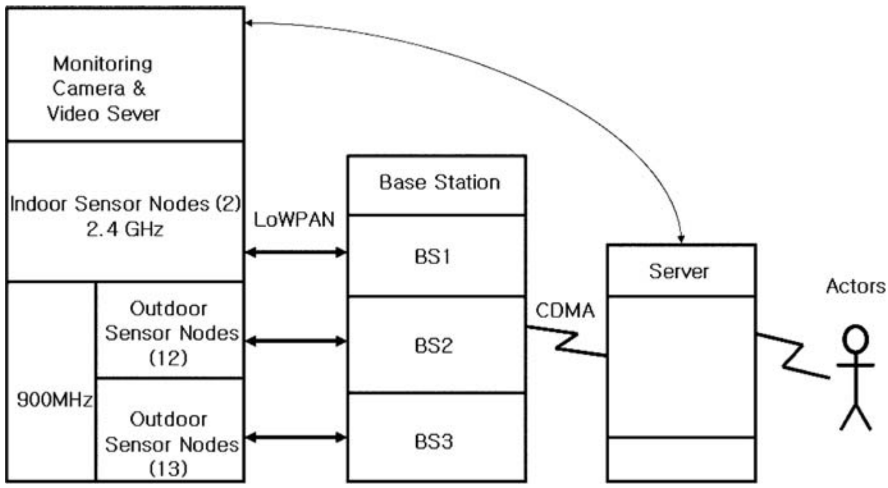

Figure 4. System architecture.

Table 1 shows the hardware specifications of sensor nodes. The outdoor sensor nodes installed around the outer wall of the temple collect information for detecting forest fires. The collected data from the indoor sensor nodes installed in the wooden buildings can be exploited to identify and analyze environmental factors affecting cultural properties stored in the house as well as for fire detection. Factors include temperature, humidity, air pressure, carbon monoxide and flame data for a specified sensor. Table 2 describes a specification of the base station keeping connection between sensor nodes and server.

A simplified information flow in the wireless sensor network is as follows. The server sends messages, such as commands for controlling the sleeping period to minimize power consumption, through each corresponding base station to each sensor node. Each base station aggregates the sensing data from each sensor node and delivers them to the server through a CDMA module. The data delivered to the server are stored in the database and displayed on the server in the format requested by the user. If a fire event occurs at a certain sensor node, the corresponding event signal is delivered to the server. Then, the server sends the signal to the camera video server. The video server captures environmental images surrounding the sensor node. Duty officers observe and monitor the field on a

Table 1. Specification of sensor nodes.

Type of node	Outdoor sensor node	Indoor sensor node
Sensing data	Temperature, humidity, pressure, and luminous intensity, flame and carbon monoxide	Temperature, humidity, pressure and luminous intensity
Microprocessor	Atmel Atmega 128 L	Atmel Atmega 128 L
Memory	4 KB SDRAM, 128 KB Flash, 4 K EEPROM	4 KB SDRAM, 128 KB Flash, 4 K EEPROM
Radio	Chipcon CC1100, 900 MHz	Chipcon CC2420, 2.4GHz ZigBee (IEEE 802.15.4)
Power	Li-ion secondary battery, solar cell rechargeable	4 AA batteries
PC connector	Serial port	Serial port

Table 2. Specification of base station.

Microprocessor	PXA255 ARM RISC, 400 MHz
Memory	64 MB SDRAM, max 128 MB RAM, 64 MB NAND Flash, max 128 MB ROM
CDMA module	CDMA2000 1× RTT
Ethernet	CS8900 10 Mbps
PC connector	USB
Power	DC5V, 3A
Size	10 mm × 140 mm
Operating temperature	−20 to 70°C

computer monitor. The fire events are classified into normal, caution, emergency and fire categories according to the vote number. If the event of fire occurs, then the server can automatically send fire alarm messages to the firefighting station and duty officers as SMS on registered cellular phones. Remote actors such as conservation scientists and firefighters can display, monitor and gather necessary information on the internet.

Conclusions and managerial implications

This study describes a system for protecting cultural heritage tourism resources using advanced information technology that was developed to protect the Bulguksa temple. The fire warning system can assist policymakers and resource managers in protecting valuable cultural heritage tourism resources. The integrated system has been successfully tested and operated for several months. It has proved capable of collecting various data so that the system or officers can correctly determine a fire situation and furthermore quickly, conveniently and accurately provide the necessary information to the right agents. It can automatically notify firefighters or duty officers of an emergency situation, either via the internet or through SMSs when a fire event occurs. Four key lessons were learned from building and deploying the system:

(1) It is important to share knowledge of the USN with organization members to reduce uncertainty about the technology. Many of the members represented in the context diagram of Figure 2 possessed the following uncertainties, in particular, while deploying the system:

  (a) Uncertainty about the appropriateness and usefulness of the USN-based system related to technology advancements. Organizational staff of the Bulguksa temple frequently perceived the future of technologies related to the USN system as uncertain: on the one hand, they wondered if the USN-based system was appropriate and useful, but on the other hand, they were concerned that the system would probably be obsolete in the near future, because of the development of faster technologies.
  (b) Uncertainty about sustaining maintenance and adapting the systems to changing environments. The organizational members were concerned about how they could successfully operate and maintain the system with the support of project teams after its development or adoption. To reduce uncertainties and share understanding and knowledge about the USN-based system, training, workshops, periodical meetings with related group or institutions, exhibitions, testing and evaluations such as fire drills were conducted.

(2) Identify comprehensive information to be captured by the sensors for making decisions. One of the critical factors for successful monitoring systems based on a wireless sensor network is to simply obtain the correct types of data so that managers or the system can diagnose the situation. In our system, a fire event is detected through a variety of data such as temperature, humidity, pressure, CO, flame and real-time video monitoring. The reliability of the USN-based system depends on the information captured by the sensors.

(3) Ensure system reliability and demonstrate remarkably intelligent abilities to assure members of the benefits resulting from the USN-based systems. In general, system reliability includes accuracy, safety, security, etc. In this USN-based system, improving for reliability depends on accuracy of data captured from sensor nodes and accurate notification of fire occurrence without false alarms. We demonstrated how the system could detect fire events and notify duty officers, firefighters and others without human intervention. Error rates of data collected from sensor nodes such as temperature, humidity, flame and so on were acceptable. Such testing is mandatory for fire protection because of provisions of the National Emergency Management Agency in Korea. After a year of installation, we checked and tested the network, cameras, server and sensor nodes. The ability to comprehensively consider a variety of data captured from sensor nodes is important for accurately distinguishing fire events from false alarms. In particular, the intelligent ability to minimize false alarms has a significant impact on the system reliability when duty officers cannot watch the camera and confirm whether or not fire occurs during night. A lot of false alarms increase energy consumption of batteries. In this system, firefighters in a remote location can easily and conveniently find the location of a fire using the Web service as well as SMS notification. Thus, we are developing a server-side middleware solution which is a program based on ontology exploiting the knowledge of experts such as firefighters and conservation scientists. According to the literature on ubiquitous computing or networks and a ubiquitous society, ubiquitous technology seems to enable information or services to be offered in a more intelligent manner. Thus, many users expect that the USN-based system will provide remarkable capabilities as the technology continues to develop.

(4) Consider the regulatory environment, especially in the early stages of technology development. In Korea, government regulations and policies encourage the application of RFID/USN to many areas by providing legal and support programs for actualizing the RFID/USN. But, there is also a blind spot where it is difficult to choose an appropriate alternative because there are no clear laws or regulations, especially in the early stages of the technology. In terms of technology, the 433 MHz frequency band is appropriate to mountainous areas that are difficult to access. However, the 433 MHz band for RFID is allowed to provide only real-time monitoring and tracking of containers in Korea. In this system, the 900 MHz band was employed in the outdoor sensor network, even though 433 MHz is more appropriate technologically.

The current version of the system needs to be extended to maximize its benefits. Current sensor nodes are not capable of collecting information on smoke and CO. The sensor nodes of the system need to append other sensor modules collecting those data to enhance system accuracy. The intelligence and reliability of the system depend on the reliability of early fire detection and warning online and in real time, anywhere and anytime. Thus, we plan to extend the system by applying Semantic Web technology based on ontology, which exploits knowledge shared by human experts such as firefighters and conservation scientists. The extended system will be more intelligent and minimize the frequency of false alarms without human intervention.

The ultimate goal of the system is to realize U-Bulguksa as an integrated system enabling both the intelligent management of cultural properties based on the USN, and also U-Tourism. The final version of the system will provide a variety of other data including corrosion, crack and tilt, as shown in Figure 1, to conservation scientists both online and in real time through the wireless sensor network. And it is important to note that the Bulguksa temple is one of the most popular sightseeing locations in Korea. Thus, the system needs to allow tourists with mobile devices such as cellular phones or PDAs to obtain context-aware, personalized information and services, as well as acting as a fire warning system.

Notes on contributor/s

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Notes

1. RFID is an automatic method identifying unique objects using radio frequencies instead of the existing system of bar code.
2. USN is an infrastructure having capabilities to provide services and information anytime and anywhere by making wireless sensor nodes collect and transmit information about their surrounding environment.

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