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Defining a Conceptual Framework for Vibration-Based Damage Detection Platforms Using Blockchain

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ABSTRACT

Current vibration-based damage detection consists of two main components, including modal parameter estimation methods and detection techniques. The second component employs the first part to detect and locate damage. Therefore, both are influenced by each other. They are typically predicted upon centralized data collection techniques, which significantly affect the ability to extract information on the structural health condition. Besides, the modal domain methods play an important role in structural damage identification, and their popularity is much more than the time domain or frequency domain approach. In the same line, an advanced decentralized database technology is required for the aforesaid techniques to overcome the high maintenance cost of centralized approaches. Therefore, this study aims to improve the reliability and efficiency of current damage detection platforms through the integration of vibration-based methods and blockchain. To this end, a conceptual framework is proposed to make a connection between hardware and software components of structural damage detection.

Keywords: **Structural health monitoring, Vibration-based damage detection, Blockchain, Big data**

1. INTRODUCTION

Structural damages can change the structural properties, and consequently, changes of dynamic characteristics of structures, which can lead to out-of-service conditions [1]. Therefore, the unpredicted structural failure in civil structures can produce catastrophic collapse, economic costs, human injuries, and death [2]. Thus, the focus on structural damage identification systems has been on the rise for civil engineering applications in order to evaluate the structural integrity using structural health monitoring (SHM) methods during construction and while in service. Consequently, effective and reliable non-destructive damage detection systems are very significant to monitor the structure for the occurrence, location, and severity of any damage [3]. The majority of the vibration-based damage identification methods can be considered as some kind of pattern recognition due to their ability to find the differences between two types of data (e.g. before and after damage) [4]. For instance, modal analysis is a vibration-based approach that is used to identify damage from any changes in structural vibration characteristics with prior knowledge of the undamaged state [5]. In the modal analysis, any change in the structural physical parameters such as material changes and geometric properties changes can cause detectable effects in modal parameters [6]. Blockchain technology is a growing reality of our modern

society [7]. Besides, big data analytics can also extract meaningful information from the oceans of data produced by sensor devices [8]. The implementation of blockchain-based solutions could solve several issues, i.e. the high maintenance cost of centralized approaches [9]. Therefore, blockchain has attracted huge attention from practitioners and academics in various fields such as business, energy, manufacturing, smart cities, finance, healthcare, and transportation. This paper thus defines a conceptual framework for the implementation of SHM through the integration of vibration-based methods and blockchain. To do so, the structure of the paper is as follows. Section 2 discusses vibration-based damage detection systems. The application of sensors in SHM is addressed in Section 3. Section 4 introduces blockchain technology briefly. Then, Section 5 presents the proposed conceptual framework. Finally, Section 6 concludes the paper.

2. METHODOLOGY

2.1. CURRENT VIBRATION-BASED DAMAGE DETECTION SYSTEMS

Vibration-based damage detection consists of two main components, including modal parameter estimation methods (i.e. experimental modal analysis and operational modal analysis) and identification/detection techniques (i.e. frequency change, mode shape change, mode shape curvature/strain mode shape, modal flexibility change, modal strain energy change, matrix methods, etc.). The second component employs the first part in order to detect and locate damage. Therefore, both are influenced by each other. Hence, it is required to know about their details [10].

Theoretically, there are three components to vibrate a structure, i.e. the spatial, modal, and response models [11]. A spatial model can be described as a mathematical representation of stiffness, mass, and damping in the equation of motion. In a modal model, a structure can be defined using a series of vibration modes, and the structural response can also be identified in the response model [12]. The following review a number of vibration-based damage detection techniques, essentially those which are related to this work.

2.1.1. Modal Parameters Estimation Methods

Modal parameter estimation relies on methods of excitation as well as the accuracy of data acquisition tools. Therefore, mode identification methods can be divided into the operational and experimental modal analysis. Operational modal analysis regularly refers to output-only measurements, whereas experimental modal analysis uses input excitation and output response measurements to estimate the modal parameters [13]. In general, operational modal analysis is merely employed in practical engineering. This is due to the fact that (1) it is not possible to shut down the system while the structure is in-service, or (2) the artificial excitation is not adequate to excite the structure. Therefore, other cost-effective as well as immeasurable passive exciters, i.e. ambient forces or cyclic loads, can be utilized as the operating vibration requirement. The advantage of using operational modal analysis is that the excitation source is real with the ability to perform continuous monitoring, which is not from an isolated shaker or hammer. Hence, the modal parameters can be measured without any information related to excitation [14]. On the other hand, the output-only method has some limitations, such as difficulties in extracting damping properties, uncontrolled input amplitude, and so forth (Lee et al. 2004). An illustration of the concept of operational modal analysis is presented in Figure 1.

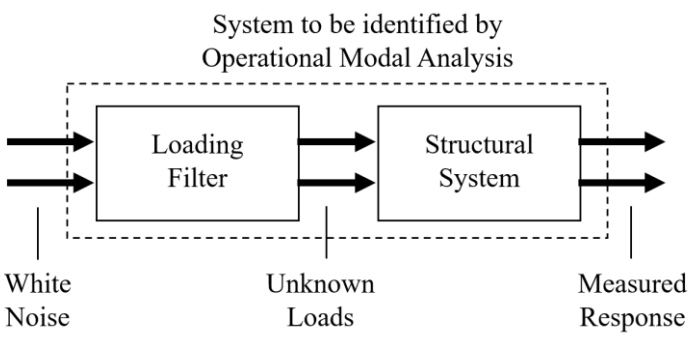

Figure 1. A schematic diagram of operational modal analysis [15]

Experimental modal analysis is generally implemented in the laboratory environment using controlled active vibration source, e.g. random forces or measurable impact, in order to compute the structural response, e.g. frequency response function (FRF) or impulse response function (IRF). In most cases of experimental modal analysis, the input excitation and output response are measured according to the time-domain approach. However, it is difficult to study damage identification in such a manner. Hereupon, time-domain data can be transformed to the frequency domain using modal analysis, and modal domain data can be extracted from the frequency domain. Consequently, the modal domain methods play a significant role in structural damage identification, and their popularity is much more than the time domain or frequency domain approach. This is due to the fact that the modal properties such as natural frequencies, modal damping, and mode shapes have their physical meaning, and they are easier to interpret in comparison to mathematical features obtained from the time or frequency domain [16]. Impact hammer and shaker are the most applicable input-output tools to generate artificial

excitation. Impact hammer is easy to use because of its portability. Nevertheless, conducting a reliable input in the impact hammer is a challenging issue due to the manual nature of the impact. To overcome this limitation, a shaker can be used in order to excite higher modes of the structure. Although, it is worth mentioning that the shaker is more expensive as well as heavier than the impact hammer, which makes it a costly device and difficult to set up in the laboratory [12]. Figure 2 is showing an architecture of the experimental modal analysis setup.

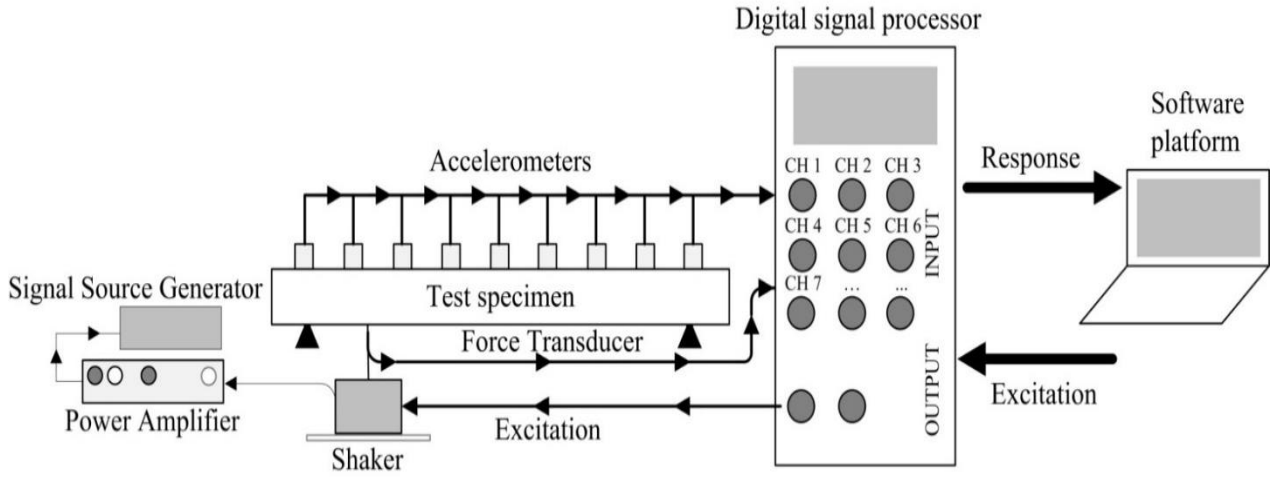

Figure 2. An Architecture of experimental modal analysis [17]

2.1.2. Structural Identification and Detection Methods

System identification is the process of developing the mathematical representation of a physical system using experimental data. When a numerical/analytical model exists a prior, it is called a forward problem, and when the structural model is obtained from experimental data, it is called an inverse problem. Structural identification can be implemented in inverse problems. Global properties of any structure can be defined by modes of vibration, and any mode is identified by the dynamic characteristics of the structure. Accordingly, these characteristics comprise three parameters, i.e. modal frequencies, corresponding mode shapes, and modal damping, which can be obtained from FRF measurements. For the identification of a theoretical model of the structure, it is convenient to present the result in the frequency domain, since the output of a modal test is typically given as a function of the frequency. The response model of the structure is merely the solution of the equations of motion under a given excitation and is presented as a function of time or frequency in the form of FRFs [12]. The theoretical background of aforesaid explanations is briefly discussed. The equation of motion of an n-DOF structural dynamic system under forcing function F(t) in the time domain is presented in Eq. (1), where M, C, and K represent mass, damping, and stiffness, respectively. It should be noted that the dots over u in Eq. (1) is referring to the first and second derivatives of the displacement with respect to time [18].

$$M\ddot{u} + C\dot{u} + Ku = F(t) \qquad (1)$$

Eq. (2) is a rewritten version of Eq. (1) in the frequency domain which is extracted by means of Fourier transform.

$$\begin{cases} S(\omega).x(\omega) = F(\omega) \\ S(\omega) = (-\omega^2 M_{i\omega C} + K) \end{cases} \qquad (2)$$

Where, ω is the frequency, $S(\omega)$, $x(\omega)$ and $F(\omega)$ are the system matrix, the vector of nodal DOFs and nodal forces, respectively. Eq. (3) illustrates the changes of vibration frequencies in an undamaged system. In this equation, λ_i and ϕ_i represent the *ith* eigenvalue and eigenvector, respectively.

$$(K + \lambda_i M).\varphi_i = 0 \qquad (3)$$

According to [19], vibration-based damage identification levels consist of damage presentation, damage localization, damage extension, and prognosis of remaining Life. Hence, in the past few decades, a number of vibration-based approaches have been reported to identify aforesaid levels, as indicated in Table 1 [12].

Table 1. Summary of existing vibration-based damage detection techniques

Category		Methodology
Modal Parameters	Natural Frequency	● Frequency change
		● Residual force optimization
	Mode shapes	● Mode shape change
		● Modal strain energy
		● Mode shape derivatives
Matrix Methods	Stiffness – Based	● Modal updating
		● Optimization techniques
	Flexibility – Based	● Dynamically measured flexibility
Other Techniques		● Time history analysis
		● Evaluation of FRFs

2.2. SENSORS IN STRUCTURAL DAMAGE DETECTION

A number of sensors such as strain, displacement, and temperature sensors have been utilized in damage detection in order to monitor any structural changes [7]. Sensors in structural health monitoring (SHM) can be divided into two categories, i.e. old generation and new technology of sensors. For instance, there are different types of conventional sensors which have been used in SHM for the past decades, such as acoustic emission sensors [20] and piezoelectric accelerometers (Wilcoxon Snap, Kistler, etc.). These sensors are mostly independent, and they cannot communicate with other types of sensors. Another limitation of these sensors is that they are not low-cost sensors. For example, piezoelectric sensors have a high cost of fabrication. Besides, these types of sensors are not flexible. Optical fiber sensors [21], wireless sensor networks (WSNs) [22], and embedded radio frequency identification (RFID) systems [23] are some of the latest emerging sensors technology. The advantage of using the new sensor technology is that they are cost-effective. They also don't need complex installation. For instance, in comparison to other sensors, optical fiber Bragg grating (FBG) sensors are easier to install. In other words, this type of sensor has easy installation to current structures, including inaccessible locations. Another advantage of these sensors is that they need less calibration in comparison to dated generation of sensors. Wireless sensors have been designed according to the developing application of low-power system-on-chip wireless transceivers, as these transceivers are successfully functioning in the majority of the license-free ISM (Industrial, Scientific, and Medical) frequency bands (see Figure 3). Moreover, WSNs, as the basic layer of the Internet of Things (IoT), can support real-time and continuous data transmission, which is based on frequency division multiplexing technology [24]. Therefore, they have recently been employed for SHM systems. This is because of great computing ability and intelligent sensing in WSNs [25]. As can be seen from Figure 3, in the monitoring process, the network of accelerometers is utilized to create a database using response data collection in buildings, bridges, and roads.

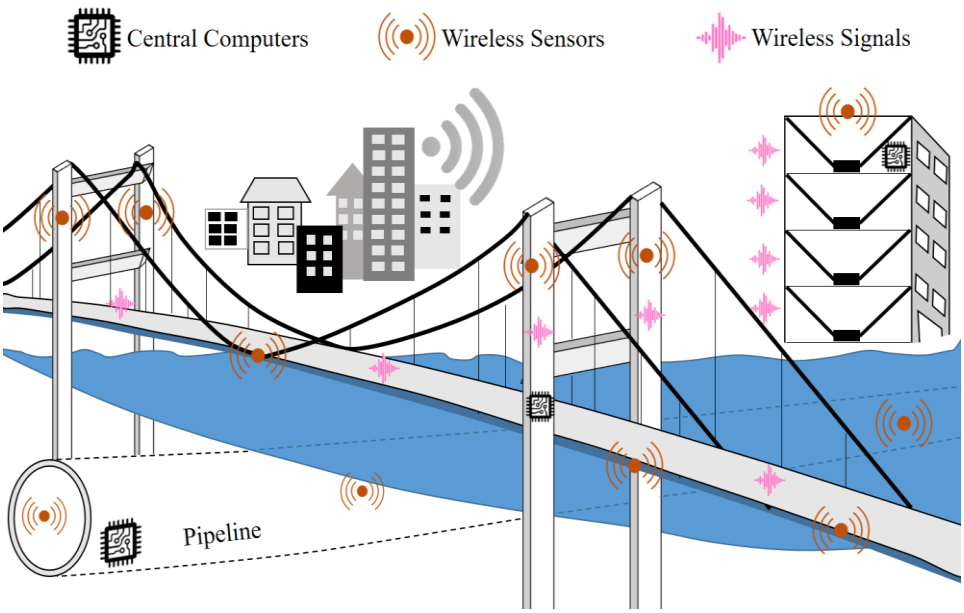

Figure 3. Wireless sensor networks

3. RESULTS AND DISCUSSION

3.1. BLOCKCHAIN

Blockchain is described as a decentralized database technology of recording any data in a continuously encrypted and irreversible ledger [25]. Data can be defined as any value, fact, number, or transaction which can be proceeded by computers [27]. Therefore, Blockchain has attracted huge attention in a number of fields, as shown in Figure 4.

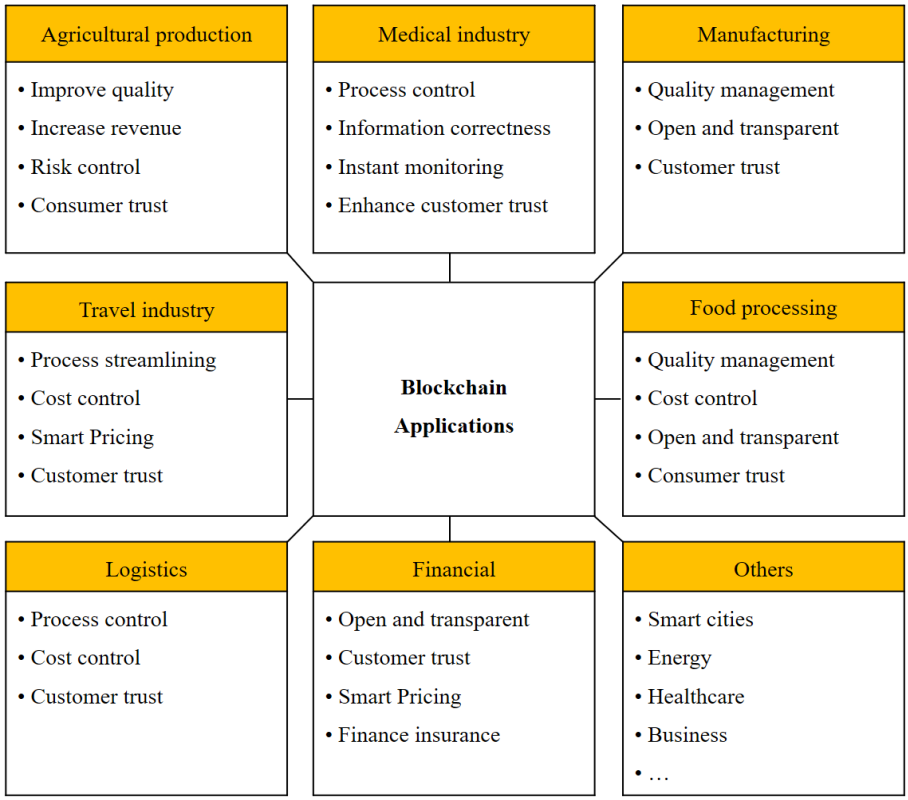

Figure 4. Blockchain Applications

Blockchain works on a network by many different participants (or nodes) based on transparency. To this end, in Blockchain, a pre-developed interaction is generated by a transaction which is called a block. Information can be exchanged between nodes using this interaction. Then, all nodes are continually synchronized in a digital ledger of transactions to grow as blocks. In the same line, Figure 5 is presenting the structure of a blockchain in the form of a series of blocks linked sequentially to each other. Besides, each block is chained to another using a hash. It should be noted that a cryptographic hash function can produce the hash through running contents of the block [28]. Consequently, the hash of the previous block can be maintained in each block. As a result, any unmatched data or any modification is obviously detectable in the following block. Eventually, a secure network is created using valid data amongst all participants, including trusted and untrusted nodes. The only data, which acknowledged by the majority, can consider valid. Hence, according to the blockchain strategy, any entrance of data to a blockchain cannot be done due to the accessibility of all nodes. Therefore, the agreement from the majority is required for any entry into the Blockchain [29].

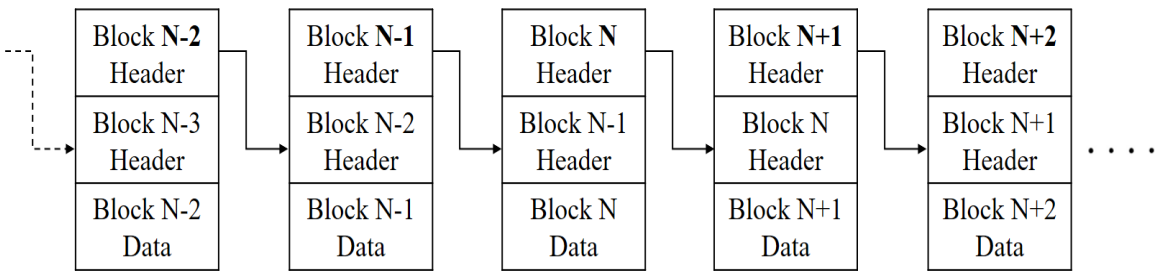

Figure 5. Illustration of blockchain and Chaining of the blocks

A "Block" in Blockchain has several components, such as index, data, hash, previous hash, and timestamp (see Figure 6). To understand blockchain, it is required to understand what a "hash" is. A "hash" is a series of random characters in the "block," which represents a digital fingerprint of digital data. Each hash value is unique. It means it's impossible to produce the same hash value entering different inputs [30].

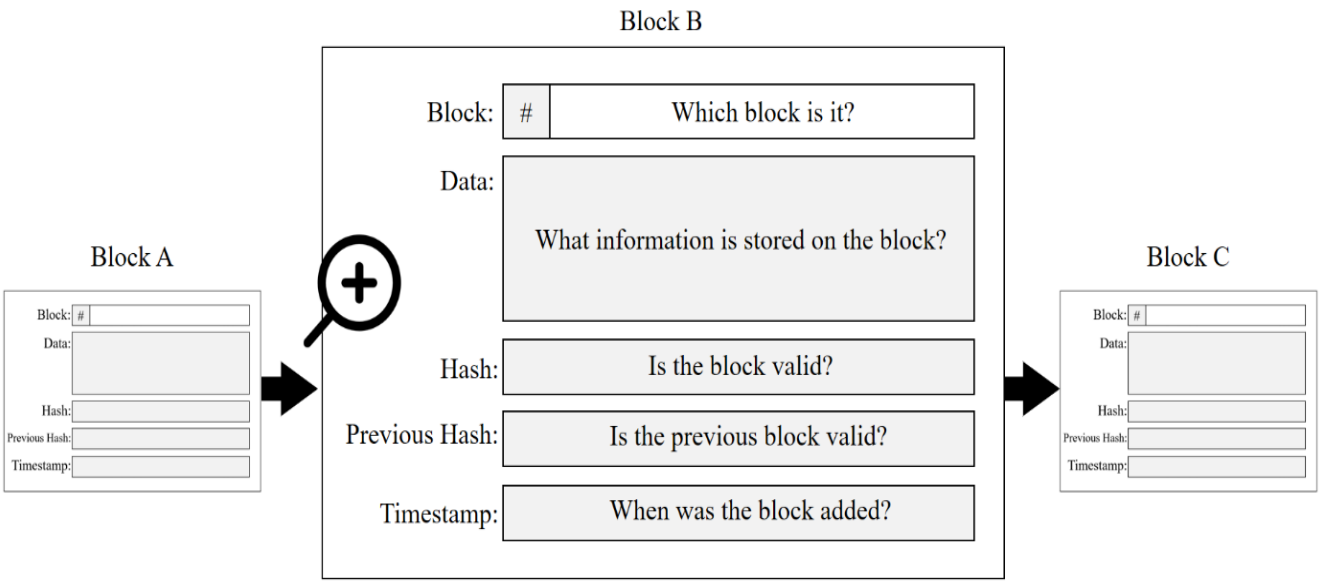

Figure 6. Structure of Blockchain

3.2. CONCEPTUAL FRAMEWORK

According to [31], one of the most important benefits of blockchain is that it can manage decentralized databases without failure. In the same line and by taking advantage of this feature, before starting the SHM procedure for any in-service structure, a reliability evaluation of the recorded data needs to be carried out in advance to verify the authenticity of the sensors' signals. Therefore, a new investigation on the application of blockchain technology in SHM is required to increase the robustness of the databases. Besides, an applicable data analysis technique should be utilized to create a suitable sensor's data as a signature block in the blockchain algorithm. The technique will train the data for various functions, e.g. optimization, classification, or prediction. As a matter of fact, a central database is easy to compute, but it is difficult to manage the decentralized database. From this perspective, the advantage of using blockchain technology is to increase the reliability of the recorded database. In this direction, a blockchain algorithm is able to validate all sensor data to determine which sensor is giving genuine signals for further processing. For the sake of clarity, an effort is made to present a step-wise approach in the following paragraph. In this section, a conceptual framework is proposed to improve the reliability and efficiency of SHM-related technologies for civil structures through making the connection between hardware and software components, as shown in Figure 7. As it can be observed from this figure, SHM process of the in-service structure starts with data measurement. In most cases, the input excitation and output response are measured in the time domain. However, it is difficult to study damage identification in such a manner. Hereupon, time-domain data can be transformed to the frequency domain using modal analysis, and modal domain data can be extracted from the frequency domain. Consequently, the modal domain methods play a significant role in structural damage identification, and their popularity is much more than the time domain or frequency domain approach. This is due to the fact that the modal properties such as natural frequencies, modal damping, and mode shapes have their physical meaning, and they are easier to interpret in comparison to mathematical features obtained from the time or frequency domain. Then, blockchain technology is utilized to increase the reliability of the recorded database. The blockchain algorithm will validate all sensor databases on these blocks to determine that the sensor is giving genuine signals for further processing. Therefore, any recorded sensor data cannot be added to the SHM input database without agreement from the blockchain. In the next step, an applicable vibration-based damage detection algorithm using artificial intelligence and machine learning is suggested to be applied for training the database in order to generate the test design, and patterns creation. Last but not least, pattern validation is also detailed to determine the severity and location of the damage.

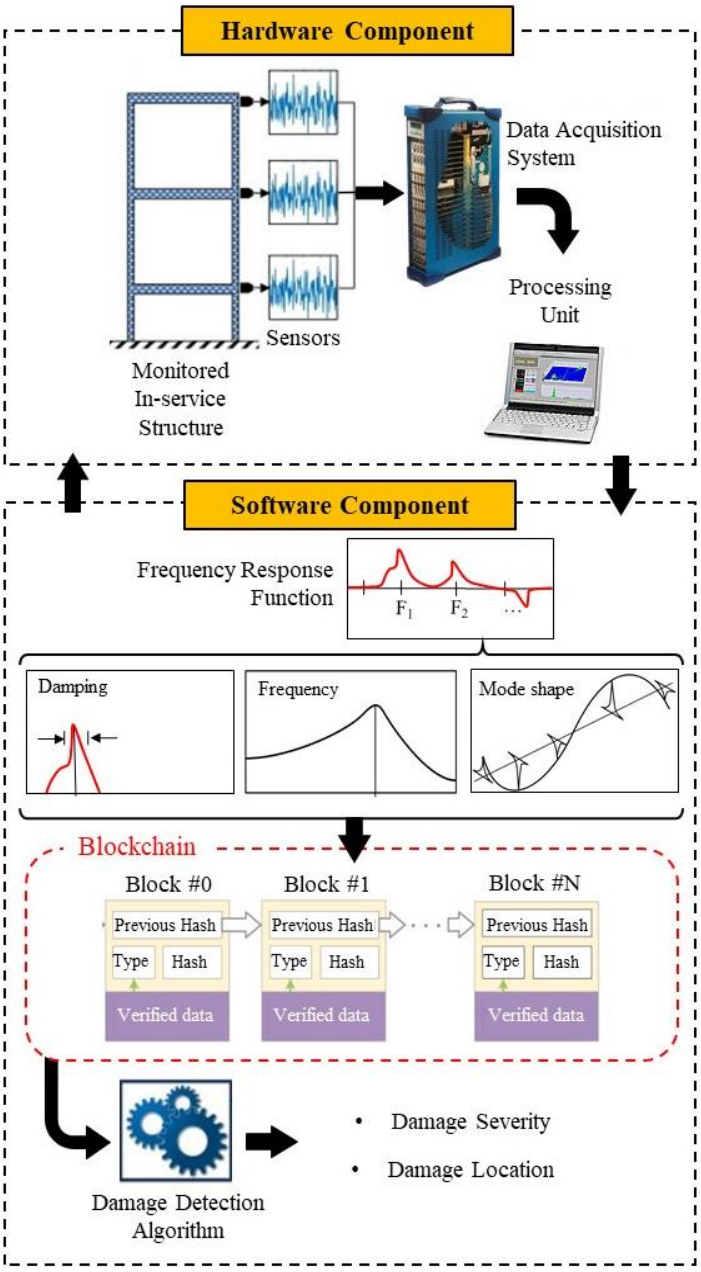

Figure 7. Schematic illustration of the proposed conceptual framework

4. CONCLUSION

Civil infrastructures, such as high-rise buildings, long-span bridges, and large hydraulic structures may experience damage induced by different reasons such as common weakening of material properties, fatigue, aging, delamination, wear, corrosion, creep, microstructural defects, environmental influences, overloading, changes in loading patterns or various unexpected causes such as wind excitations, earthquake and vehicle impact during their service life which can critically disturb their integrity and safety. Therefore, the unpredicted structural failure in civil infrastructures can produce catastrophic collapse, economic costs, human injuries, and death. Thus, the focus on structural damage identification systems has been on the rise for civil engineering applications in order to evaluate the structural integrity using SHM methods during construction and while in service. Consequently, effective and reliable non-destructive damage detection systems are very significant to monitor the structure for the occurrence, location, and severity of any damage. Besides, computer-based knowledge discovery technologies such as Internet-of-things (IoT), blockchain, and data mining have recently gained growing attention in SHM because of their potential ability to be combined with diagnostic systems. Therefore, they have been used in the development of structural damage identification as reliable monitoring tools. It is because what all of these technologies have in common is their connection with wireless sensors network (WSN), which eventually could be considered as a practical tool in SHM. In this regard, in the present study, a conceptual framework based on blockchain technology along with modal analysis steps has been proposed for structural condition assessment of in-service structures. It is worth noting that, to the best of our knowledge, this is the first time to develop vibration-based damage detection platforms using blockchain technology.

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AUTHORS CONTRIBUTION

This study was carried out in collaboration among all authors.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest

5. REFRENCES

[1] Gordan M, Razak HA, Ismail Z, Ghaedi K. Data mining based damage identification using imperialist competitive algorithm and artificial neural network. Latin American Journal of Solids and Structures. 2018;15(8). [View at Google Scholar] ; [View at Publisher]

[2] Bazazan Lotfi S, Rahimi M. A Study on Vulnerability of Urban Neighborhoods to Earthquake (Case Study: Farahzad Neighborhood, Tehran). Journal of civil Engineering and Materials Application. 2017 Jun 1;1(1):1-7. [View at Google Scholar] ; [View at Publisher]

[3] Gordan M, Razak HA, Ismail Z, Ghaedi K. Recent developments in damage identification of structures using data mining. Latin American Journal of Solids and Structures. 2017;14(13):2373-401. [View at Google Scholar] ; [View at Publisher]

[4] Gordan M, Ismail Z, Razak HA, Ghaedi K, Ibrahim Z, Tan ZX, Ghayeb HH. Data mining-based damage identification of a slab-on-girder bridge using inverse analysis. Measurement. 2020 Feb 1;151:107175. [View at Google Scholar] ; [View at Publisher]

[5] Gordan M, Ismail Z, Razak HA, Ibrahim Z. Vibration-Based Structural Damage Identification Using Data Mining. In: 24th International Congress on Sound and Vibration (ICSV24) London. 2017a. [View at Publisher]

[6] Türker T. Ambient vibration test of building base slab for different ground conditions. Measurement. 2014 Jun 1;52:77-84. [View at Google Scholar] ; [View at Publisher]

[7] Jo BW, Khan RM, Lee YS. Hybrid blockchain and internet-of-things network for underground structure health monitoring. Sensors. 2018 Dec;18(12):4268. [View at Google Scholar] ; [View at Publisher]

[8] Talebkhah M, Sali A, Marjani M, Gordan M, Hashim SJ, Rokhani FZ. Edge computing: Architecture, Applications and Future Perspectives. In: IICAIET2020 (IEEE International Conference on Artificial intelligence in Engineering and Technology). Sabah, Malaysia; 2020. [View at Publisher]

[9] Casino F, Dasaklis TK, Patsakis C. A systematic literature review of blockchain-based applications: current status, classification and open issues. Telematics and informatics. 2019 Mar 1;36:55-81. [View at Google Scholar] ; [View at Publisher]

[10] Hooman M. Model updating and damage detection of frame structures using output-only measurements/Hooman Monajemi (Doctoral dissertation, University of Malaya). [View at Google Scholar] ; [View at Publisher]

[11] Tan ZX, Thambiratnam DP, Chan TH, Gordan M, Abdul Razak H. Damage detection in steel-concrete composite bridge using vibration characteristics and artificial neural network. Structure and Infrastructure Engineering. 2020 Sep 1;16(9):1247-61. [View at Google Scholar] ; [View at Publisher]

[12] Lee LS, Karbhari VM, Sikorsky CH. Investigation of integrity and effectiveness of RC bridge deck rehabilitation with CFRP composites. SSRP. 2004;8. [View at Google Scholar] ; [View at Publisher]

[13] Qu CX, Yi TH, Li HN. Mode identification by eigensystem realization algorithm through virtual frequency response function. Structural Control and Health Monitoring. 2019 Oct;26(10):e2429. [View at Google Scholar] ; [View at Publisher]

[14] Rahman AG, Ong ZC, Ismail Z. Enhancement of coherence functions using time signals in Modal Analysis. Measurement. 2011 Dec 1;44(10):2112-23. [View at Google Scholar] ; [View at Publisher]

[15] Brincker R, Ventura C. Introduction to operational modal analysis. John Wiley & Sons; 2015 Sep 8. [View at Google Scholar] ; [View at Publisher]

[16] Hou J, Jankowski Ł, Ou J. Frequency-domain substructure isolation for local damage identification. Advances in Structural Engineering. 2015 Jan;18(1):137-53. [View at Google Scholar] ; [View at Publisher]

[17] Gordan M, Razak HA, Ismail Z, Ghaedi K, Tan ZX, Ghayeb HH. A hybrid ANN-based imperial competitive algorithm methodology for structural damage identification of slab-on-girder bridge using data mining. Applied Soft Computing. 2020 Mar 1;88:106013. [View at Google Scholar] ; [View at Publisher]

[18] Abdo M. Structural health monitoring, history, applications and future. A review book. Open Science. 2014. [View at Google Scholar] ; [View at Publisher]

[19] Rytter T. Vibrational Based Inspection of Civil Engineering Structures. PhD Thesis, Department of Building Technology and Structural Engineering, Aalborg University, Denmark; 1993. [View at Google Scholar] ; [View at Publisher]

[20] Rehman SK, Ibrahim Z, Memon SA, Jameel M. Nondestructive test methods for concrete bridges: A review. Construction and building materials. 2016 Mar 15;107:58-86. [View at Google Scholar] ; [View at Publisher]

[21] Luo D, Ma J, Ibrahim Z, Ismail Z. Etched FBG coated with polyimide for simultaneous detection the salinity and temperature. Optics Communications. 2017 Jun 1;392:218-22. [View at Google Scholar] ; [View at Publisher]

[22] Li Z, Guo J, Liang W, Xie X, Zhang G, Wang S. Structural health monitoring based on realadaboost algorithm in wireless sensor networks. InInternational Conference on Wireless Algorithms, Systems, and Applications 2014 Jun 23 (pp. 236-245). Springer, Cham. [View at Google Scholar] ; [View at Publisher]

[23] Chin S, Yoon S, Choi C, Cho C. RFID+ 4 D CAD for progress management of structural steel works in high-rise buildings. Journal of Computing in Civil Engineering. 2008 Mar;22(2):74-89. [View at Google Scholar] ; [View at Publisher]

[24] Gordan M, Ismail Z, Ghaedi K, Ibrahim Z, Hashim H, Ghayeb HH, Talebkhah M. A Brief Overview and Future Perspective of Unmanned Aerial Systems for In-Service Structural Health Monitoring. [View at Google Scholar] ; [View at Publisher]

[25] Belghith A, Koubaa A, Shakshuki E. Challenges and trends in wireless ubiquitous computing systems. Pers Ubiquitous Comput. 2011;15(8):781–2. [View at Google Scholar] ; [View at Publisher]

[26] Gürkaynak G, Yılmaz İ, Yeşilaltay B, Bengi B. Intellectual property law and practice in the blockchain realm. Computer law & security review. 2018 Aug 1;34(4):847-62. [View at Google Scholar] ; [View at Publisher]

[27] Gordan M, Ismail Z, Ibrahim Z, Hashim H. Data Mining Technology for Structural Control Systems: Concept, Development, and Comparison. InRecent Trends in Artificial Neural Networks-from Training to Prediction 2019 Oct 25. IntechOpen. [View at Google Scholar] ; [View at Publisher]

[28] Sikorski JJ, Haughton J, Kraft M. Blockchain technology in the chemical industry: Machine-to-machine electricity market. Applied energy. 2017 Jun 1;195:234-46. [View at Google Scholar] ; [View at Publisher]

[29] Dorri A, Kanhere SS, Jurdak R. MOF-BC: A memory optimized and flexible blockchain for large scale networks. Future Generation Computer Systems. 2019 Mar 1;92:357-73. [View at Google Scholar] ; [View at Publisher]

[30] Severeijns L. What is blockchain? How is it going to affect Business? Vrije Univ Amsterdam. 2017. [View at Publisher]

[31] Makhdoom I, Abolhasan M, Abbas H, Ni W. Blockchain's adoption in IoT: The challenges, and a way forward. Journal of Network and Computer Applications. 2019 Jan 1;125:251-79. [View at Google Scholar] ; [View at Publisher]