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Telematics in the Technical Condition Monitoring of Concrete Dams Structures Using Wireless Sensor Networks

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ABSTRACT
The safety of concrete dams, such as gravity dams, buttress dams, and arch dams, is directly related to not only its social and economic benefits, but also the personal and property safety of residents around the reservoir area. Therefore, it is of great importance to monitor the health of concrete dams using the obtained real-time information. In this paper, reviewed using an automatic wireless sensor monitoring system for temperature and humidity monitoring within concrete structures and A Real-Time Temperature Data Transmission Approach for Intelligent Cooling Control of Mass Concrete by using temperature sensors in arch dam. Structural Health Monitoring (SHM) aims to develop automated systems for the continuous monitoring, inspection, and damage detection of structures with minimum labour involvement.

KEYWORDS: wireless sensor networks, telematics, concrete dams, structural health monitoring decision making

1. Introduction

The safety of concrete dams, such as gravity dams, buttress dams, and arch dams, is directly related to not only its social and economic benefits, but also the personal and property safety of residents around the reservoir area. Therefore, it is of great importance to monitor the health of concrete dams using the obtained real-time information. Structure health monitoring (SHM) is a process to search for reasonable and economical ways to monitor structural state, so that its remaining structural life can be known and possibly extended [1].

Structure health monitoring (SHM) [2] is a process to search for reasonable and economical ways to monitor structural state, so that its remaining structural life can be known and possibly extended. For traditional static dam health monitoring methods, the commonly measured quantities are displacement, seepage flow, temperature, and so forth. With the measured data of these quantities, we usually can only detect the local damage of a structure where the instruments are installed and it is very difficult to evaluate the global state of large hydraulic structures. The structural vibration characteristics, such as frequencies, damping ratios, and modal shapes, can reflect the local and the global structural damage information. In addition, with the construction of vibration monitoring system of structures, such as the dam strong earthquake monitoring system and the powerhouse vibration monitoring system, the real-time vibration monitoring data of concrete dams can be acquired conveniently now. Therefore, recently, the vibration-based structural health monitoring technology is widely concerned in the hydraulic engineering [3].

The previous studies development of an automatic wireless sensor monitoring system for civil engineering structures. The objective is to provide a solution to measure both temperature and humidity inside a concrete structure. The research has been focused in the early age and curing phase period. Four solutions have been addressed. The first one involves the use of a negative temperature coefficient (NTC) thermistor and an IRIS mote allowing for the creation of an IEEE 802.15.4 network. However, the results have shown that the sensor measurements present a 5 standard deviation between the actual and the experimental values. The second one considers the use of the SHT15 (humidity/temperature) sensor, together with the PIC18F4680 microcontroller or the Arduino platform. The third solution involves the use of the SHT21S (humidity/temperature) sensor and the eZ430-RF2500 wireless development tool platform for the MSP430 microcontroller. The primary objective of this interdisciplinary research is to develop a prototype for Wireless Sensor Networks (WSNs) allowing for remotely monitoring certain concrete structures. WSNs are formed by tiny devices, known as motes, that incorporate a microcontroller, sensors, memory, a power unit and a communication module. They are able to sense the environment and communicate the information gathered from the sensors to the sink node through wireless links [4].

Sensors and associated monitoring systems to assess materials performance form an important element in the inspection, assessment and management of concrete structures. There are more than fifty different types of sensor whose deployment into practical devices facilitates long-term monitoring of structural changes, reinforcement corrosion, concrete chemistry, moisture state and temperature [5]. The development of new sensor concepts allows for a more rational approach to the assessment of repair options, and scheduling of inspection and maintenance programmes in different civil engineering structures. Currently, there is a growing number of recent studies for the development of sensors in concrete structures, to monitoring from earlier-age parameters to environmental conditions that can cause deterioration processes, some of which may be highlighted [6]. Studied the performance of a fibre-optic sensor for monitoring cracks of concrete, masonry and bituminous elements. The proposed sensor does not require prior knowledge of the locations of cracks, which is significantly advanced over existing crack monitoring techniques. Moreover, according to the authors, several cracks can be detected, located and monitored using a single fibre [7].

Embedded sensors in the concrete near the surface (depth of 50 mm) enable measurements of the spatial and temporal distribution of the electrical characteristics within the cover-zone. Thereby it allows for an integrated assessment of its performance. Regular monitoring can enable cover-zone response to different ambient environments, namely changes in the temperature [8]. Insertion of small sensors inside or at the surface of the concrete can be considered as one of the most promising development in order to monitor the long-term behaviour of concrete structures. Corrosion monitoring is possible using different sensors and methods that can work in the alkaline media of concrete for several years. Recorded data for corrosion potential and electrical concrete resistance obtained in real structures exposed to the environment can be used to determine the corrosion rate that corresponds to the concrete structure [9].

An effective SHM system can in real time, and online, detect various defects and monitor strain, stress, and temperature so that the optimum maintenance of the structures can be carried out to ensure safety and durable service life. In general, a typical SHM system includes three major components: a sensor system, a data processing system (including data acquisition, transmission, and storage), and a health evaluation system (including diagnostic algorithms and information management). The first step to set upthis system is to incorporate a level of stable and reliable structural sensing capability [10].

Smart Wireless sensors and technology

The sensing interface includes an interface to which sensors can be connected and an analog-to-digital converter (ADC). The computational core generally consists of a microcontroller for the computational tasks, a random access memory (RAM) to stack the measured and processed data, and a flash memory with software programs for the system operation and data processing. The wireless transceiver is an integral component of the wireless system, which is composed of a RF radio modem and antenna to communicate the processing information with other wireless sensors and to transfer the processed data to a remote data server. When a structure is monitored using a smart wireless sensor, the performance and functionality of each subsystem must be carefully selected considering the structural type, quantities to monitor, sensor locations, and environment of the structure. For a case of vibration-based monitoring algorithm, an ADC with 16-bit or higher conversion resolution is preferred due to small amplitudes of the vibration signals, and the wireless transceiver must have enough transmission range for stable wireless communication. If the embedded software requires long-time history data and high computational power, the microcontroller and peripheral RAM must have large data bus and memory space. For acoustic or ultrasonic NDE, high sampling capability of the ADC is required [11].

2. Previous Experiments Works: Monitoring of Concrete Dams Structures Using Wireless Sensor Networks

In the context of WSNs applied to civil engineering structures it is important to create a monitoring device platform that is able to accommodate a wide range of sensors, depending on the needs, expandability and cost, while sharing the information across the network. For this purpose, remote agents can be collectors of information either by storing the data into a microSD card, to be accessed later on, or by wirelessly transmitting this information, in real time, to a Mote Interface Board (gateway) that is connected to a PC, allowing for a rapid intervention of civil engineers, if needed, as shown in Fig. 1 [12].

2.1 SHT15 humidity and temperature sensor [13]

The SHT15 digital sensor was used, facilitating to measure both temperature and humidity with high accuracy in a single chip sensor.The conversion from the raw value returned by the SHT15 sensor, $R_{xval,}$ to the temperature and humidity values was performed by using the following equations:

$$\text{Temperature } [\,] = (\, R_{xva} l \text{ X } 0.01) - 40 \quad (1)$$

$$\text{Humidity } [\ \%HR] = -4.0 + 0.0405 \text{ x } R_{xva} l - 0.0000028 \text{ x } R_{xva} l \text{ x } R_{xva} l \quad (2)$$

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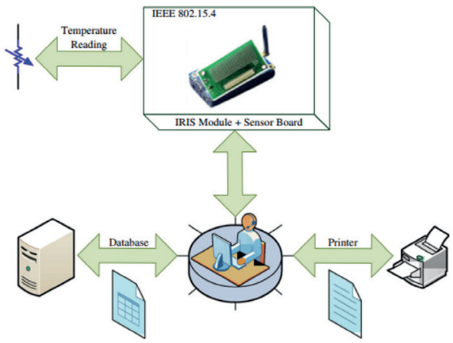

Fig. 1. Wireless sensors architecture for the monitoring of civil engineering structure [12]

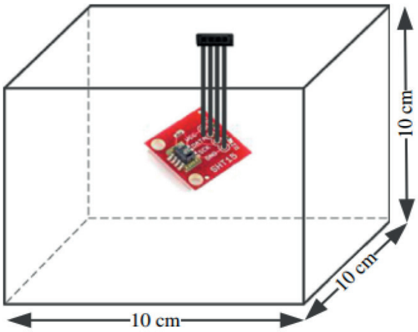

Fig. 2. Schematic representation of process to measure the temperature and humidity within the concrete cube [12]

2.2 The result

SHT15 humidity and temperature sensor tests considers the use of the SHT15 sensor, allowing for measuring both the humidity and temperature. Two solutions were tested, one with the PIC18F4680 microcontroller and another one using the Arduino platform. Before using the SHT15 sensor in a real scenario, some tests have been performed to verify the accuracy of the temperature and humidity readings. By using a temperature of 16.3 C inside a fridge chamber, and by comparing the results obtained from the sensor with the ones obtained from the sensor probe, we conclude that the results are very similar, as shown in (Fig 3). To measure humidity we place the SHT15 sensor inside a small mortar cube for sensor protection, Then, the cubes were placed in a tray (with 2–3 mm water level), we observed the rise of water inside the cube by capillary, as shown in (Fig 4). After around one minute, the humidity reaches a value of 98% RH. The objective of this test was to verify the sensor integrity, as well as the porosity effect of its mortar shell. The results obtained from both PIC18F4680 and Arduino platform were identical. The tests were carried out during several hours, to observe if any variation of humidity and temperature could be detected. In another experiment a SHT15 sensor with a mortar shell was fully immersed in water. One observes that the temperature was decreasing while the humidity was increasing. After 20 min of accurate measurements, we have decided to prolong the test during one week. However, after one day, the SHT15 temperature sensor went off. Then, after 4 days the same happened to the humidity sensor. It is believed that the primary reason for this occurrence is that some chemical reactions inside the mortar shell have affected the capacitance of the sensor.

Sensor components might not resist to alkaline ions present in cement, namely calcium hydroxide, which can be released in water from its mortar shell during immersion. To solve this problem, instead of making a cement-based mortar shell it may be preferable to shield the sensor using other material, textile or polymer based.

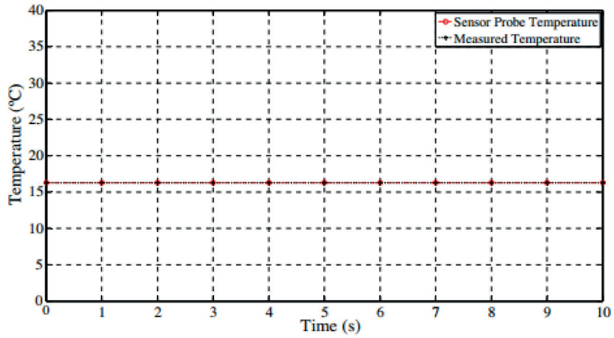

Fig. 3. Sensor probe temperature versus measured temperature inside the fridge chamber by using an SHT15 temperature sensor [12]

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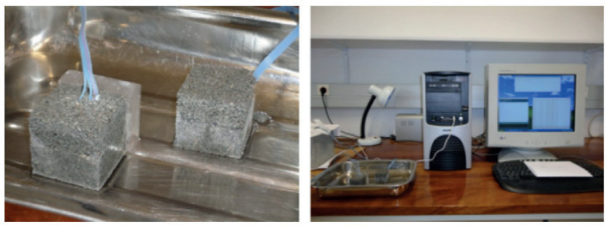

Fig. 4. Setup to measure temperature and humidity using an SHT15 sensor inside a mortar cube for sensor protection [12]

3. A Real-Time Temperature Data Transmission Approach for Intelligent Cooling Control of Mass Concrete by using temperature sensors [14]

Peng Lin, Qingbin Li, and Pinyu Jia 2014 studied about a real-time temperature data transmission approach for intelligent cooling control of mass concrete by using sensor. A mathematical description of a digital temperature control model is introduced in detail. Based on pipe mounted and electrically linked temperature sensors, together with post data handling hardware and software, a stable, real-time, highly effective temperature data transmission solution technique is developed and utilized within the intelligent mass concrete cooling control system. Once the user has issued the relevant command, the proposed programmable logic controllers (PLC) code performs all necessary steps without further interaction. The code can control the hardware, obtain, read, and perform calculations, and display the data accurately. Hardening concrete is an aggregate of complex physicochemical processes including the liberation of heat. The proposed control system prevented unwanted structural change within the massive concrete blocks caused by these exothermic processes based on an application case study analysis. The proposed temperature data transmission approach has proved very useful for the temperature monitoring of a high arch dam and is able to control thermal stresses in mass concrete for similar projects involving mass concrete.

This paper, relating to a real-time temperature data transmission approach at a super high arch dam site, presents a detailed description of certain aspects of a control system that is intended to ensure the structural integrity of massive concrete structures during the construction process. The cooling control system prevents unwanted structural changes within massive concrete blocks by carrying away the heat generated by the exothermic processes of cement hydration. The proposed temperature transmission approach collects temperature data from many sensors and prevents the hardening concrete from overheating by controlling the water flow inside the cooling pipes constructed within the concrete structure. The temperature transmission system includes the acquisition of temperature data, management of various intelligent modules, temperature data handling, sorting and filtering, and temperature data transfer to the module control server. The detailed PLC software configuration and programming are also illustrated. An application case of temperature monitoring of the Xiluodu arch dam during the construction period is discussed in detail. The paper aims to provide a convenient solution to the process of cooling control via the pipes in a situation where the laying of cables is not possible.

3.1 Application Case Study

3.1.1 Brief Introduction to Dam Site

The proposed method was applied to the temperature control of the Xiluodu arch dam during construction [17, 18]. The project is located on the Jinshajiang River, in the Leibo County of Sichuan province. The principal structures consist of a double-curvature arch dam 285.5 meters high, crest length about 700 meters, spillway, underground powerhouse, and logway. A total of 6,000,000 cubic meters of concrete were poured. Because of the high stresses in an arch dam structure and the construction process control difficulties the basic temperature control principle was to maintain ultimately small temperature differences between neighbouring areas of concrete by slow cooling and early cooling. The cooling process should be based on the concrete temperature measurement results taking into consideration the partitioning of the concrete, pouring temperature, water pipes, density of concrete, and ambient temperature. The cooling water flow is adjusted in a timely manner to meet the targeted temperature requirements. A flexible network structure for field temperature monitoring of the super high arch dam during the construction was developed based on the state of the art intelligence control technology [19]. By employing flexible network structure architecture, the bus was also connected to other types of sensors such as dam strain measurement meters, dam compressive stress measurement meters, meters for monitoring joint openings, rock-deformations, and piezometers for seepage flow, all of which were are designed to suit this network specification. Thus, the measurement scope utilized covered a wide spectrum as well as the many concrete temperature measurements sufficient for a super high arch dam.

3.1.2 Site Control System Arrangement

The control cabinets were prepared in the workshop. Because of the complex electromagnetic environment on the construction site, wiring to the site flow valves and sensors were employed. Fig. 5 shows a preassembled cabinet for digital data transmission. Here is the brief description of the main parts of PLC control cubicle.

BOX1: The intelligent temperature module. The circuit connection diagrams for connecting the temperature sensors to the module are shown in Fig. 6.

PS307: The Simatic S7-300 PLC power module.

CPU315: The Simatic S7-300 PLC CPU with integrated Profibus and Ethernet interfaces.

CP341: The Simatic RS485 communication processor for the intelligent temperature module.

IM153: The Simatic interface module, which can extend the CPU control to remote areas by Profibus network.

AI8: The Simatic analogue input module, which can read 8 analogue signals (current, voltage, resistor, or PT100sensors). The circuit diagram for connecting the flow meters to the analogue input module is shown in Fig. 8. The symbol "SM331" is the analogue input module, which is able to read 8 water flow transducers; please refer to "(6) AI8" of Fig. 5.

AO8: The Simatic analogue output module, which can drive 8 analogue valves. The circuit diagram for connecting the electric valves to the analogue output module is shown in Fig. 7. The symbol "SM332" is the analogue output module, which is able to control8 proportional valves; please refer to "(7) AO8" of Fig. 5.

On the dam site, the operators connect the valves, flow meters, and temperature sensors into the PLC cabinets asrequired according to construction progress.

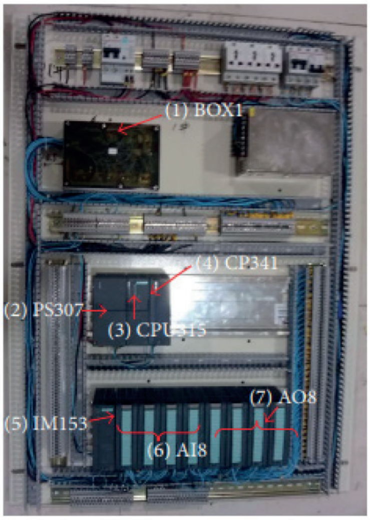

Fig. 5. The internal layout of the PLC control cubicle [14]

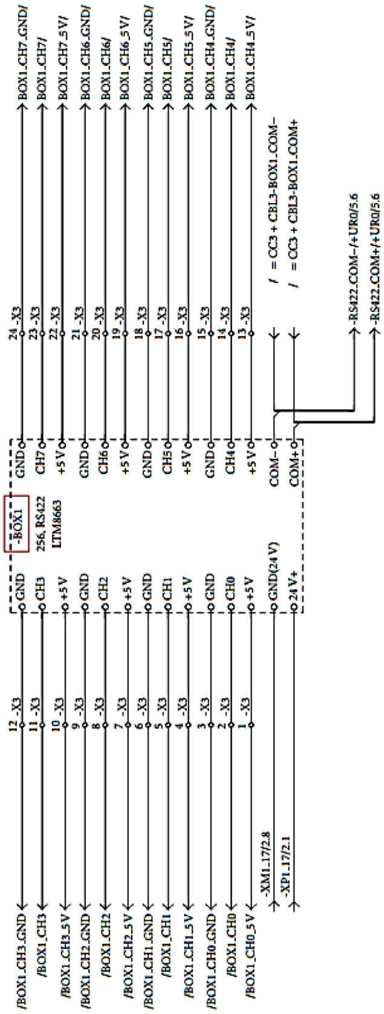

Fig. 6. The circuit diagram for connecting the temperature sensors to the module [14]

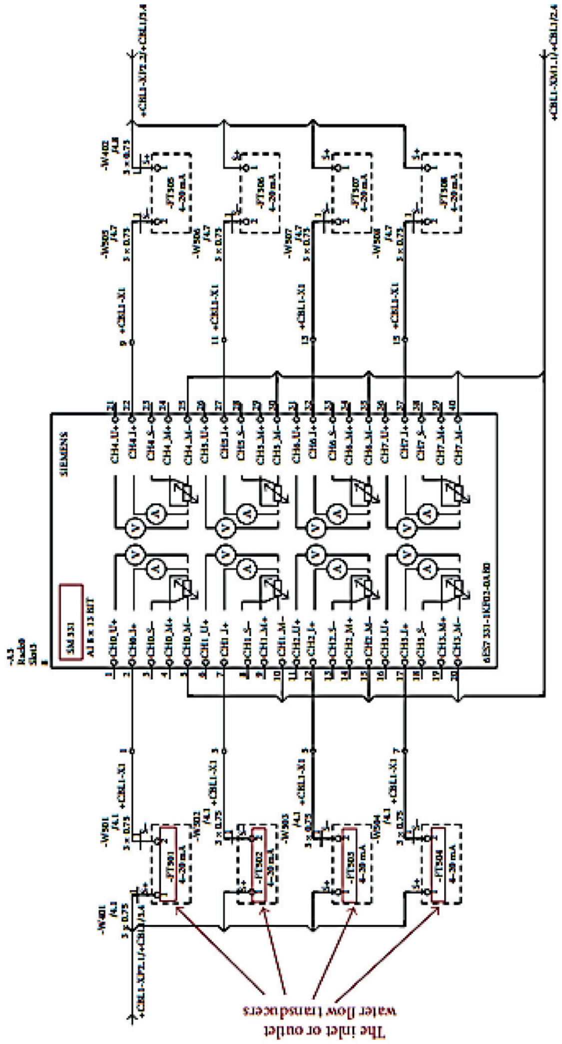

Fig. 7. The circuit diagram for connecting the temperature sensors to the module [14]

3.1.3. Temperature Field Analysis Basis of Real-Time Temperature Data

On the Xiluodu arch dam site, the intelligent cooling control system used modern feld bus technology extensively and Siemens PLC devices to comprehensively track the temperature data change at the pouring of every block in real time. Adjustment of the valves and control of water flow were performed using the PID algorithm based on temperature control requirements and key factors such as the highest temperature reached, cooling rate, and temperature gradient. A web graphical user interface (GUI) was provided for integrated query, analysis, and prewarning [20]. Based on the proposed temperature data transmission system, the intelligent cooling system overcomes the shortcomings in traditional manually collected data systems, providing an effective dam concrete temperature control and cracking prevention technology both advanced and more intelligent. In particular the advances consist of (1) changing simple manual data collection to real-time data acquisition and feedback, (2) automatically obtaining large quantities of thermodynamic parameters with respect to every block of poured concrete enabling a more customized control function, and (3) enabling a 3D real-time temperature field analysis be carried out, as illustrated in Fig. 8. Based on the real-time temperature field analysis, further stress fields can be analiyzed to study alternative temperature control plans, not only limited to water flow, but the whole pipework scheme can be adjusted to more optimal configurations.

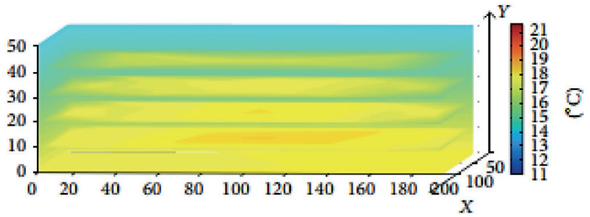

Fig. 8. Real-time three-dimensional temperature field [14]

3.1.4 Inference

Using this system on the Xiluodu arch dam site enabled some key problems to be solved including huge quantities of raw data interchange with the module server, personalized and flexible control for each water cooling circuit, and accurate and punctual water conditional control data collection instead of traditional manual checking. The proposed approach provides a convenient solution in process cooling control pipes where cabling is not possible. The system also has lower installation and maintenance costs, operates reliably, and is of robust and flexible construction. It is proved suitable for heat of hydration control in dam construction concreting applications. Based on this study, the future research will be focused on the combination of real-time site monitoring analysis and numerical simulation on thermal stress for control cracking of mass concrete in construction period.

4. Conclusion

This paper present the review of using the telematics system in the technical condition testing of concrete dam structure by using the sensors. In the large scale of hydropower plant there are many important components and structure. The basic element in any sustainable structure or infrastructure project is safety for example, cause a complicated crack pattern in highly statically indeterminate arch dams, which cannot be reliably predicted by numerical models. The dynamic behavior of the dam would become very complex.

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