MONITORING OF HISTORICAL/HERITAGE SITES WITH INTERNET OF THINGS

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Abstract

Historical or heritage sites including buildings, monuments and other structures are considered an important asset for any country or society. They not only reflect the cultural past but also have strategic and economic significance to both the country and the people living in that area. UNESCO has declared the heritage sites belong to the entire world irrespective of where are actually located. Hence governments and other organizations make special efforts to preserve them. One of the important pre-requisites for effective conservation is the proactive monitoring of them. An effective monitoring scheme needs to monitor these sites around the clock and alert the responsible parties when immediate attention is required. This paper presents a model for using Internet of Things for effective monitoring of heritage sites and artifacts along with a prototype system that has been developed for this purpose.

Keywords: Internet of Things, heritage sites and artifacts, tourist attraction, monitoring, Arduino BT, prototype.

Introduction

Historical sites such as buildings, monuments, religious sites and other structures are considered important assets for countries and societies (Ismail, 2013). Historical artifacts represent and reflect the rich cultural past of societies and countries and hence considered cultural icons by almost all the nations. In addition to being the witness to the past cultural and technical supremacy of a nation, they also contribute to the present day economy of the country by attracting cultural tourists both local as well as foreign (Perera, 2013). Visiting sites of cultural significance is commonly known as cultural or heritage tourism. Cultural or heritage tourism has been officially defined as the travel directed towards experiencing the arts, heritage and activities that represent the stories and people of the past and present of a particular region (Csapo, 2012). Cultural tourism has been identified as one of important component of the larger tourism sector. Economically, cultural tourism plays an important role in attracting foreign exchange as well as revitalizing the local economy of the areas. Cultural sites attract different types of people including casual visitors, students, academics and researchers. Cultural tourists are considered to be better educated, wealthy and well travelled compared to other tourists (Gunlu et al., 2009). Hence, they are considered to belong to the upscale travelers who fall under the category of desirable visitors spending substantially more than the standard tourists generally do.

Over and above the economic reasons, states and governments are required by international conventions to maintain heritage sites (Ismail, 2013). UNESCO requires governments and other

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state and non state actors to take all possible positive actions to preserve heritage sites and monuments, so that they will be available for the future generations similar to that of the past and present generations. UNESCO further states that all the world heritage sites belong to all the people of the world irrespective of the territory on which they are located underscoring the importance of conserving them (Anglin, 2013). In order to preserve the heritage sites properly, it is of vital importance to monitor them of various aspects that may harm their quality and life.

In this paper, the authors take a look at how Internet of Things (IoT) can be effectively used for monitoring various environmental parameters that may affect the life of heritage sites. This paper has been divided into six sections as follows; Section 1 presents an introduction to the paper along with the problem studied. Section 2 discusses the importance of the protection of historical/heritage sites with brief analysis of various methods used. Section 3 introduces Internet of Things an emerging paradigm in Future Internet. Section 4 critically analyses the related work with special emphasis on their strengths and weaknesses. Section 5 presents the proposed model along with the prototype system developed in this research. Finally, Section 6 concludes the paper.

Protection of Historical Sites

As outlined above, governments and other international and national organizations have realized the importance of preserving heritage/historical sites for the benefit of present as well as future generations. Several methods have adopted by interested parties in preserving these artifacts and sites. General guidelines associated with the conservation of heritage sites and artifacts follow three critical points. That are minimal human intervention, appropriate materials and reversible methods and complete and comprehensive documentation of all the work carried out (Stubbs, 2009). Conservation of heritage sites is not a trivial task including multi faceted activities such as preventive conservation, examination, documentation, research, treatment, and education (Boersma, 2016). Hence, conservators are often required to deal with many competing demands including arriving at compromises between preserving appearance, maintaining original design and material properties, and ability to reverse changes. Reversibility is now considered one of the important aspects of restoration so as to reduce problems with future treatment, investigation, and use. Thus, for conservators to choose an appropriate strategy and apply their professional knowledge and experience appropriately, they are required to take into account views of the stakeholders, the values and meaning of the work/site, and the physical needs of the material.

Many methods have been adopted by conservators for maintaining heritage sites. One of them is to put them for contemporary use (Ismail, 2013). This method has been applied in preserving old building situated within cities. Rehabilitating and converting old building for contemporary use instead of replacing them with new ones have many advantages. These advantages include the preservation of cultural heritage, enhancing the local economic activities through attracting tourists and maintaining the environmental sustainability (Boarin et al., 2014; McDonagh & Nahkies, 2010).

The other method is to restore, preserve and maintain the heritage sites as tourist attractions (Gunlu et al., 2009). Many types of heritage sites and artifacts such as places of worship, museums, historical monuments, towns and urban areas and landforms fall under this group. When these places are restored, the conservators try their best to maintain the look and setting of the places as original as possible. In doing so, they would try to preserve the original design and materials while keeping the reversibility of operations the prime objective (D'Agostino & Bellomo, 2003).

Once the restoration work has been completed, these sites need continuous monitoring for changes in the restored work as well as health of the overall structure (Anastasi et al. 2009). This is mainly owing to the reason that these structures are considered very vulnerable and subjected to high risk due to their age and methods and materials used for construction. As places become popular or located close to urban centers, they attract lot of visitors. These visitors usually travel by vehicles to these places. The movement of vehicles adjacent to historical sites create many problems including the generation of vibration patterns that are transmitted through the ground to the sites and the emission of polluting gases that may degrade the look of the artifacts as well as interact with the construction materials adversely. Also, the presence of people in large numbers may also have negative effects, if not managed properly. Hence the causes associated with the degradation of these sites artifacts must be identified and controlled before it becomes too late. Identifying the causes may not be straight forward as the results observed are generally the effects of multiple factors. Hence long term data collection and advanced analysis methods need to be employed. Also, data must be collected on many factors using non intrusive methods for long times at regular intervals. Hence, manual methods of data collection may not be feasible. Hence automatic data collection using advanced technologies does become a must.

Internet of Things

Internet of Things (IoT) is a recent paradigm in distributed sensors and other related real as well as virtual objects on the Internet that is expected to shape the Future Internet (FI) (Gubbi et al., 2013). The objects in IoT include both physical as well as virtual components or elements. A sensor node monitoring the operation of the engine or the tire pressure of a vehicle is a real object whereas a middleware component of a software system that monitors the performance of an application is a virtual object. All these objects are connected together and communicate with each other over the Internet (Vermesan & Friess, 2013). IoT is the result of the advances made in many related fields including hardware, software and communication technologies (Firdhous et al., 2017). Similar to IoT, mobile computing, pervasive computing, wireless sensor networks, and cyber physical systems have also attracted the attention of the researchers and advances are made in all these independent but related fields. The binding force that keeps all these research areas together is the objective of making this planet a better and smarter one for all living beings (Tiwari, 2017). Though the above areas appear to work on different problems and applications, there are several things in common and they are dependent on a few common underlying technologies such as real-time computing, machine learning, security and privacy, signal processing and data analytics.

The IoT has extended the reach of the Internet beyond the traditional boundary of computing devices to day to day objects such as household appliances, vehicles and their components, environment monitors etc., (Mattern & Floerkemeier, 2010). IoT enables the real world objects to be connected to virtual objects such as software processes making them to be monitored and controlled real time with minimum or no human intervention. This makes computing truly ubiquitous and pervasive. The inclusion of sensing, data capturing, processing and analyzing ability into common everyday objects and devices make them smart creating the foundation for a smarter society. Smart objects with built-in communication capability have the potential to revolutionize the utility of the devices they become part of. These objects can sense and understand the environment along with their context through the sensors embedded in them.

The context awareness comes through the communication with other similar objects and intelligence at the central (distributed) processing and analytics system (Liu et al., 2013). Digitally enhancing the everyday devices this way upgrade these devices along with their functions and capabilities beyond their traditional boundaries. This development is already evident today as more and more devices including sewing machines, exercise bikes, electric toothbrushes, washing machines, electricity meters and photocopiers are being computerized and equipped with network interfaces (Mattern & Floerkemeier, 2010).

Internet connectivity to everyday objects with sensing and controlling capability enables them to be monitored remotely. Also, the possibility of continuous monitoring and up-to-date information collection with fine resolution on real world objects and the surrounding environment enables many aspects of the real world to be observed at previously unattained levels of detail. The advances in hardware and software technologies facilitate all these things to be realized at negligible costs. This allows us to better understand the underlying processes and principles of many real world and natural phenomena with added ability of better and more efficient control and management of many of them as well. The ability to react to events in the physical world in an automatic, expeditious and informed manner not only opens up new opportunities for dealing with complex or critical situations, but also enables a wide variety of processes to be optimized. The real time interpretation of data from the physical world would lead to the influx of novel systems and services delivering substantial economic and social benefits. All the above have been summarized into a single definition by the European research cluster of IoT (IERC) as:

> The Internet of Things allows people and things to be connected anytime, anyplace, with anything and anyone, ideally using any path/network, and any service.
>
> Razzaque et al., 2016

Figure 1 shows the elements of IoT in a more user friendly graphical format.

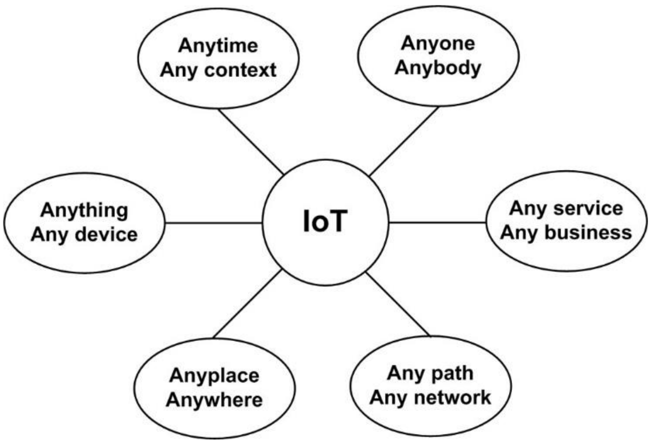

Fig. 1: Elements of IoT
Source: Razzaque et al., 2016

Thus, IoT based applications have been proposed and implemented in several areas including environment management, environment monitoring, home monitoring, security systems, energy management in public and private spaces, elderly care systems and microclimate monitoring systems (Shah & Mishra, 2016). The heritage site monitoring model proposed in this research would enable the conservators to carry out their jobs more effectively and efficiently. It is proposed to use both semiconductor sensors and electromechanical transducers along with other supporting elements directly connected to the IoT board. The IoT system would be programmed to collect data at regular intervals in an unobtrusive manner and transfer it to the central processing station. The IoT device would need to be connected to the Internet and transfer the data to the processing station using the 4G/5G mobile communication network.

Related Work

Several attempts have been made to monitor the historical monuments using advanced technologies. This section takes a brief look at them with a critical analysis of the advantages and disadvantages of them.

Merello et al., (2012) have studied the internal environment of the Ariadne's house in Pompeii, Italy. Ariadne's house is an upper class single family house built in the 2nd century BC. The inner walls of this house are decorated by frescos, which are as old as the house itself. The house has been damaged by several natural disasters including earth quacks and volcanic eruptions from the near mount Vesuvius. Also, most part of the time the house has been left without a roof leaving the frescos exposed to sun light and rain. Most of the frescos have been damaged due to continuous exposure to sunlight and rain. In the 1970s few of the rooms in the Ariadne's house have been covered by transparent polycarbonate roofs protecting the frescos from the direct impact of rainwater. But the frescos are still exposed to direct sunlight, heat and humidity and seasonal changes of environmental factors. In order to monitor the environment surrounding the frescos a set of sensors have been deployed and the readings taken. The main drawback of this setup is the absence of data communication facility to the central data analyzing system. Hence, this cannot be considered a fully automated system. This hampers the usability of the system and a hindrance to a comparative study between multiple or distributed sites.

Balletti et al., (2009) have presented a microclimate monitoring system for small size museums. The main objective of this work is to use simple instruments and tools to monitor the conditions of wooden paintings housed in a museum. The temperature, relative humidity and lighting conditions were monitored using data loggers at regular intervals. The data has been collected manually by logging the data in a journal. This system lacks any automated way of data collection and analysis and hence have limited application in today's context.

Grosso and Basso (2014), Garziera et al., (2007), Calcina et al., (2013) and Anastasi et al., (2009) conducted research on the structural health monitoring of heritage buildings with special reference to the effects of vibrations. With the development of modern transportation networks, increase of vehicles on the roads and other human induced activities, ground vibration has become a common phenomenon in urban areas. Vibrations are created and transferred to the underlying ground by vehicles which in turn are transferred to structures standing on them. Vibration has a deteriorating effect on the health of manmade structures as they affect the quality of the work as well as materials used. Vibration sensors have been implemented for detecting the strength of vibrations along with other attributes. The sensors employed are all independent and do not interact with others. Also, the monitoring is carried out onsite and hence remote monitoring is not possible.

Alshawabkeh and El-Khalili, (2013) have employed photogrammetry and laser scanning techniques for detecting material movement in historical buildings. This is a novel method but still suffers from several shortcomings including non automation of monitoring and detection requiring a lot of human intervention. Hence this has limited applicability in today's widespread application of remote monitoring techniques. But photogrammetry and laser scanning techniques can be incorporated into modern monitoring systems enhancing their ability of detecting material changes.

Ristic and Radovanovic, (2013) have used infrared thermography in moisture and earthquake damage detection. This is a novel scheme for detecting the environment attributes related to heat and heat induced changes. But the implementation lacks the automatic monitoring and characterization of changes. Also, there is no remote monitoring capability with the system implemented. Hence this method has limited applicability as it is but can be improved by infrared thermographic sensors into a modern monitoring system. (Ristic & Radovanovic, 2013)
From the above discussion, it can be seen that the current implementation of heritage site monitoring schemes suffer from many shortcomings. None of the above scheme is capable of remote monitoring and make use of the recent advances in information and communication technologies. Hence, the proposed IoT enabled heritage site monitoring system will fill the gap.

Proposed IoT-basedHeritage Site Monitoring System

The proposed heritage site monitoring system consists of three main units. They are namely the sensor networks, gateway node and the data processing node (system). A collection of sensors such as temperature sensor, humidity sensor, sensors for detecting various gases and solid particles etc., are used to monitor various parameters of the environment. These sensors are in turn connected to a single low end IoT board known as a sensing node. These sensors will sense the different environment parameters at regular intervals. The sensing node will then transfer the data collected to the gateway node, which then transmits the data to the processing node. The communication between the sensing node(s) and the gateway node takes place using low power short distance Wi-Fi network. The data transfer between the gateway node and the processing node through 3G/4G network using TCP/IP protocol. Figure 2 shows the architecture of the proposed monitoring system. This system can be easily extended to cover large areas by increasing the number of sensing nodes as well as gateway nodes keeping the processing node implemented on a more powerful computer or simply hosting it on the cloud.

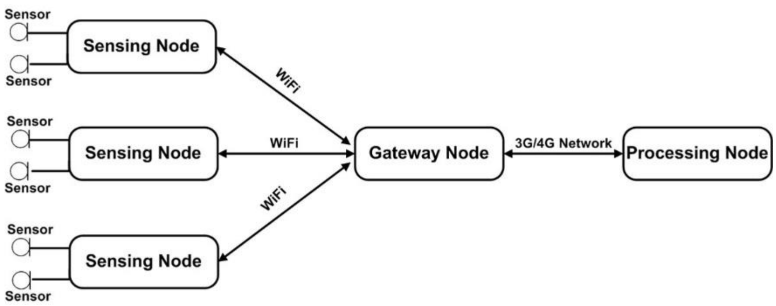

Fig. 2: Architecture of the Monitoring System
Source: author

The software required for data acquisition, storage, processing and dissemination has been implemented through a layered model. Figure 3 shows the proposed layered model. The layered model enables the management of the application easier and better. This model can be extended easily to accommodate new requirements and applications. The lowest layer (data acquisition layer) is implemented on the sensor nodes while the data transmission layer would be on the gateway nodes. All the other layers including the data cleansing and storage are implemented on the processing node. Handling of the storing of data within a single layer enables the data storage to be independent of applications and sharing the same data by many applications. Data dissemination layer is implemented using the web making the access of information easier using any web browser on any device.

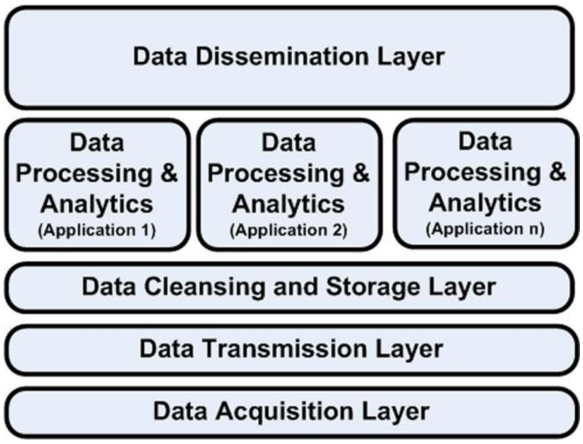

Fig. 3: Layered Software Model
Source: author

A prototype data acquisition and dissemination system has been developed for testing purposes. The prototype sensing node has been implemented using Arduino BT prototype board along with other components in the laboratory. For testing purposes, only two types of sensors namely, temperature and humidity sensors were used. These two types of sensors have been selected as simple high accuracy semiconductor sensors can be purchased from the market at very low prices. Also, these sensors can be calibrated in the laboratory with relative ease using traditional calibration techniques. Figure 4 shows the prototype sensing node implemented in the laboratory.

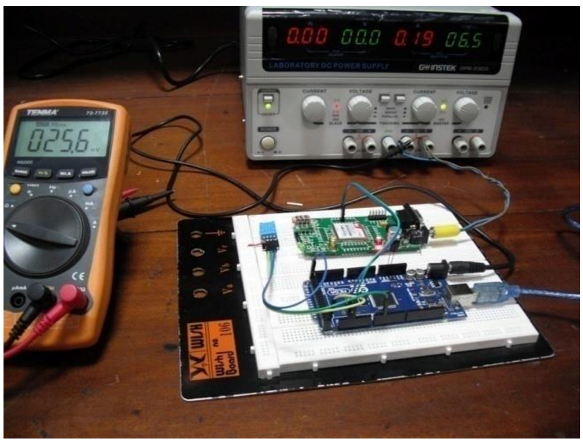

Fig. 4: Prototype Sensing Node
Source: author

The data collected by the monitoring system has been uploaded to the server setup within the laboratory itself for further processing. The real processing node can be hosted on the cloud when better resilience, security, availability and lower cost compared to the conventional in-house servers are required.

The testing of the prototype has been carried out by installing the sensors just outside the laboratory. Two temperature sensors for measuring the inside and outside temperature for comparison purposes and humidity sensors were selected for monitoring and testing. Figures 5 show the inside temperature against that of outside temperature along with the relative humidity respectively.

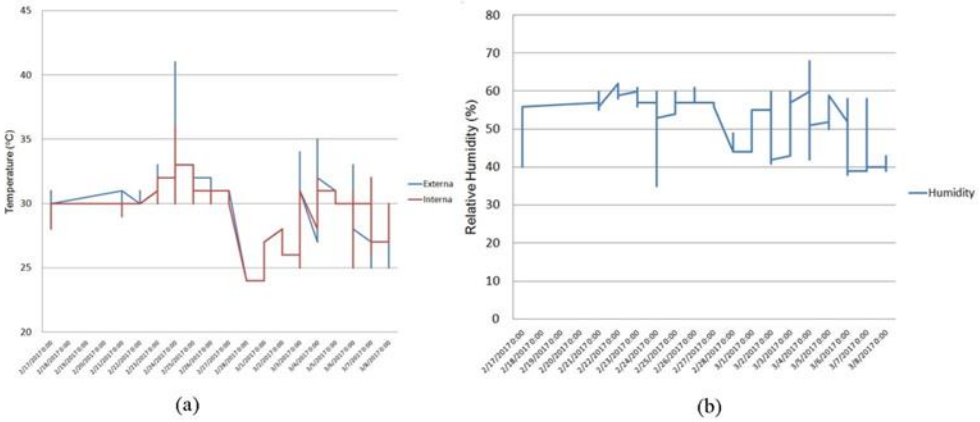

Fig. 5: Experiment Results
Source: author

From Figure 5, it can be seen that even the small momentary changes in the observed parameters are also captured by the system. The sensitivity of the system can be adjusted to suit the requirement by selecting the right type of sensor without modifying other parts of the system. Similarly, the sensing (sampling) interval can be easily modified programmatically.

Conclusions

This paper presented the IoT based heritage site monitoring system developed for tracking different environment parameters near a site. The design of the system followed an open design philosophy so that it can be expanded to cover larger areas with minor modifications. The prototype was developed with a single sensing node with three sensors, a gateway node and a processing node. The number of sensing nodes within a specific area can be expanded without affecting the other parts of the network or noncontiguous or very large contiguous areas can be monitored with multiple gateways and sensing nodes. Currently the gateway and processing nodes are located within the same area communicating through a Wi-Fi network. But this is not a requirement or limitation of the design. The processing node can be either hosted locally or moved to the Internet with a minor configuration change of modifying the destination IP address in the gateway nodes. A single sensing node can monitor many environment parameters as the Arduino BT prototype board contains six analog and 14 digital I/O pins on a single board.

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