ISSN: 0974-5823 Vol. 7 No. 1 January, 2022

International Journal of Mechanical Engineering

Review On Structural health monitoring of the civil engineering structures

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ABSTRACT: The structural health monitoring of the civil engineering structures is one of the important matters that give a clear vision of the defect and damage who's caused by environmental and climatic factors, as well as its remaining life span of the structure. Monitoring process helps to make the right decision related to the direct intervention in the event of significant damage and carrying out maintenance and rehabilitation work necessary to maintain the integrity of the buildings. The monitoring process also helps to reduce the cost and investment of unnecessary maintenance and rehabilitation. Previously, the monitoring process was carried out through the eyes vision detection of buildings, but due to the great development that took place in electrical and electronic engineering as well as communications engineering, the monitoring process has become through smart electronic sensors that have the ability to transmit damage diagnosis and provide a full report on the current and expected building status in the future. In this research, we will give a general vision about the concept of building control, dealing with how this process has evolved and its importance to preserving lives, in addition to the economic and social aspects that will be addressed here in details.

In this paper we will explain how the structural health monitoring process is developed within last five decays. The structural health monitoring implemented with sensors detection of buildings dates back to 1980 (Jiazhan Su, 2020), when computers and analyzers were at the work site in the past, and the sensors were connected to the analysis devices through cables, as this process was expensive and took a lot of time, in addition to the fact that the results were not accurate (Annamdas V G M, 2016). But due to the scientific revolution in communications engineering, smart sensors have become wirelessly working, as the data collected by these sensors is sent through a frequency band to the main calculator center, which includes a comprehensive analysis of that data according to programs and algorithms designed for this purpose, as each building has its own mathematical model. And this model is responsible for analyzing the data sent and giving a comprehensive final report on the building's condition, as well as the number of years remaining before the collapse occurred. The general challenges that face the structural health monitoring system are also disused here. This research also discuss a number of researches that related to structural health monitoring of civil engineering structure in literatures review section.

KEY WORDS: *Structural health; health monitoring process; sensors detection*

1. INTRODUCTION

Because of the large financial costs of buildings, bridges and dams and their importance in the growth of the country's economy in the face of population growth, it has become necessary to monitor the efficiency of these buildings and analyze the changes that have occurred in them for the purpose of maintaining and rehabilitating them when needed (Samir Mustapha, 2020, P. The process of monitoring of the structural of building can be called as structural health monitoring. The structural health monitoring can be applied to the body of aerospace and mechanical equipment (Muhammad Hassan Bin Afzal, 2012, P), in this research we will focus on the structural health monitoring in the civil engineering.

The proper definition of the structural health monitoring can be given as "It is the process of collecting and analyzing data obtained through smart electronic sensors that connect on board of the buildings which need to be analyzed" (Alfredo Güemes, 2020). While the main purpose of the structural health monitoring to know the behaviors and the changes that occurred to building from time of build it to time forecasted of deterioration, and study their changes in the specifications due to factors that occurred it, these changes can be occur as a result of natural factors such as earthquakes, environmental, climatic changes, heavy wind and others, while the abnormal ones are due to excessive consumption and overloading as in bridges (Carmelo Scuro, 2018).

About more than fifty years ago at least, there was no idea about structural health monitoring present in the field of civil engineering at all, but due to the great development that occurred in the field of electrical and electronic engineering in recent years and the great revolution in the field of sensors and communications industry, the idea was merged with the aging analysis of buildings through these sensors are to know the life span of buildings as well as the results of weather and climatic changes to it and become one of the necessary safety principles (Priyo Suprobo, 2013) (Jerome P. Lynch, 2016).

The continuous monitoring process of the dynamic response for building has become available due to the availability of smart sensors as well as communication equipment; it was possible to monitor the results directly through certain centers that were prepared for this purpose, the accurate measurement of the dynamic response of loads (heavy wind or traffics) of the representation loads is become a hard mission, these devices have been developed to operate within different frequencies in order to choose the required frequency for each type of load as well as for each type of building (Antonios Kamariotisa, 2021).

The process of monitoring in real time state via internet can be called as Internet of Things (IoT), this process can help the decision maker about the maintains and rehabilitation in addition to alarms before failure of civil engineering buildings (H. Chang, 2018, P) .When designing a structural health monitoring system it is also very important to understand the structure completely to insure proper design of the buildings.

Due to the great development that we referred to earlier in sensors and communications equipment, this system has been developed to work with smart phone devices in the process of data collection and analysis, which is collected inside the vehicles that pass over the bridge (in case of the structural health monitoring proposed to connect on bridge), it can be used to discover many media frequencies of the bridge with each specific load, these smart phone devices measure the impact of each load on the bridge through its own frequency (Thomas J. ma Tarazzo, 2018).

In this research we will discuss and explain the important of using structural health monitoring, the major components and the applications of the structural health monitoring system and also the challenges that face this system, although all the references are related to our work. The literatures review references showing others related papers and researches to our research, and finally we will conduct how this system can increase and enhance the safety of the buildings and peoples and improve the reliability of structures, on the other hand the structural health monitoring reduce the financial issues that related to maintenance and rehabilitation costs. The IoT sensors and their properties is also discussed in this work.

2. Components of Structural Health Monitoring

Usually, buildings and other civil infrastructures are built for a long life and can withstand fluctuations in climatic and environmental conditions. For the purpose of analyzing the loads imposed on it and determining its life time period, a structural health monitoring method was proposed (Piervincenzo Rizzo, 2010) . The basic concept of this method by using smart sensor that collects and transmit the data momentarily to analysis the dynamic characteristics of civil engineering structures during various loads conditions. In the past the smart sensors were connected to the computers by cables and the computers should be near to the building (D. Cusson, 2010).

In the last years and because of the internet development the smart sensors connected via internet web through a various wireless sensor nodes with main super-node that used to transmit the data acquisition to the main computers for analyses process (YoungSoo Park, 2015). The smartphones can also use to report the data and inform the client by the load analyses results. The basic concepts can be represent in Figure (1), that used to monitoring the load of the bridge, the system of structural health monitoring consist of smart sensors, super-node, internet, computers for receive and analysis the results and also smart phones (Peter Cawley , 2018) and (D. Cusson, 2010). The structural health monitoring system transact with continuous data, and need to simulate the results at real time, the following components are the main components of structural health monitoring:

(i) Sensors.

(ii Data acquisition system,

(iii) Communication system,

(iv) Data processing,

(v) Data storage,

(vi) Data diagnostic,

(vii) Data retrieval,

The data are collected by sensors, the sensors placed in concrete or steel structure of the civil engineering infrastructures, there are many types of sensors depend on the required functional for example sensors of vibrations, corrosion, cracks , etc. The old types of sensor were connected with cable, nowadays and because of the electrical and electronic revolutions, the new sensor can be connected wireless with communication system to transfer the reading of the data these types of sensors called smart sensors.

The next step is acquisition system, the collected data for each sensor that measured by the sensors such as (wind speed, temperature, vibration, earthquake, et.) and transfer then via communication system. Normally many numbers of sensors are places of one engineering building, and distributed in manner to help the users to find the weak points and the damage. There are many parameters and methods can be used to find the demonstrate the input data, including resonant frequencies, frequency-response function, mode shapes and mode-shape curvatures, modal strain energy, dynamic flexibility, damping, Ritz vectors, other related features.

The communication system used to transfer the data to main station for processing purpose, the communication media normally is Internet, in old version the computers brings to the engineering site, while now the computers are special office and the data transfer to them, many problems occurred with old methodology of structural health monitoring system related to capital cost and increase the losses, the communication system use super-nodes for collecting and transfer the data.

High performance computers are used for analysis the data during processing stage, the data processing done by using a model algorithm programs such as MATLAB or any other program, the model used to simulate the civil engineering building in some cases in 3D demonstration (Abdullah Al-Hussein, 2017) and (Young-Jin Cha, 2018). Another aspect after the data simulated is the storage system, for example for bridge structure, the data should be taken for long time, then the simulation need to store in special devices. The depth, location and the impact of the damages can be diagnostics in data diagnostics stage, and these data can be restored anytime and anywhere as in data retrieval stage (Hua-Peng Chen, 2018).

The main important points that should be taken in consideration during simulation the results are: (i) type of damage, (ii) economic aspects; (iii) environmental or operational limitations; and (iv) data management.

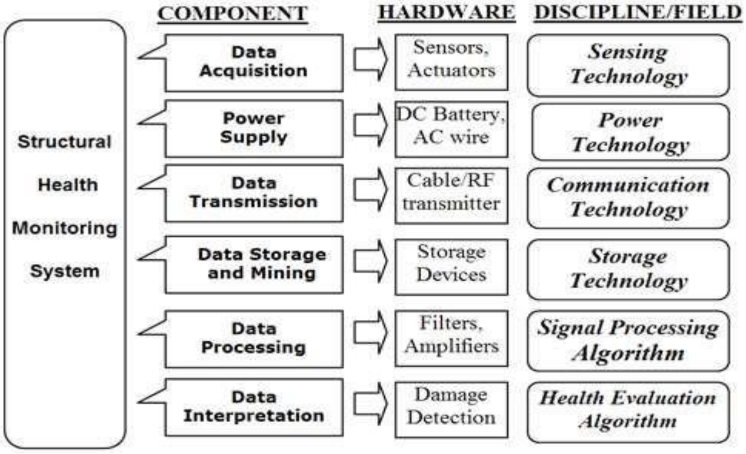

Figure (1) Components of structural health monitoring

Source : Dhakal, D. R., Neupane, K. E. S. H. A. B., Thapa, C. H. I. R. A. Y. U., & Ramanjaneyulu, G. V. (2013). Different techniques of structural health monitoring. Research and Development (IJCSEIERD),P61

The structural health monitoring is an integrated system submits offers great facilities to the user, and it is an advanced system that was produced about fifty years ago and has proven its worth in building analysis.

3. Major Advantages of Structural Health Monitoring

There are many advantages for using structural health monitoring that can be discussed in the fact, but here in this work we will focus on the major advantages that can be listed as below (Srinivasan Chandrasekaran, 2019):

1- The continuous monitoring produces an update of the integrity of the structure and help the engineer for detection of early risk.

2- Enhance the values of the structure i.e., use the structure in optimal manner.

3- Reduced maintains time.

4- Increase the safety of the peoples.

5- Reduced the cost of the non-necessary maintenance and rehabilitation schedule, also the maintenance labour investments costs are reduced as possible.

One of the major focal points of utilizing structural health monitoring is that it incorporates the decrease of taken a toll related to assessment and relief of effect of auxiliary catastrophes caused by nature. Advance, it decreases the requirement for prompt repairs and in this manner makes strides open security (Mitsheal, A. D. 2017). The structural health monitoring system can increase and enhance the safety of the buildings and peoples and improve the reliability of structures, on the other hand the structural health monitoring reduce the financial issues that related to maintenance and rehabilitation costs (Shi Yan, 2017).

4. Internet Of Things (IOT)

Before the revolution in the development of electronic devices and communications equipment, the traditional sensors of the structural health monitoring system were connected through cables with the main computer station, as the number of these cables was very large and expensive at the same time, and the transmitted signals were inaccurate. After using electronic smart sensors which connected to the Internet, data transmitted has become reliably (Tholeti Satya Kiran, 2015).

The collected data by these sensors are transmitted through a base station called super node then the super node connected with main computer station. The smart sensor can be programming by writing algorithms through programs such as MATLAB and C (Tholeti Satya Kiran, 2015). Wireless sensors are considered less expensive than traditional sensors, and their capacity is greater and at a high level of efficiency (Tholeti Satya Kiran, 2015).

On the other hand, the Internet of Things (IOT) is a term that refers to a system based on IP protocol that works with sensors that can collect data from the things around us and transmit these data in a smart environment and are seamlessly integrated into the information network by using smart devices (C. Jr. Arcadius Tokognon, 2017, P). The major technical specifications of the smart sensors that work under IOT strategy are (F.Lamonaca, 2018):

1- The ability to connect to telecommunication networks.

2- Include a material structure that is interconnected in terms of shape, size and principle of action and has the ability to be sensitive to one of the physical phenomena such as vibration, light, heat and others.

3- Dedicated to sensing one type of signal and according to what it was designed on, and its data can be read easily. 4- Each sensor has its own unique ID address that distinguishes it from others in the network 5- The ability to connect to computers.

6- Their operation can be controlled (remotely turn on and off).

In the IOT sensors the percentage of error reduced of damage detection in the structures as possible in some cases to 0%, i.e. this type of sensors work with very high efficiency and the losses due the cable connection are reduced also.

The sensors are distributed in the virtual private network for the purpose of collecting all the data to be sent to the base station to receive that data for the purpose of analysis, as each sensor has its own identifier that differs from the other, and these devices also allow the possibility of controlling them remotely through the base station As well as recall data and readings and analyze the results at any time.

The (IoT) architecture is an open architecture based on multiple layers. Service-oriented architecture is one of the approaches that researchers have adopted in recent years to implement an Internet of Things (IoT) system. Layers interact with each other by providing different services such as sensing, transmission, aggregation, storage, and information processing. The only drawbacks of this type of sensor are the imposition of arithmetic restrictions and others that lock in power. To achieve interoperability across heterogeneous networks and allow data to be exchanged seamlessly across the (IoT) system, various protocols and standards are established (C. Jr. Arcadius Tokognon, 2017).

The Figure (2) shows the IoT system architecture that consist of the wireless sensing network, this network may be one of the following (BAN- Body Area Network, PAN- Personal Area Network, LAN- Local Area Network and MAN- Metropolitan Area Network) these network connected the sensors and the gateways, the gateways connected with user accesses and control unit via internet network and also connected with data center in order to storage the data.

The user access and control unit connected with data center and also with wireless sensing networks, the collected data transferred from the data cent unit to data processing and analysis center the final report and alarms are obtained from the data processing and analysis center. There any many programs and algorithms that can be used in analysis stage, each reading of each sensor and modeling separately and the final report can complain all of them.

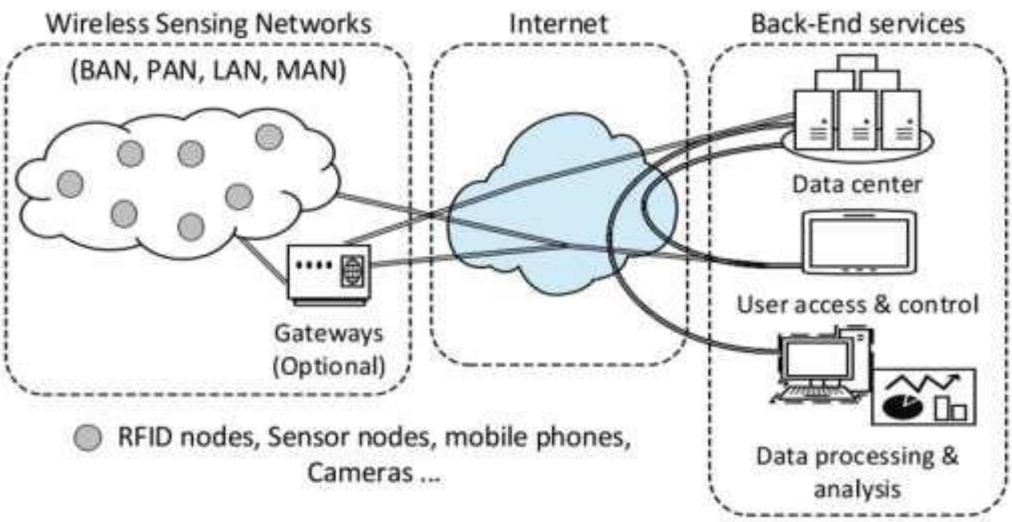

Figure (2) IoT system architecture (C. Jr. Arcadius Tokognon, 2017)

5. Literature Survey

The historical for studies related structural health monitoring in general more several years. Therefore, large amounts of literature, which deal with the topic, are in hand for researchers. Presented in this section, a brief overview of selected relevant research work regarding, structural health monitoring.

Medha Kapoor, Evangelos Katsanos, Lazaros Nalpantidis, Jan, Winkler and Sebastian Thöns, (2021), in this paper the authors discuss the case of using an Unmanned Aerial Vehicle to evaluate and management their impact on the structures by using a structural health monitoring system. The traditional method was the most costly and needed more cables and human efforts. This technology may make a revolution in structural health monitoring system because the process of investments takes very short time as compared with the traditional method. This new technology increases the accuracy of the results by reaching places and corners that were previously difficult to reach, one of the most example of the Unmanned Aerial Vehicle are the drones, as explained by the authors.

Qingkai Kong, Richard M. Allen, Monica D. Kohler, Thomas H. Heaton, and Julian Bunn, (2018), the authors of this paper show how the benefits of using smartphones in a structural health monitoring system and how this techniques can also be used for small houses. The advantages of using smartphones can be addressed as: millions of structures can be monitoring in the same time, the cost is very small, the maintenance cost is also reduced as compared with the computers, can be used for real-time monitoring state. The authors also propose this method to forecast the earthquake and also to reduce its impact. Also, a smartphone monitoring system is complementary to existing structural health monitoring system by providing more data in the same building for validation and to fill in spatial sampling gaps and have the ability to analysis the results.

Pengcheng Jiao, King-James I. Egbe, Yiwei Xie, Ali Matin Nazar and Amir H. Alavi, (2020), the study discussed in the paper by the authors is related to using piezoelectric sensing in a structural health monitoring system, the technique that used here is self-powered systems (the meaning of piezoelectric is to produce electrical charge when mechanically stressed), and this system also can be fed the ultrasonic Lamb wave-sensing. The authors of this paper also discuss the importance of this type of sensor and its design in future, and the results that related to this type shows high accuracy in the results and no need for external power so easy in apply and maintenance.

Arvindan Sivasuriyan, Dhanasingh Sivalinga Vijayan, Wojciech Górski, Łukasz Wodzy nski, Magdalena Daria Vaverková, and Eugeniusz Koda, (2021), in this paper the authors discuss the parameters of structural health monitoring by applying many aspects such as dynamic, static, and finite element methods to forecast the damage and defect in the buildings early. Four major features can explain in this study the presence, location, their impact and how many years still to build to withstand this impact. MATLAB program is used in this paper to analysis the result; the authors use a Bayesian approach method for structural health monitoring to forecast the damage in the buildings. Bayesian approach gives accurate results in dynamic state and evaluation at real-time. The authors also explained in general the advantages of using structural health monitoring in civil structures.

Denise Bolognani, Andrea Verzobio, Daniel Tonelli, Carlo Cappello, Branko Glisic, Daniele Zonta and John Quigley, (2018), the authors of this paper discuss the advantage of of structural health monitoring by using Value of Information concept, Value of Information means the variations in results which can be evaluated in case of use/not use the structural health monitoring system. The main purpose of this paper is to formalize a logical way for quantifying the Value of Information in case of two different actors are concerned in the decision making (the manager of the project and the owner of the project), although the two decision makers have same data about the building and they working in rational but the way of the evaluation is different,

In the paper the authors take an actual case study of Streicker Bridge, a pedestrian bridge in Princeton University campus armed with fiber optic smart sensors. The two decision makers are Malcolm and Ophelia, are involved: Malcolm is the manager who decides whether to keep the bridge open or close it following to an incident; Ophelia is the owner who decides whether to invest on a monitoring system to help Malcolm making the right decision, the results shows that when manager and owner are two different individuals, the benefit of monitoring could be greater or smaller than when all the decisions are made by the same individual. Under appropriate conditions, the monitoring of Value of Information could even be negative, meaning that the owner is willing to pay to prevent the manager to use the monitoring system, the same issue is also submitted by the authors with same procedure and same results of using Value of Information **Matteo Pozzi, Armen Der Kiureghian, (2011)**.

Ahmed Abdelgawad and Kumar Yelamarthi, (2017), here, in this paper the author discuss the important of using structural health information to evaluate the aging of the buildings and how the results can be improved and enhanced by using communication devices for transfer the data, this technology is integrated with internet, the term Internet of Things (IoT) applied for the such technology, the integrated system of structural health monitoring with the (IoT) can transfer the data anytime anywhere with any value. The authors of this paper propose a system consisted of Wi-Fi module, a Raspberry Pi, an Analog to Digital Converter (ADC), a Digital to Analog Converter (DAC), a buffer, and piezoelectric (PZT) sensors. A mathematical model is proposed here to identify the damage (location and size) and the data in this work are stored on the Internet.

Arvindan Sivasuriyan, D. S. Vijayan, A. LeemaRose, J. Revathy, S. Gayathri Monicka, U. R. Adithya, and J. Jebasingh Daniel, (2021), in this paper, the authors discuss the structural health monitoring system that related to different bridge structures, with the following items (i) using many type of sensors for many different issues, and discuss their technical specification and requirements. (ii) The maintenance and rehabilitation of the bridges are discussed according to structural health monitoring results. (iii) The monitoring of bridges should be for long period of time to insure the sensor can withstand the variation in claimant. (iv) How the human errors affected on the results such as the wrong installation of the sensor. (v) The method of forecasted analysis has been conducted; this method will help to select the structure, environment, operational limitations, and practicality of using the technique.

Jyrki Kullaa, (2014), the author of this paper uses a Gaussian model to minimize the nonlinear variations in environmental or operational, which impact on the vibration characteristic. When these factors are non-taken into consideration, the results may be incorrect indications of damage. When these factors are taken into consideration and represent in a Gaussian mixture model. Many advantages are explained by the author of the Gaussian mixture model, but the most important one is to minimize the percentage of the error of damage detection by applying principal component analysis which depends on signal-to-noise ratio (SNR) analysis.

LI Huia, OU Jinping, (2011), the authors of this paper explains the concepts and advantages of using structural health monitoring system in civil engineering. A piezo-electric ceramic and optical fiber Bragg Grating sensors are used with an ultrasonic monitoring method, the sensors are proposed to detect the damages caused by corrosion, earthquake and stress, etc. In this work, it is proposed that there is an absence and persistence detection approach taking into account the uncertainties of the integrity of civil structures and environmental factors. An example of this approach is to determine the probabilistic damage based on dynamic sensitivity analysis and the damage detection approach using information fusion techniques. The approach technique and algorithm use a multi-scale finite element model for insuring the health of the buildings.

Andrea E. Del Grosso, (2013), the author of this paper, summarize the related research papers dealing with structural health monitoring system, many of the issues remain not clear and may be present in the future. The main purpose of structural health monitoring system is to insure the safety of the structure during variation of the environmental. The design of structural health monitoring for restoration of existing structures, as well as for new structures, the presence of the monitoring system can redefine the probabilistic modeling of design uncertainties. The authors of this paper also propose new model called EF model that used to evaluate the defects in the structures.

Mirco Muttillo, Vincenzo Stornelli, Rocco Alaggio, Romina Paolucci, Luca Di Battista, Tullio de Rubeis and Giuseppe Ferri, (2020), in this paper the author explains how the Internet of Things can be used for structural health monitoring to estimate the defects and damage in the smart buildings. In this system the authors use a microcontroller with high-resolution digital accelerometers with high speed communication devices. The devices (sensors and super-nodes) are synchronizing with each other at high speed via Internet of Thing technology. The old sensors (analog) cannot be monitored with the new structural health monitoring system, an analog to digital conversion is needed to use it, and it was expansive, the new sensors that connected via the Internet of Things are cheap compared with the traditional one.

H. Chang and T. Lin, (2017), in this paper, the authors show how the structural health monitoring system can provide the results through the monitoring system and inform the client about the predicted damage. In this work the authors illustrate the smart sensors connecting in a structural health monitoring system via the internet and communication devices and work momentary in real-time. The data collecting and analysis at the main station for analyization purpose, the result can be in 3D form to show the dynamic response variation in the structure in real-time. We also create the inverted movement calculation method that converts the sensor device's local three-dimensional displacements into overall 3D structural model's global movement. The three demotions simulation shows the accurate and correct results of the correct movement without any delay.

Thomas J. ma Tarazzo , Paolosan Ti, shamimn. Pakzad, kris To , Pher CarTer , Carlora T Ti, Ba Bakmoaveni, Chrisosgood, and nigel Ja CoB, (2018), in this paper, the authors explain the structural health monitoring system of the bridge; the case study is measure the impact of the vibration on Harvard Bridge (Boston, MA), by using smartphones, the traditional inspections of defect was difficult before using the smart sensors and smartphones. The bridge is evaluated for long time period in order to take large number of reading data of smartphones for more accuracy results. The frequencies of the smartphones that putted in vehicles can be used to detect the damage of the bridge when it passing through them. This method can be classified as the lower cost method with short time, the results of this method is accurate and can be used for decision-making aspects.

6. Advance Sensing Technology and Sensor and their Challenges

Safety of the civil infrastructure is very important because they have high capital cost and insure human lives. Then the structures need to be inspected within a period of time to detect the damage and predicate the remaining age of the building. Sensors can detect the damage and transfer to the processing unit, the sensors can detect many types of variables, the Table (1) below shows the variable that can be monitored by a structural health monitoring system (Jinping Ou, 2013):

Table (1) Variables to be monitored

Types	Variables
Load	Earthquake ground motion, wind speed and wind pressure, vehicles, impact load, explosive load, and other accident loads
Environment factors	Temperature, humidity, acid, salty solution, alkali, carbon dioxide, etc.
Effects of load	Global responses: acceleration, velocity, static deformation and dynamic displacement, altitude, etc. Local responses: strain, crack, tension force, et
Performance deterioration	Fatigue damage, corrosion, material ageing, carbonization, freeze-thaw, ultraviolet radiation, etc.

Source: Jinping Ou1,2,* and Hui Li2 , Structural Health Monitoring in mainland China: Review and Future Trends , P220

The variables listed as in Table (1) above can be monitored with high performance sensors to demonstration the results, the sensors as they listed below, each type of the sensor have work principle differ from the others, the sensors convert the mechanical, electromechanically, chemical energies variation into electrical energy and waves that can be applied to the computer to simulate the input data with the building model to evaluate the impact (M. Sun, 2010), here we will discuss the four main types of smart sensors as below:

1- Optic-Fiber Sensor

The optic-Fiber sensors are developed in recent years, there are two types, the older production was optic-fiber Bragg-grating (FBG) used for temperature and strain sensing, and the new type is fiber reinforced polymer (FRP) that uses reinforced polymer for protection. The FBG-FRP type is used with sensing the temperature and strain with reinforced polymer protection with high performance, efficiency, stable for a long time period, corrosion resistance and many other high specifications.

These sensors are embedded into reinforced concrete or in steel structure, such types of sensors have low sensitivity coefficient (Jinping Ou1, 2013). Figure (3) shows an example of a complete framework to monitor the health of particular bridge components using fiber optic sensors (Muhammad Hassan Bin Afzal, 2012).

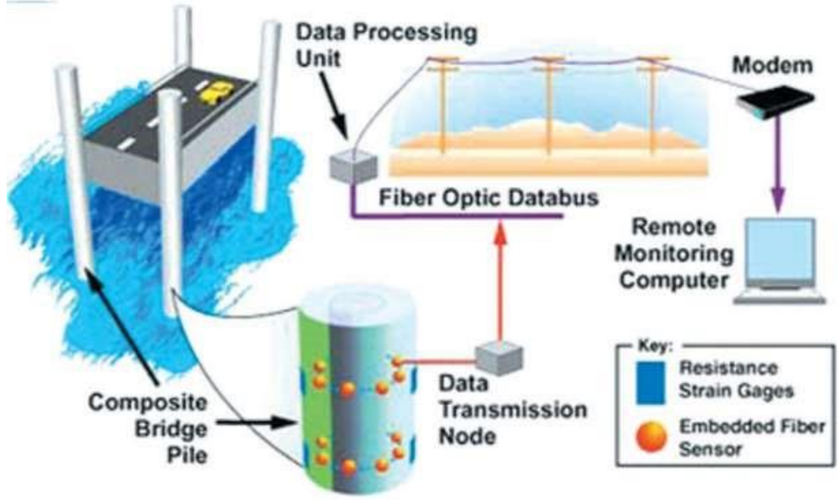

Figure (3) a complete framework to monitor the health of particular bridge components using fiber optic sensors (Muhammad Hassan Bin Afzal, 2012).

2- Piezo-electric Ceramics Sensors

The work principle of Piezoelectricity sensor can explain as the change of mechanical stress to electrical signal (charge) this charge produced by crystalline materials (for example quartz). Reverse phenomena can be applied in some cases by observing the strain/deformation variation with the applied voltage to the sensor (Francesc Pozo, 2021).

There are many applications of Piezoelectricity technology to produce sound, frequency, cigarette lighters and many others. These sensors are modified to work under high strength with large and stable piezoelectric. In the last years, the piezoelectric has been used in intelligent systems for sensors, actuators and transformers, these sensors are embedded into reinforced concrete (Jing Zhang, 2020).

Figure (4) shows the Piezo-electric Ceramics sensor used for crack on structure, the mechanical signals converter to electric impedance through the impedance analyzer, when the electric impedance changed, and the applied voltage also changed then the transmitted data will depend on transmitted voltage of dada (Abdul Aabid, 2021)

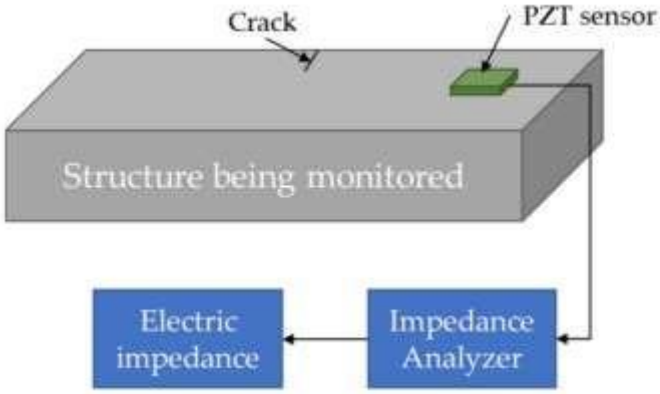

Figure (4) structural health monitoring of the cracked structure by impedance analyzer (Abdul Aabid, 2021)

3- Cement-Based Strain Sensors

Cement Based Strain Sensors (CBS) is one of the most sensors that is used in civil engineering structure during structural health monitoring, and it can be used in bridges, buildings, pavements, etc. Cement based Strain Sensors consist of carbon fiber, Nanomaterials with high conductivity, conductive metals, Piezo-electric Ceramics, or it may consist of two or more of the material.

The work principle of this sensor can be explained with the aim of the sketch in Figure (5) below for cement based strain test with applied load: when the load is applied on the cement, the embedded sensor which consists of short carbon fibers and Nanoparticles will sensing the load and convert the load to resistance, the resistance can change the voltage as the load is changed. The reading of the data will depend on the voltage while the applied voltage of such sensors is depending on the applied load (Egemen Teomete, 2011).

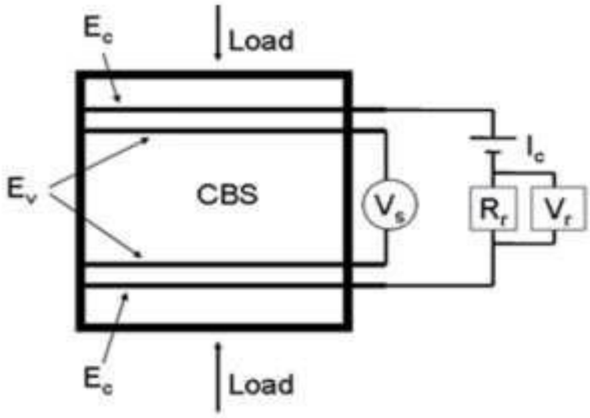

Figure (5) Compression test with electrical resistance measurement (Egemen Teomete, 2011)

4- Corrosion Sensors

The corrosion is one of the most important problems that faced the civil engineering buildings, the early detection of corrosion avoids spending a lot of money during the maintenance process and reduces the possibility of risks that may cause damage of a structure because of that the corrosion test needs to be monitored in an accurate manner. The corrosion sensor needs to work with high accuracy and efficiency with a long-life period. The work principle of the corrosion sensors depends on the transmitted and received signals.

The obtained data results show that the energy of the signal shifts from low frequency to high frequency during the corrosion process. Figure (6) below shows the components of the corrosion sensor, two electrodes are a stainless steel reference electrode and a steel reinforcement electrode. An external interrogator coil coupled with the sensor coil monitors the sensor resonant frequency shift remotely by measuring the impedance change from the source end. In case of corrosion typed as electrochemical corrosion, the total generated electrical power due to the electrochemical corrosion reaction can be added and then used as the battery power of wireless corrosion sensors (Jinping Ou1, 2013) and (Khalada Perveen, 2014).

The interrogator and sensor coils are used to transmit and receive the wireless signals and work as antenna, while the sensor circuit it responsible to convert the reading of the data into variable frequencies varied when the defect of corrosion detected.

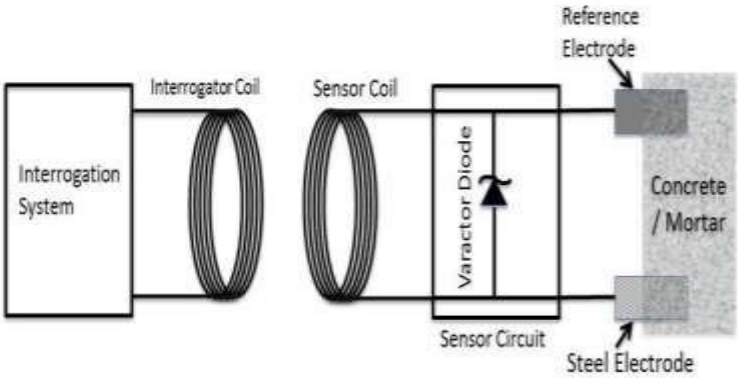

Figure (6) Block diagram of inductively coupled corrosion sensor (Khalada Perveen, 2014)

Although smart sensors have the ability to diagnose defects in buildings with high reliability and accuracy, but still there are some challenges and obstacles they face, which will be briefly listed here (Jinping Ou, 2013):

1- Due to resonant phenomena and the equalization of the local frequency and sensor frequency, in some cases it difficult to detect the local damages.
2- The structural health monitoring system may be fail to detect the damage related to oxygen carbonization, material ageing, freeze-thawcycle, acid reactions, alkali-aggregate reaction, because of the defect cannot sensing still now with the available smart sensors.
3- Due to the long life of the building as compared with the life of smart sensor, the accurate results from monitoring system can be achieved by replacement these sensors.
4- Nano technology-based sensors and bio-inspired sensing technology and sensors.
5- In some cases the structural health monitoring need to thousands of sensors, wire sensors will make implementation problems with high cost and labor needed.
6- The optimal location of the sensors still one of the major challenges during monitoring stage, the results are strongly affect by the locations.
7- Reduction the cost of the smart sensors and increasing the robustness, all the time the consumer’s search about low cost and high robustness.
8- The last challenges that may be mention here, the compressive of data during transmit and receive the data and the relating problems.

7. Challenges in Structural Health Monitoring

There are several challenges related to structural health monitoring that can address here in this section, such as (Shukla Alokita, 2019) and (Charles R Farrar, 2007):

I. Neglected of structural health monitoring system results may be cause damage for building and human lives.

II. Failure of infrastructure in any country reduces the national gross domestic product by approximately 1%.

III. Each civil engineering structure needs different monitoring method from others also the types of sensors are differing.

IV. Problems related to transmit and receive the data and wave interfering that many be make lack in accuracy and reliability.

V. Difficulty to reach to the some sensor locations in the structure.

VI. Difficult to carry out the data from sensors to processing unit in case of wired system.

VII. The old structural health monitoring system (wired system) were expensive while now for (wireless system) inexpensive.

VIII. The increasing of temperature effect on the efficiency of structural health monitoring system.

IX. Wireless sensing unit is associated with various factors such as collocation of computational power and precision of integration

8 . CONCLUSION

In this research, a topic of structural health monitoring in civil engineering has been reviewed and emphasized, the importance of structural health monitoring was addressed here will all respects in economics, social, and other aspects. Other points are discussed here to evaluate the benefits of implementation of structural health monitoring in civil engineering, such as; improve safety of public, detect the risk early, increase the life time period of the civil structure, and decrease in the capital expenditures involved and unnecessary maintenance and rehabilitation. Many related studies and papers are discussed in the paper which includes many examples that explain the benefits, components, challenges and other issues using structural health monitoring. This research also shows the importance of using smart sensors and smart technology to evaluate the defect of the damage, the civil engineering now interconnected with electrical, electronic and communication engineering and structural health monitoring will develop and enhanced as the other engineering's developed.

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