Advancements in IoT Based Intelligent Systems for Bridge Health Monitoring

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Abstract

With the advancements in the field of Internet of Things (IoT) and its implementation to Structural Health Monitoring (SHM), IoT has garnered attention from the academic as well as the industrial community. Health monitoring of bridge structures is consequential because of their security concerns and strategic significance. IoT has proved to be relevant for bridge health monitoring because of its ability to monitor health in real-time, collect, transmit, store, analyze as well as generate warnings. Research has also been conducted and improvised cost-effective, as well as energy-efficient IoT systems, have been proposed. In this paper, a detailed study of the latest advancements in the field of applications of IoT in bridge health monitoring have been studied based on several parameters such as advancements in cloud architecture, advanced techniques for fusion with IoT, and cost and energy effective IoT systems, and suggestions have been made.

Keywords. Structural Health Monitoring (SHM), Cost-Effective Monitoring System, Energy Efficient Monitoring System, Bridge Health Monitoring, Internet of Things (IoT), IoT fused with Advanced Techniques

1. INTRODUCTION

Bridges have long been the backbone of the transportation industry as well as the development of a nation by facilitating the connection between important locations and hence serve as infrastructures of security concerns and strategic significance. With the advent of rapid development, bridges have been tested with the passage of time due to changes in loading pattern, weather conditions, and degradation of bridge material often leading to fatal collapse of the bridge structures leading to huge loss of lives and economy. Thus making bridge health monitoring indispensable. With the traditional monitoring in place, it was very difficult to investigate the entire bridge structures manually; not sooner till Internet of Things (IoT) advent into the field of Structural Health Monitoring (SHM).

IoT is a system of physical objects embedded with sensors used to collect, store, analyze and exchange the data with other devices which are connected with other systems over a communication network. IoT has long been successfully implemented for health monitoring and as early warning systems to improve operational efficiency and level of safety in bridges [1]. The IoT systems used for bridge health monitoring often comprise of sensors connected by IoT, monitoring system, data storage and a data processing module that evaluates data in real-time [2].IoT has also been used to assess inclined angles, bends of various parts of the bridge, monitor the looseness of the bolt joints, and project this data to a smartphone app, generating warnings by flashing LEDs [3]. Health monitoring of a cluster of bridges has also been made possible with the use of wireless gateway and cloud platform [4].

Much of the advancements, related to IoT in Bridge Monitoring Systems, have been done in the area of cloud architecture and cost and energy effective IoT enabled monitoring systems. Improvised IoT enabled bridge monitoring systems fused with advanced techniques such as machine learning, artificial intelligence etc. have also developed. Section 2 discusses the advancements in all of these areas.

2. Advancements in Intelligent Systems Embedded with IoT for Bridge Health Monitoring

This section covers the advancements in the field of IoT enabled bridge health monitoring systems. Three criterions, namely, advancements in cloud architecture, fusion of advanced techniques in IoT enabled health monitoring systems and cost and energy efficient IoT enabled health monitoring systems have been covered.

2.1 Advancements in Cloud Architecture for IoT Based Bridge Health Monitoring

Data collection and exchange have been very important aspects of IoT. Research works have been conducted to develop effective systems for data exchange. For monitoring bridge health, a cloud-based cyberinfrastructure platform based on peer-to-peer distributed database architecture has been built [5]. It allows for scalable data administration, sharing, and use. Amazon Web Services (AWS), a cloud computing platform, has also been used to link IoT devices as well as to store and analyse data. Sensors in AWS-integrated systems relay data to nodes via the Xbee protocol (raspberry pi). Data is then sent to the cloud using message protocols [6].

2.2IoT Fused with Advanced Techniques Systems for Bridge Health Monitoring

Advanced techniques such as machine learning, neural networks, artificial intelligence, soft computing, etc. are employed to identify and locate the damaged area in a bridge structure [7]. Machine Learning (ML) and Artificial Intelligence (AI) are employed for bridge health monitoring including irregularity or crack detection. Traditional prediction algorithms from regression modelling and data mining may encompass problems of data scaling and difficulty adapting to dynamic changes in the data input. To overcome this drawback, bridge health is monitored by integrating predictive analytics based on artificial intelligence into the IoT sensors [8].

Stable systems comprising of Convolutional Neural Network (CNN) fused with AI and Raspberry Pi 4 embedded computer integrating IoT has been developed to monitor bridge health by Google Firebase cloud database based apps and websites [9]. Novelty detection and location algorithms based on machine learning have also been created for monitoring data. Using the collected data such as external conditions, interior temperature, or data from other sensors and training set, neural networks assisted multiple regression models are built for each sensor [10]. Deep neural networks have also been used to effectively monitor the health of bridges. Auto-encoder-based methods inspired by the deep neural network's ability to automatically extract feature have proved to be effective for bridge health monitoring [11]. In other systems, bridge crack photographs collected and processed by neural network model-simulated and trained by MATLAB have also been shown to have overall accuracy greater than 90% [12]. IoT systems are also used in conjunction with a Fiber Bragg Grating (FBG) optical sensing technology to sense the load and strain distribution on bridges in order to keep track of unanticipated conditions caused by load variations. At each data source, various techniques such as random forest (RF) and K-nearest neighbor (KNN) were used [13].Advancements have also been done in the area of reducing the latency response and extending network lifetime while guaranteeing desired coverage of the IoT systems by bringing computing close to the source of data production. SHM Fog and Edge computing architectures have been developed for this purpose [14]. Learning automata (LA) is a reinforcement learning model that provides sensor scheduling strategy which is energy-efficient by integrating Confident Information Coverage (CIC) model in an IoT-based bridge health monitoring system to ensure network coverage and extend network lifetime [15].

2.3Cost & Energy Effective IoT Systems for Bridge Health Monitoring

Cost-effectiveness and energy-effectiveness have always been among the major deciding factors for the adoption and implementation of a system. A structural health monitoring system based on Internet of Things (IoT) have proved to be low-cost, energy efficient, secure and reliable system [16]. With the advancements in the field of IoT, research works in this area have also taken place, which allows long-distance monitoring and is immune to Electromagnetic (EM) radiations. Self-powered IoT systems have been developed consisting of sensors that derive energy from slight strain variations in the structure [17]. Energy harvesting systems, incorporated in IoT networks in Sunshine Skyway Bridge, consisting of bimorph piezoelectric cantilever beams and used to provide powers to the wireless sensors have also been developed [18]. Integrated distributed sensing systems consisting of IoT, Fiber Bragg grating sensors, Big Data technology and Kafka have been developed to develop long-distance and cost-effective bridge health monitoring systems

[19]. Low-cost systems incorporating multiple regression models based on neural networks have also been developed. Learning automata (LA) is a reinforcement learning model that has been combined with the Confident Information Coverage (CIC) model to considerably increase network lifetime as well as its coverage. For the monitoring of structures, an efficient and effective data management platform called PIERS that is compatible with the IoT method has also been given [20]. Low-cost distributed systems for bridge health monitoring systems with Butterworth filter for efficient signal processing for IoT and cross-correlation for damage detection have also been designed [21]. Fog computing has also been emerging as an efficient approach in terms of power consumption to structural health monitoring [22].

Strive is now made in the direction of ultra-low-cost wireless, energy-efficient, and high-performance SHM system with IoT connectivity and such a system has been installed at Itztal bridge, Germany [23]. Monitoring systems is also one of the key factors in deciding the cost associated with the operation of the system. Instead of cabled monitoring systems, open-source IoT-based frameworks have been developed to support Wireless Structural Health Management Systems thus making the monitoring systems cost-effective [24]. Studies have also been conducted for the development of low-cost and low-power wireless acceleration sensors [25, 26, 27].

3. RECOMMENDATIONS AND DISCUSSIONS

The utilization of drone technology, robots, Virtual Reality (VR), Augmented Reality (AR), and digital twin, an emerging technology, in the field of IoT-enabled bridge health monitoring systems is, however, seems to be absent from the literature and needs rigorous research. Drones integrated with IoT and machine learning can be used to detect faults and irregularities in different parts of the bridges. Augmented reality can also be integrated to IoT systems for visualization of data in real-time and can also be implemented to details of structural faults on the bridge model. Digital Twin is an emerging technology and can also be incorporated in the field of bridge health monitoring to monitor real-time health monitoring even from places far off the bridge location. Therefore, suitable efforts can be made to venture into the field of IoT-enabled bridge health monitoring systems incorporating the aforementioned untouched technologies which could lead to further more efficient monitoring systems.

4. CONCLUSIONS

IoT has recompensed in the area of bridge health monitoring with a whole lot of new opportunities for better monitoring of critical structures. As reviewed in the above sections, wireless real-time monitoring IoT systems have been upgraded with better cloud infrastructure leading to efficient management and better exchange of data. Many improvements have also been made in the integration of modern technologies such as blockchain, Machine Learning (ML) and Artificial Intelligence (AI). The use of neural networks, a kind of machine learning, allows for easy monitoring of bridges via websites or mobile apps. Efforts have been made in the direction of power-efficient and cost-efficient IoT enabled monitoring systems including edge/fog assisted devices, self-powered IoT systems, energy harvesting systems, Fiber Bragg grating sensors, Kafka, Big Data technology Research works, effective data management platforms, and effective data management platform thus leading to more power and cost-efficient bridge monitoring IoT systems. However, integrating new technologies along with IoT and venturing further into the well-established technologies can lead to unexplored pathways.

5. REFERENCES

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