RUGGED BLOCK-BASED DISPLACEMENT MONITORING FOR STRUCTURES UNDER EXTREME ENVIRONMENT

Shenghua Jiang
School of Civil Engineering, Dalian University of Technology, Dalian, 116024, P.R. China

Zhi Zhou
School of Civil Engineering, Dalian University of Technology, Dalian, 116024, P.R. China

Minghua Huang
School of Civil Engineering, Harbin Institute of Technology, Harbin, 150090, P.R. China

Jinping Ou
School of Civil Engineering, Dalian University of Technology, Dalian, 116024, P.R. China

Structural behavior can be characterized as deformation, large strain, crack or failure, foundation release or scour, etc. As such, displacement is the significant parameter to assess the performance of structural stability and safety using the behavior information. A rugged, real-time, durable, reliable and low-cost monitoring technique for the exterior and internal displacements is still in great need for the infrastructures under extreme harsh environments. In this paper, a novel displacement field monitoring technique is proposed to access the behavior of the structures using the smart label-based block, originating the concept of Internert of things (IOT). The smart-labels mainly can be set up on any kind of wireless tags, such as magnetic matters, radio frequency identification (RFID) tags and even global position system (GPS) measuring sensors as well. Each node can be used to describe and identify the local structural information at the fixed point, which can be used to configure a new network, internet of things (IOT). In practice, these smart-labels are packaged in certain highly-protected block, namely smart block or rock. The smart block can be attached or embedded directly on the structure so that the information of position and physical parameters can be recorded and transmitted accordingly... The proposed system can be regarded as a real-time, durable, reliable and low-cost displacement field monitoring IOT. And it is feasible to be widely applied in infrastructures ranging from high geological slop, dam embankment and bridge foundation.

Corresponding author's email: zhouzhi@dlut.edu.cn

RUGGED BLOCK-BASED DISPLACEMENT MONITORING FOR STRUCTURES UNDER EXTREME ENVIRONMENT

Shenghua Jiang[1], Zhi Zhou[1], Minghua Huang[2] and Jinping Ou[1, 2]

[1] School of Civil Engineering, Dalian University of Technology, Dalian, 116024, P.R. China
[2] School of Civil Engineering, Harbin Institute of Technology, Harbin, 150090, P.R. China

ABSTRACT: Structural behavior can be characterized as deformation, large strain, crack or failure, foundation release or scour, etc. As such, displacement is the significant parameter to assess the performance of structural stability and safety using the behavior information. A real-time, durable, reliable and low-cost monitoring technique for the exterior and internal displacements is still in great need for the infrastructures under harsh environments. In this paper, a novel displacement field technique based on the smart-labels is proposed to monitor behavior of the infrastructures. The smart-labels mainly can be set up on any kind of wireless tags, such as magnetic matters, radio frequency identification (RFID) tags and even global position system (GPS) measuring sensors, etc. Each node can be used to describe and identify the local structural information at the fixed point, which can be used to configure a new network, internet of things (IOT). In practice, these smart-labels are packaged in certain highly-protected block, namely smart block or rock. The smart block can be attached or embedded directly on the structure so that the information of position and physical parameters can be recorded and transmitted accordingly... The proposed system can be regarded as a real-time, durable, reliable and low-cost displacement field monitoring IOT. And it is feasible to be widely applied in infrastructures ranging from high geological slop, dam embankment and bridge foundation.

1 INTRODUCTION

Behavior monitoring plays a key role in Structural Health Monitoring (SHM). When large deformation occurs during extreme accidents of earthquake, landslide, rockfall, surface subsidence, dam failure, collapse of barges and building, etc, there will be high risk of disasters. The behavior monitoring is mainly concerned with displacement of structure, large strain, crack, foundation scouring, etc. So far, geodetic method (Gikas etal., 2008; Vasco etal., 2008), photography technique (Chen etal., 2011), optical fiber sense and testing technology (Zhu etal., 2008; Li etal., 2010), 3D laser scanning technology (Xu etal., 2010; Yue etal., 2010), GPS satellite localization (Wang etal., 2010; Wen etal., 2010) and other monitoring systems are widely used in the behavior monitoring of civil engineering health monitoring.

However, lots of general problems exist in the present behavior monitoring. With regard to the major structures under extreme harsh environment, it is difficult or dangerous to monitor manually on site, and it is expensive to maintain the wired sensors. There is a lot of data in the process of collection and transmission, but the behavior data is analyzed and processed offline, which can't guarantee the real-time demand. The management departments or owners can't acquire the significant and effective information behind the massive monitoring data due to the lack of professionals. The calamity caused by behavior can't be forecasted or warned in advance by the present monitoring system. The current behavior monitoring is operated manually with personal subjectivity and no timeliness, which influence operation of the structures and the affiliated facilities. The behavior monitoring systems are mostly equipped with wired sensors, and the wired sensor has mature communications protocol, excellent interconnectedness and high precision. But in the application of behavior monitoring, maintenance cost of wired sensor is extremely high; it's difficult to arrange wires in some special places and it's vulnerable to be destroyed by the environment, and the transmission distance is limited to the wire arrangement.

The present behavior monitoring system requires continuity, real-time, automation, efficiency and high reliability, so the advanced monitoring instruments and automatic systems must be equipped to ensure the behavior monitoring system can function with long-term stability and reliability in harsh environment. The internet of things (IOT) is defined as the material objects connected to the Internet, which is a network through radio radio-frequency identification (RFID), infrared sensors, global positioning systems, laser scanners and other information sensing device (Wu etal., 2011). By means of IOT, information exchange and communication can be realized intelligently and automatically for the connected goods or things to achieve intelligent identify, locate, track, monitor and manage.

Information technology of the next generation can be applied to the civil engineering health monitoring based on IOT. First of all, the wireless sensors are installed in the structures such as the bridge, tunnel, highway, building, dam, oil and gas pipeline, etc. And the wireless sensors transmit behavior data by the internet so that the professional institute, the center of data analysis and early warning, can analyze the state of the structures and issue the results. Therefore, the behavior monitoring can be carried out by real-time awareness, and the service condition can be supervised and warned timely for the structures.

In this paper, the magnetic matters, radio frequency identification (RFID) tags and global position system (GPS) measuring sensors, etc, are used as smart tags and built up in the structures. And the IOT system for behavior monitoring are realized based on short distance wireless communication and internet in order that the behavior of structure can be monitored real-timely, continuously, automatically, efficiently and dynamically in the harsh environment.

2 SMART-LABEL-BASED DISPLACEMENT MONITORING SYSTEM

2.1 Behavior monitoring IOT system based on smart tags

The behavior monitoring IOT system is composed of wireless sensor networks, data transmission network and data processing system. The three subsystems implement collection and delivery of behavior data, data transmission, information processing and

publishing respectively. Altogether, the visualization of query, monitoring and warning can be carried out through the client viewer.

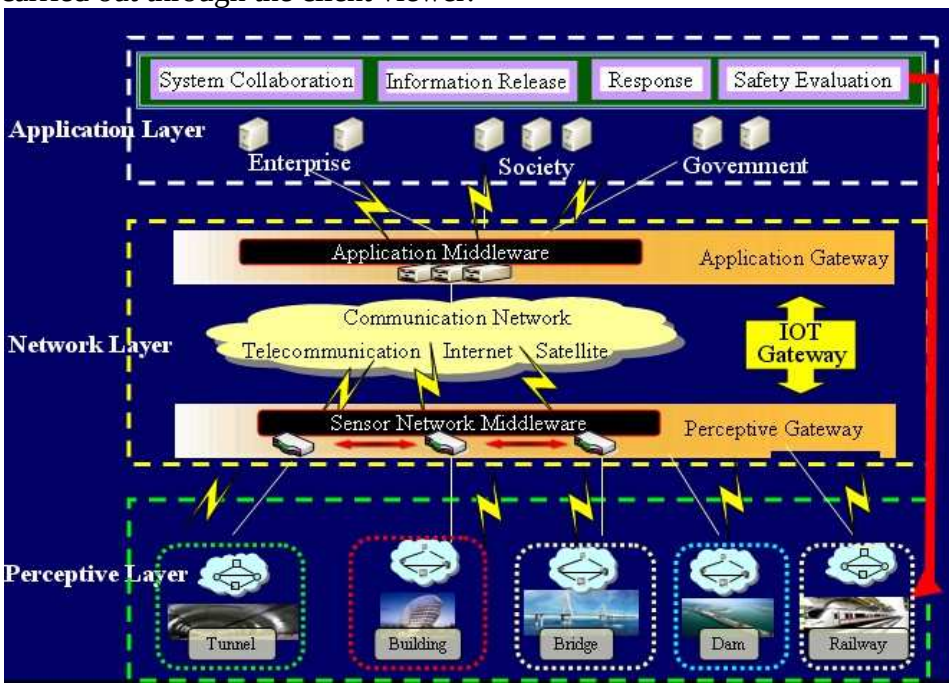
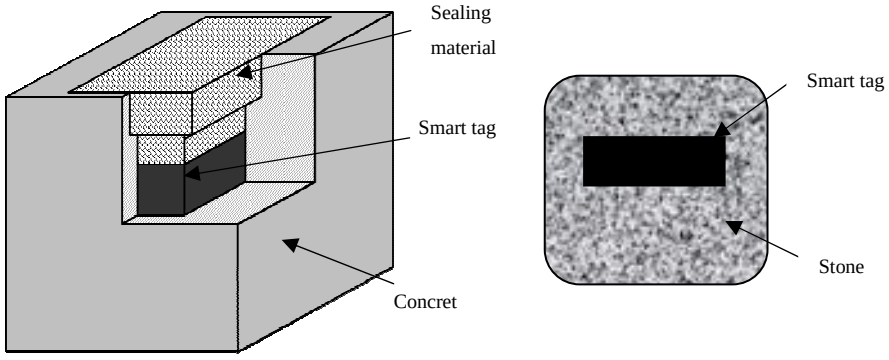


Fig 1. The behavior monitoring IOT system based on smart tags

2.2 Fabrication of smart tags

The magnetic matters, RFID labels, GPS devices and other wireless sensors are packaged in the concrete or other materials to make extensive sensors for displacement monitoring; or these smart tags are installed in some position of structures. The smart tags collect and send deformation data through wireless communication, and transmit data by means of internet.

The smart tags are packaged or sealed to prevent the intrusion of humidity, dust and other foreign matter. On the other hand, the smart tags are made with special manufacturing techniques to resist the physical, electronic and chemical corrosion, which overcomes the defect of traditional sensors' low survival rate in harsh environment. There are two examples of sensors based on smart tag, one by means of sticking and the other by sealed or casted in concrete or other materials, see Figure 2.



(a) sealing (b) sticking

Fig 2. Smart-label-based block sensor

2.3 Data transmission network

The nodes of wireless sensor are constructioned based on Zigbee protocol and IEEE802.15.4 protocol to achieve short distance wireless communication with the characteristic of low cost, lower power consumption and high speed. Hence, the wireless sensor network is set up to ensure the efficient transmission of deformation data and high service efficiency of nodal electrical power.

The wireless sensor network is composed of sensor nodes, sink nodes, data relay device and main control center. The displacement, crack and other deformation parameters are monitored by the wireless sensor, and transmitted to sink nodes through wireless launcher. The sink nodes convey the data through RS485 serial port to data relay device with controller core of ARM processing unit. Finally, the monitoring data are transmitted to main control center by means of 3G communication method.

3G communication method is the mobile communication technology of third generation, which supports high-speed data transmission. The system capacity, communication quality and data transmission speed can be improved in the deformation monitoring IOT system on basis of 3G communication method. The wireless communication and internet can be combined with seamless roaming technology between different networks; consequently, the mobile terminal user can get the service of real-time query and warning.

2.4 System of data processing and warning

When the deformation data are transmitted to the processing system by the internet, the data are saved in the background database. After computation and analysis, the system can provide the users with different kinds of visual query and warning in the selected positions of the structures.

The functions of visual query are listed as follows. (1) Based on geographical information system, the locations of the sensors and their real-time deformation data can be displayed on the map, so the overall situation of deformation monitoring can be supervised and it can be judged that where's the zone of frequent hazards. (2) The variation of deformation with time can be showed in order that the changing relation can be revealed on basis of the environment and load. (3) All of the sensor nodes are displayed real-timely, and the monitor-evaluator can extract deformation data of any sensor node.

The system of warning can provide following functions. (1) The warning messages are displayed on the software interface. (2) The multimedia devices can be sounded with warning. (3) The warning text messages are dispatched to the mobile equipments.

3 THE APPLICATIONS OF SMART-LABEL-BASED BEHAVIOR MONITORING IOT SYSTEM UNDER HARSH ENVIRONMENTS

The bridge pier, ocean platform, embankment and other structures are located in the harsh environments with the loads of current, wind and wave, etc. It's difficult to install and maintain rational sensors in these structures due to the susceptibility to physical, chemical and electrical materials. As a result, the magnetic matters, radio frequency identification (RFID) tags and even global position system (GPS) measuring sensors, etc, are used as smart tags and set up in the structures. Based on short distance wireless communication and internet, the smart tags can be tracked or analyzed by the system of

data processing and warning, by which And the IOT system for behavior monitoring are realized. The behavior Monitoring IOT System can be used in the bridge pier, ocean platform, embankment, poles and towers of transmission line, chimney and other structures in harsh environments.

3.1 Scouring monitoring of bridge pier and ocean platform

At present, it's urgent to develop a scouring monitoring method with reliability, practicality and easy operation which can be applied in bridge pier, ocean platform and other large infrastructures. The magnetic matters, RFID labels and other wireless sensors are packaged in the natural or artificial riprap to make smart tags with self-awareness based on scouring riprap protection. The stones of smart tags are embedded in the foundation of the bridge pier and ocean platform, see Figure 3. The displacements of the stones with smart tags are sent to the data processing center by the short distance wireless communication and internet, and the displacements of the stones can be converted to the scouring depth and area. The scouring of foundations can be calculated for safety evaluation and risk analysis of bridge pier and ocean platform.

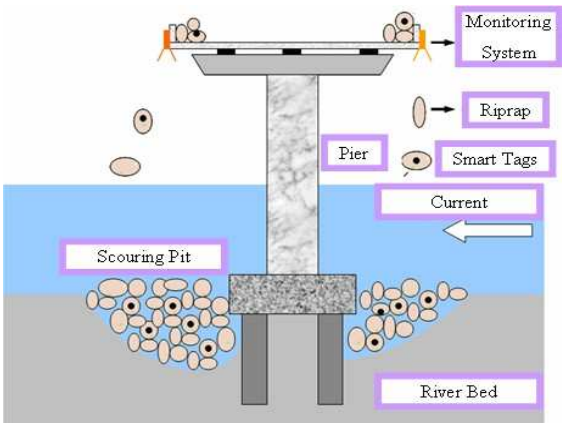


Fig 3. Scouring monitoring of bridge pier

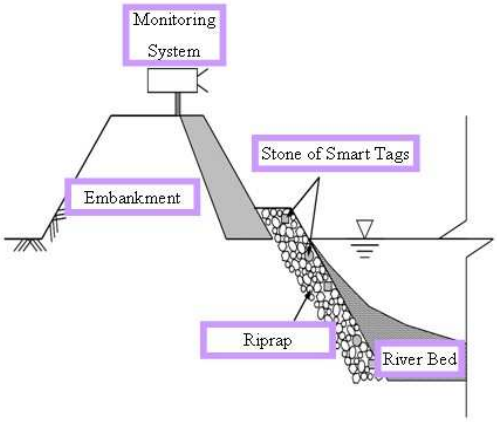


Fig 4. Monitoring for foundation stone's loss

3.2 Monitoring for foundation stone's loss

The embankment is the major project to defend flood, and the stability of embankment foundation is directly related with its safety. So it's very important to ensure the stability and integrity of the foundation stone structures. However, there may be some adverse and inevitable factors such as insufficient gradient, uneven depth, unbalanced foundation, inappropriate arrangements and other engineering influence in the foundation structures, and the foundation stones run away under scouring of the current.

The stones installed with smart tags are embedded dispersedly in the area of foundation stone, see Figure 4. Under the action of current, the stones installed with smart tags move along with the foundation stone. And the displacements of smart tags are sent to the data processing center by the short distance wireless communication and internet. By the analysis of the displacements of smart tags, the motion path can be indirectly described for foundation stones so that the loss of foundation stone can be realized based on the stone of smart tags.

3.3 Behavior monitoring of slope

The stones of smart tags with magnetic materials are embedded with different depth in selected locations of the slope. The Monitoring IOT System is established for the slope deformation based on the short distance wireless communication and internet. The Monitoring IOT System is composed of wireless sensor equipments on site and remote analysis devices. There are stones of smart tags, Zigbee wireless transport module and GPRS wireless transport module in the wireless sensor equipments on site. The no-wiring on site is realized because of wireless transmission technology, and it's easy to maintain with low cost. The remote analysis devices comprise data processing system with special software. During the operation of monitoring, the deformation of slope is detected by the stones of smart tags and transmitted to the Zigbee wireless transport module. Afterwards, the data processing center receives deformation data by GPRS wireless transport module. The slope is analyzed for safety evaluation and warning in the data processing center.

3.4 Behavior monitoring of high-rise structures

There will be abnormal variation of horizontal displacement and dip in the high-rise structures such as poles and towers of transmission line, chimney, when these structures are subjected to strong wind, great snow, foundation deformation and so on. Behavior sensors with smart tags are installed in the high-rise structures to detect the horizontal displacement, vertical displacement, dip and verticality of poles and towers of transmission line, chimney, etc. The behavior monitoring data are transmitted from the sensors to data relay devices, and then the simulating signals are transformed into digital signals, which will be transmitted to data processing center by GRPS network. The horizontal displacement, vertical displacement, dip and verticality can be compared with indices in the design code or calculated by finite element method, by which the high-rise structures are evaluated for the service state and the warnings are sent to the construction maintainers.

4 CONCLUSIONS

The magnetic matters, radio frequency identification (RFID) tags and global position system (GPS) measuring sensors, etc, are used to make smart tags and set up in the structures. And the IOT system for behavior monitoring is realized based on short distance wireless communication and internet. The characteristics of the IOT system are summarized as follows. (1) The smart tags can prevent the intrusion of humidity, dust and other foreign matter. And the smart tags are made with special manufacturing techniques to resist the physical, electronic and chemical corrosion, which overcomes the defect of traditional sensors' low survival rate in harsh environment. (2) It's suggested to embed the sensors in harsh environment extensively and vastly by the behavior monitoring IOT System based on smart tags. And behavior monitoring IOT System can be applied in the scouring of bridge pier and ocean platform, loss of foundation stones for embankment, the behavior poles and towers of transmission line, chimney and other structures in harsh environments. (3) By means of behavior monitoring IOT System based on smart tags, the behavior of structure can be monitored real-timely, continuously, automatically, efficiently and dynamically in the harsh environment.

REFERENCES

Chen S. E., Rice C., Boyle C. and Hauser E. (2011). Small-format aerial photography for highway-bridge monitoring. *Journal of Performance of Constructed Facilities*, 25: 2, 105-112.

Gikas V. and Sakellariou M. (2008) . Settlement analysis of the Mornos earth dam (Greece): Evidence from numerical modeling and geodetic monitoring. *Engineering Structures*, 30: 11, 3074-3081.

Li K., Shi B., Tang C. S., Wei G. Q. and Wang B. J. (2010). Feasibility research on soil deformation monitoring with distributed optical fiber sensing technique. *Rock and Soil Mechanics*, 31: 6, 1781-1785.

Vasco D. W., Ferretti A. and Novali F. (2008). Reservoir monitoring and characterization using satellite geodetic data: Interferometric synthetic aperture radar observations from the Krechba field, Algeria. *Geophysics*, 73: 6, 113-122.

Wang, J. P., Gao J. X., Liu C. and Wang J. (2010). High precision slope deformation monitoring model based on the GPS/Pseudolites technology in open-pit mine. *Mining Science and Technology*, 20: 1, 126-132

Wen H. J., Zhao L. and Li X. (2010). Combination of GPS monitoring and ANN prediction for slope deformation. *Journal of Chongqing University*, 33: 2, 79-82.

Wu T. Y., Liaw G. H., Huang S. W., Lee W. T. and Wu C. C. (2011). A GA-based mobile RFID localization scheme for internet of things. *Personal and Ubiquitous Computing*, 1-14.

Xu J. J., Wang H. C., Luo Y. Z., Wang S. Q. and Yan X. Q. (2010). Deformation monitoring and data processing of landslide based on 3D laser scanning. *Rock and Soil Mechanics*, 31: 7, 2188-2191.