Lecture Notes on Data Engineering
and Communications Technologies 148

Ngoc-Thanh Nguyen
Nhu-Ngoc Dao
Quang-Dung Pham
Hong Anh Le *Editors*

Intelligence of Things: Technologies and Applications

The First International Conference on Intelligence of Things (ICIT 2022), Hanoi, Vietnam, August 17–19, 2022, Proceedings

Springer

Lecture Notes on Data Engineering and Communications Technologies

Volume 148

Series Editor

Fatos Xhafa, Technical University of Catalonia, Barcelona, Spain

The aim of the book series is to present cutting edge engineering approaches to data technologies and communications. It will publish latest advances on the engineering task of building and deploying distributed, scalable and reliable data infrastructures and communication systems.

The series will have a prominent applied focus on data technologies and communications with aim to promote the bridging from fundamental research on data science and networking to data engineering and communications that lead to industry products, business knowledge and standardisation.

Indexed by SCOPUS, INSPEC, EI Compendex.

All books published in the series are submitted for consideration in Web of Science.

More information about this series at https://link.springer.com/bookseries/15362

Ngoc-Thanh Nguyen · Nhu-Ngoc Dao ·
Quang-Dung Pham · Hong Anh Le
Editors

Intelligence of Things: Technologies and Applications

The First International Conference on Intelligence of Things (ICIT 2022), Hanoi, Vietnam, August 17–19, 2022, Proceedings

Springer

Editors
Ngoc-Thanh Nguyen
Wroclaw University of Science and Technology
Wrocław, Poland

Quang-Dung Pham
Vietnam National University of Agriculture
Hanoi, Vietnam

Nhu-Ngoc Dao
Sejong University
Seoul, Korea (Republic of)

Hong Anh Le
Hanoi University of Mining and Geology
Hanoi, Vietnam

ISSN 2367-4512 ISSN 2367-4520 (electronic)
Lecture Notes on Data Engineering and Communications Technologies
ISBN 978-3-031-15062-3 ISBN 978-3-031-15063-0 (eBook)
https://doi.org/10.1007/978-3-031-15063-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Preface

This volume contains the proceedings of the First International Conference on Intelligence of Things (ICIT 2022), held in Hanoi, Vietnam, during August 17–19, 2022. The conference was co-hosted by the Hanoi University of Mining and Geology (HUMG) and Vietnam National University of Agriculture (VNUA), Vietnam, in cooperation with the Ho Chi Minh City University of Technology (HCMUT), Ho Chi Minh City Open University (HCMOU), and the University of Danang, Vietnam–Korea University of Information and Communication Technology (VKU), Vietnam. Due to the COVID-19 pandemic, the conference was organized in a hybrid mode to allow both on-site and online paper presentations. This event also marks the 20th anniversary of the Faculty of Information Technology, HUMG. Since its establishment in 2002, the Faculty of Information Technology has set the goal of becoming one of the prestige research and training centers, especially in applications of information technology for Earth sciences, mining, environment, and energy. Currently, the faculty has 64 staff members working in seven departments and one laboratory. It will continue to develop high-quality human resources in IT and make a positive contribution to society in Vietnam.

In recent years, we have witnessed important changes and innovations that the Internet of things (IoT) enables for emerging digital transformations in human life. Continuing impressive successes of the IoT paradigms, things now require an intelligent ability while connecting to the Internet. To this end, the integration of artificial intelligence (AI) technologies into the IoT infrastructure has been considered a promising solution, which defines the next generation of the IoT, i.e., the intelligence of things (AIoT). The AIoT is expected to achieve more efficient IoT operations in manifolds such as flexible adaptation to environmental changes, optimal trade-off decisions among various resources and constraints, and friendly human–machine interactions. In this regard, the ICIT 2022 was held to gather scholars who address the current state of technology and the outcome of ongoing research in the area of AIoT.

The organizing committee received over 100 submissions from 12 countries. Each paper was reviewed by at least two members of the program committee (PC) and external reviewers. Finally, we selected 40 best papers for oral presentation and publication.

We would like to express our thanks to the keynote speakers: Schahram Dustdar from Vienna University of Technology, Austria, Gottfried Vossen from the University of Muenster, Germany, and Jiming Chen from Zhejiang University/Zhejiang University of Technology, China, for their world-class plenary speeches.

Many people contributed toward the success of the conference. First, we would like to recognize the work of the PC co-chairs for taking good care of the organization of the reviewing process, an essential stage in ensuring the high quality of the accepted papers. In addition, we would like to thank the PC members for performing their reviewing work with diligence. We thank the local organizing committee chairs, publicity chair, multimedia chair, and technical support chair for their fantastic work before and during the conference. Finally, we cordially thank all the authors, presenters, and delegates for their valuable contribution to this successful event. The conference would not have been possible without their support.

Our special thanks are also due to Springer for publishing the proceedings and to all the other sponsors for their kind support.

Finally, we hope that ICIT 2022 contributed significantly to the academic excellence of the field and will lead to the even greater success of ICIT events in the future.

August 2022

Ngoc Thanh Nguyen
Nhu-Ngoc Dao
Quang-Dung Pham
Hong Le Anh

Organization

Organizing Committee

Honorary Chairs

Thanh Hai Tran	Hanoi University of Mining and Geology, Vietnam
Lan Nguyen T.	Vietnam National University of Agriculture, Vietnam
Thanh Thuy Nguyen	Vietnam National University, Vietnam
Huynh Cong Phap	The University of Danang, Vietnam–Korea University of Information and Communication Technology, Vietnam

General Chairs

Nhu-Ngoc Dao	Sejong University, South Korea
Quang-Dung Pham	Vietnam National University of Agriculture, Vietnam
Hong Anh Le	Hanoi University of Mining and Geology, Vietnam
Tran Vu Pham	Ho Chi Minh City University of Technology, Vietnam

Program Chairs

Takayuki Okatani	Tohoku University, Japan
Vo Nguyen Quoc Bao	Posts and Telecommunications Institute of Technology, Vietnam
Duy T. Ngo	The University of Newcastle, Australia
Shin Nakajima	National Institute of Informatics, Japan
Diep N. Nguyen	University of Technology Sydney, Australia

Steering Committee

Ngoc Thanh Nguyen (Chair)	Wroclaw University of Science and Technology, Poland
Hoang Pham	Rutgers University, USA
Sungrae Cho	Chung-Ang University, South Korea
Hyeonjoon Moon	Sejong University, South Korea
Jiming Chen	Zhejiang University, China
Dosam Hwang	Yeungnam University, South Korea
Gottfried Vossen	Muenster University, Germany
Manuel Nunez	Universidad Complutense de Madrid, Spain
Torsten Braun	University of Bern, Switzerland

Track Chairs

Dinh-Thuan Do	The University of Texas at Austin, USA
Ngoc Thanh Dinh	Soongsil University, South Korea
Khac-Hoang Ngo	Chalmers University of Technology, Sweden
Kim Phuc Tran	University of Lille, ENSAIT, GEMTEX, France
Trung V. Phan	Chemnitz University of Technology, Germany
Quoc-Viet Pham	Pusan National University, South Korea
Thuy Nguyen	Vietnam National University of Agriculture, Vietnam
Mai Dung Nguyen	Hanoi University of Mining and Geology, Vietnam
Ngoc Thinh Tran	Ho Chi Minh City University of Technology, Vietnam
Thanh Tho Quan	Ho Chi Minh City University of Technology, Vietnam
Thanh-Binh Nguyen	The University of Danang, Vietnam–Korea University of Information and Communication Technology, Vietnam
The-Son Tran	The University of Danang, Vietnam–Korea University of Information and Communication Technology, Vietnam
Quang-Vu Nguyen	The University of Danang, Vietnam–Korea University of Information and Communication Technology, Vietnam

Liaison Chairs

Tien-Hien Nguyen	Vietnam National University of Agriculture, Vietnam
Duy Huy Nguyen	Hanoi University of Mining and Geology, Vietnam

Finance Chair

Tuyet-Lan Nguyen T.	Vietnam National University of Agriculture, Vietnam

Local Arrangement Chairs

Trong Kuong Nguyen	Vietnam National University of Agriculture, Vietnam
Bich-Thuy Nguyen T.	Vietnam National University of Agriculture, Vietnam
Tuan-Anh Ngo	Vietnam National University of Agriculture, Vietnam
Hoang Long Nguyen	Hanoi University of Mining and Geology, Vietnam
Hoai Nga Nguyen	Hanoi University of Mining and Geology, Vietnam

Publication Chairs

Laihyuk Park	Seoul National University of Science and Technology, South Korea
Woongsoo Na	Kongju National University, South Korea
Luong Vuong Nguyen	Chung-Ang University, South Korea
Trong-Hop Do	Vietnam National University, Vietnam
Ngoc-Lam Dao	The University of Danang, Vietnam–Korea University of Information and Communication Technology, Vietnam

Registration Chairs

Xuan-Thao Nguyen	Vietnam National University of Agriculture, Vietnam
Hien Thanh T. Duong	Hanoi University of Mining and Geology, Vietnam
Cong Hoang Diem	Hanoi University of Mining and Geology, Vietnam

Multimedia Chairs

Vu-Ha Tran	Vietnam National University of Agriculture, Vietnam
Cong-Thang Ngo	Vietnam National University of Agriculture, Vietnam
Thu Hang Nguyen	Hanoi University of Mining and Geology, Vietnam

The Loc Nguyen	Hanoi University of Mining and Geology, Vietnam
Minh-Nhut Pham-Nguyen	The University of Danang, Vietnam–Korea University of Information and Communication Technology, Vietnam

Program Committee

Daisuke Ishii
Takako Nakatani
Kozo Okano
Trong-Minh Hoang
Ngoc Phi Nguyen
Mai The Vu
Bui Nam Hoai Khac
Khac-Hoang Ngo
Laihyuk Park
Trong-Hop Do
Tieu Long Mai
Nam D. Vo
The-Vinh Nguyen
Woongsoo Na
Trung V. Phan
Xuan Dieu Tran
Ngoc Thanh Dinh
Thanh Phung Truong
Thuy Nguyen
Hai Chien Pham
Ngoc-Son Dang
Thu-Hong Phan T.
Duc-Kien Thai
Nguyen Xuan Mung
Hoang-Huy Nguyen
Luong Vuong Nguyen
Tri-Hai Nguyen
Huu-Du Nguyen
Anh-Tien Tran
Tran Van Tien Si
Demeke Shumeye Lakew
Arooj Masood
Van Hung Le
Dieu Tien Bui
The Vinh Bui
Khanh Hoang Doan
Ninh-Thuan Truong
Duong Quang Khanh Ngoc
Van-Quan Pham
Shariq Bashir
Daphne Teck Ching Lai
Thongchai Surinwarangkoon
Kittikhun Meethongjan
Kietikul Jearanaitanakij
Satya Ranjan Dash
Phuong T. Nguyen
Thanh-Lanh Le
Nguyen Thi Lieu
Quoc Cuong Pham
Vinh Truong Hoang
Dat Nguyen Tien
Xuan Le
Huu-Thanh Duong
Viet-Tuan Le
Thanh Binh Nguyen
The-Son Tran
Quang-Vu Nguyen
Ngoc-Tho Huynh
Duc-Hien Nguyen
Anh-Quang Nguyen-Vu
Cuu Long Le-Phuoc
Van-Phi Ho
Sy-Thin Nguyen
Dai-Tho Dang

Contents

Theoretical Intelligence Analyses

Structural Health Monitoring and IoT: Opportunities and Challenges

Marzuki Kamal(✉) and Atif Mansoor

The University of Western Australia, Perth, Australia
{marzuki.kamal,atif.mansoor}@uwa.edu.au

Abstract. As structures like sky scrappers get taller and bridges are getting longer, there is a need to closely monitor the health of the structures, particularly under varying environmental effects. The traditional wire-based structural health monitoring systems that require laying down cables are costly and time-consuming. New and miniaturised sensors coupled with Internet of Things (IoT) and powerful cloud computing platforms lead to a new cost-effective approach to SHM. This paper introduces Structural Health Monitoring (SHM), its conventional approaches of Visual, Destructive and Non-Destructive evaluations. After discussing the limitations of conventional SHM approaches, Internet of Things and its components are introduced. SHM with IoT, its strengths and challenges are reviewed in light of published literature. This is evident that SHM will benefit enormously from IoT, provided technical challenges like energy consumption, scalability, data security and reliability are handled.

Keywords: Structural Health Monitoring (SHM) · Internet of Things (IoT) · Non-destructive evaluation · Safety · Data security

1 Introduction

Since ancient times, humans have been building structures for living. With the advancement of technology, the structures improved from wood, stone, mud to iron, steel and new construction technologies. Additionally, structures are also getting taller, longer and bigger. The tallest structure in the world is currently the Burj Khalifa in Dubai, United Arab Emirates with a height of 828 m [1] and the longest bridge is the Danuang-Kunshan Grand Bridge, located between Shanghai and Nanjing, China [2]. Proper measures and planning are made to ensure the safety and integrity of the structures. However, with age or environmental effects, the structure deteriorates and needs to be maintained otherwise accidents may happen. For instance, between 2020 and 2021, four bridges collapsed including the 111-year-old bridge in northern Italy which injured 2 persons [3]. Similarly, 98 people were killed in a collapse of Champlain Towers South apartment building in Florida, USA on 24 June 2021 [4]. There are many aging structures in the world and among them, many are used on daily basis. This demonstrates that regular maintenance and inspection need to be done to maintain its structural integrity.

N.-T. Nguyen et al. (Eds.): ICIT 2022, LNDECT 148, pp. 3–15, 2022.
https://doi.org/10.1007/978-3-031-15063-0_1

Traditionally, the structures are visually inspected by experienced professionals for their health [5]. The visual inspections require a trained human resource that needs travelling and accessibility to the structure. A regular and timely visual inspection of the scattered structures in a vast area will require huge costs and human effort. This subjective evaluation at times may overlook important indications. Further with bigger structures, visual inspection of the whole structure becomes very difficult. The health of the structure is also observed through specialized evaluations. There are two types of such evaluations; destructive evaluation (DE) and non-destructive evaluation (NDE). In destructive evaluation, the evaluation is performed on a sample of structures to gauge the health of the whole structure. In non-destructive evaluation, testing such as Ultrasonic and Acoustic Emission are performed to evaluate the health of the structure [6].

Both destructive and non-destructive evaluations, like visual inspections, are limited by the availability of technical human resources and equipment. This led to Structural Health Monitoring (SHM), which is a non-destructive evaluation technique [7] that performs a continuous observation of the structure [8]. The data gathered from SHM system over time give an insight that was not earlier available and thus aids in proper maintenance action to be taken. Although SHM provides benefits over NDE, it has limitations of high initial cost and later continuous maintenance due to installation and cables [9]. This is where IoT can be integrated into SHM with its miniaturised sensors and wireless communication technologies. With a low initial cost of IoT, SHM can be deployed and maintained easily. Combine with intelligent sensors, ubiquitous connectivity and a powerful cloud computing platform, IoT based SHM allows seamless and effective data collection, storage and processing.

This paper aims to review the literature to provide an overview of the use of Structural Health Monitoring in combination with IoT. The rest of the paper is structured as follows: Sect. 2 introduces Internet of Things (IoT), Sect. 3 gives details of Structural Health Monitoring while Sect. 4 explains the combination SHM and IoT. Section 5 discusses the Challenges of IoT in SHM and the paper is concluded in Sect. 6.

2 Internet of Things (IoT)

There is no agreed upon definition of Internet of Things. IBM describes IoT as things that connect to the Internet, and other devices [10], whereas Oracle describes it as an ordinary object which has sensors and software and connects to the Internet and exchange information with other devices [11].

Internet of Things devices typically consists of 4 components; sensors, communication, data processing and user interface. The sensor collects information from its environment. Then, the information is stored and processed by the data processing system. Data storage and processing can be done either onsite or offsite. The data is transmitted via a communication protocol. Various communication protocols can be used to transmit the data depending on the requirements such as data rate, range, cost and power consumption. Table 1 compares different IoT communication protocols on the basis of these parameters.

Table 1. IoT communication protocols [12–14]

Technology	Frequency	Data rate	Range	Power usage	Cost
2G/3G	Cellular Bands	10 Mbps	35 to 150 km	High	High
Bluetooth/BLE	2.4 GHz	1,2,3 Mbps	50–150 m	Low	Low
LoRa	sub-GHz	<50 kbps	2.5–15 km	Low	Medium
LTE-M	Cellular Bands	1–10 Mbps	35 to 150 km	Medium	High
NB-IoT	Cellular Bands	0.1–1 Mbps	35 to 150 km	Medium	High
SigFox	sub-GHz	<1 kbps	3–50 km	Low	Medium
WiFi	2.4 GHz, 5GHz	0.1–54 Mbps	50–100 m	Medium	Low
Zigbee	2.4 GHz	250 kbps	10–100 m	Low	Medium
Z-Wave	sub-GHz	40 kbps	∼30 m	Low	Medium

The data transmitted over the communication channel is then processed in a server or a cloud computing platform to give meaningful insights through data visualisation and alerts.

3 Structural Health Monitoring (SHM)

The objective of SHM is to enhance structural safety by continuous monitoring of the structure. In SHM system, multiple sensors are placed at the structure, which normally sends parameters related to structure health to a data processing system via a communication channel. Once the data is obtained, the condition of the structure can be evaluated by an expert or a machine learning algorithm that analysed the data.

SHM can deliver real-time information of the condition of the structures or even predict future events [15,16]. Malekloo et al. [17] discussed the use of machine learning and SHM by employing machine learning algorithms such as k-nearest neighbour (kNN), support vector machine (SVM), k-means, random forest and neural network for damage assessment. Zhang et al. [18] proposed the use of Acoustic Emission (AE) sensors to collect data and predict the state of blades on a gas turbine engine.

Typically, the current approach of structure monitoring and maintenance is scheduled on time. With SHM, the maintenance schedule can be based on the condition of the structure, facilitating preemptive maintenance [19]. Cusati et al. [20] have demonstrated SHM to monitor the structure of aircraft through a condition-based maintenance approach resulting in cost lowering.

Kim et al. [21] have designed and deployed 64 nodes accelerometer sensors on the Golden Gate Bridge, San Francisco, USA. The sensors network placed on the bridge has provided an accurate, high-frequency sampling with low jitter data for analysis of bridge health. Diamanti and Soutis [22] discussed the use of ultrasonic transducers permanently attached to aircraft for its condition monitoring. Hodge et al. [23] reviewed numerous use of SHM in the railway industry which can be divided into movable monitoring (i.e. train) and fixed monitoring (i.e. rail tracks). Schubel et al. [24] compared multiple structure health monitoring methods for wind turbine blades. One interesting application of SHM is monitoring the structure of historical buildings. Vestroni et al. [25] installed 12 accelerometers on the Colosseum building in Rome to monitor the vibration induced by the environment and relate it to structural health. Pierdicca et al. [26] demonstrated the use of vibration-based sensors to monitor the structure of the historical building "Palazzo Comunale di Castelfidardo" in Italy. These examples show that SHM is applied in diverse fields.

3.1 Wired and Wireless SHMs

According to Aygün and Gungor [27], SHM systems were originally designed to have an array of sensors wired to the system. But, the wired SHM systems were not gaining popularity due to the high cost to deploy and subsequent maintenance. Celebi et al. [28] in their paper informed the total cost of wired SHM systems for the Bill Emerson Memorial Bridge in Cape Girardeau, Missouri, consisting of 86 accelerometer sensors to be about US$1.3 million. This makes the cost of each sensor approximately US$15,000. Cao and Liu [9] analyzed the high cost of a wired SHM system is largely due to hardware and installation.

Table 2 shows the comparison between wired and wireless SHM. According to Noel et al. [29] and Muttillo et al. [30], the benefits of a wired SHM system is that it provides a high data rate and high bandwidth. But due to the high cost, the deployment of wired sensors is limited. As an example, Cao and Liu [9] mentioned that the Tsing Ma Bridge in Hong Kong has 39 accelerometers for the 2 km suspension bridge, thus limiting the accuracy.

Table 2. Wired & wireless SHM comparison [29]

Metric	Wired	Wireless
Cost	Very high	Low
Deployment time	Very long	Short
Lifespan	Long	Short
Number of sensors	Low	High
Connection bandwidth	High	Limited
Data rate	High	Low

With recent advancements in wireless technology and sensors, wireless SHM has become more feasible. They cost less and have comparatively shortened deployment time. According to Cao and Liu [9], the cost of a wireless SHM sensor node is typically less than US$500, while the wired-based system can cost more than US$10,000. Additionally, the deployment is also significantly reduced. The wireless SHM systems have low bandwidth and reduced data rate compared to the wired monitoring systems, but this shortcoming can be overcome through intelligent designs. Additionally, the technology is systematically bringing improvements.

4 IoT Components in SHM

As discussed in Sect. 2, IoT architecture comprises four components; sensors, communication, data storage and processing, and user interface. This section will discuss the sensors, data processing hardware and communication protocols used for SHM and IoT.

4.1 Sensors Used in SHM

In most structures, the parameters to monitor are vibration, strain and internal structural integrity. Different sensors are used to monitor these parameters such as accelerometer, strain sensor, acoustic emission sensor and optical fibre-based sensor.

Accelerometer sensor measures the acceleration levels of the system. With the acceleration measurement, various parameters can be obtained, such as vibration, frequency and motion [31,32]. Komarizadehasl et al. [33] mentioned different types of accelerometer used in SHM as Piezoresistive, Piezoelectric and Capacitive. These sensors could be now miniaturized as Micro-Electro-Mechanical Systems (MEMS) sensors. Villacorta et al. [34] stated that the Piezoelectric accelerometer is the most commonly used due to its high accuracy and sensitivity.

Initially, MEMS accelerometers suffered from limited bandwidth, noise and measurement range restrictions [35], but have improved with time. One of the benefits of MEMS-based accelerometer compared to piezoelectric is lower cost and lower energy consumption. Table 3 shows the comparison between the piezoelectric accelerometer and MEMS accelerometer [35]. Sabato et al. [36] analysed and surveyed the use of MEMS-based accelerometers in structural health monitoring systems. The authors concluded that the MEMS accelerometers demonstrate the same performance as the piezoelectric accelerometer. On the other hand, Bassoli et al. [37] stated that the MEMS accelerometer sensors placed on an ancient masonry bell tower showed better accuracy compared to the piezoelectric accelerometer.

Table 3. Piezoelectric accelerometer and MEMS accelerometer comparison [35]

Sensor	Cost	Potential battery life
Piezoelectric accelerometer	\$25 to \$500+	Short to medium
MEMS accelerometer	\$10 to \$30	Medium to long

Muttillo et al. [30] used digital accelerometer ADXL355 in their bridge health monitoring system in combination with a Stochastic Subspace Identification method. Pierleoni et al. [19] also proposed a structural health monitoring system using the accelerometer ADXL355 by evaluating its dynamic response. Other type of accelerometers used in different SHM projects are ADXL335 [38], LIS3L02AS4 [39], KXR94-2050 [40], SD1221L [41] and ADXL345 [42].

Strain sensors are also used in SHM. The sensor measures the structure's strain that can lead to a deformation like a crack. There are two types of strain sensors; electric strain sensors and optical fibre-based sensors. Similar to the piezoelectric accelerometer sensor, electric strain gauges are used for a considerable time in SHM. Electric strain sensors are typically arranged in a long, thin conductive strip. It works by measuring the resistance change between two terminals when strain is applied. Chanv et al. [42] and Naraharisetty et al. [43] proposed the use of strain sensors together with an accelerometer for SHM applications. Chanv et al. [42] used strain sensors BF350-3AA in their research. Although electric strain sensors have been used for many years in SHM, these have the limitation of durability and accuracy in case of continuous usage [44].

Fibre Bragg grating (FBG) sensors work differently than an electrical strain sensor by fixed index modulation. Tennyson et al. [45] have shown the use of fibre optic strain sensors for bridge health monitoring on 16 bridges. In the 6 years operational period, the sensors showed good performance compared to traditional strain gauges in terms of durability and performance.

Some SHM systems are based on acoustic emission (AE) measurements. Piezoelectric acoustic transducers are used to evaluate the internal structural damage. Dai and He [46] stated that using an array of the piezoelectric transducer and ultrasonic guided wave, the position of internal damage in the structure can be located.

4.2 Data Storage and Processing Hardware

The sensors need a platform to store, process and send the information for further analysis. Traditionally, sensors in SHM systems were connected to a wired data logger to record the sensors' data. The data loggers used in SHM are typically expensive. In IoT-based systems, a cost-effective microcontroller with some memory is normally used to process the sensors' data. Microcontroller platforms such as Arduino can connect multiple sensors and transmit the data to the users by attaching a communication module with it.

Many research works in SHM used Arduino-based microcontrollers for interfacing with sensors [42,47,48]. Chanv et al. [42] developed an SHM system that connected accelerometer, strain sensors and moisture sensor with Arduino UNO coupled with WiFi module. Paul et al. [47] used Arduino 101 to connect flex sensors, measuring the amount of deflection. STM32 Nucleo board were used by Pierleoni et al. [19] and Di Nuzzo et al. [49] for its low cost, performance and low power consumption. Patil and Patil [38] used PIC16F877 microcontroller, while Muttillo et al. [30] used SAM3X8E for their SHM systems.

There are also commercial boards to interface with the sensors. Balestrieri and Picariello [50] proposed an SHM system that used a Waspmote platform to interface with WS-3000 weather station, temperature and humidity sensors. The Waspmote itself has an embedded accelerometer. Rice and Spencer [39] used an Imote2 platform developed by Intel for their SHM system, having a variable processing speed to optimise power consumption. The authors used accelerometer sensors to interface with the Imote2 in their SHM system.

With the improvement of technology, computers are getting smaller, more powerful and energy-efficient. With a wide range of connectivity, i.e. Bluetooth and WiFi, tiny computers like Raspberry Pi are commonly used in SHM and IoT. Mahmud et al. [7] and Abdelgawad & Yelamarthi [51] proposed the use of Raspberry Pi with the help of analog to digital converter (ADC) to interface with a piezoelectric sensor. Raspberry Pi requires more energy compared to a microcontroller and therefore proper energy consideration is required when using Raspberry Pi.

4.3 Communication Protocols

In an IoT based SHM, the sensors' data need to be transmitted to a central powerful computing entity for further processing. The transmission is usually done wirelessly as there might be multiple sensor nodes in the structure [29]. As given in Table 1, there are different communication protocols to transfer the sensor's information, from short-range to long-range. Another important thing when deciding the communication besides the range is power consumption.

WiFi is also used as a communication protocol particularly if the structure is a building in a city. Chanv et al. [42] used WiFi module ESP8266 to transmit the Arduino UNO connected sensors' readings. Balestrieri and Picariello [50] used a WiFi module that connected the Waspmote board to the distant gateway. The benefit of using WiFi is high bandwidth and low latency, but it suffers from range and power consumption. WiFi also requires a router or a gateway to interface with the internet. It is suitable for IoT devices that are connected to power.

Another commonly used communication protocol is Zigbee. The Zigbee works at 433 MHz ISM (Industrial, scientific and medical) radio bands. It is a low-power and low-cost communication protocol [52]. Zigbee also requires a gateway to receive the communication from different sensors. One benefit of using Zigbee compared to WiFi is low energy consumption. Patil and Patil [38] have used Zigbee protocol in bridge health monitoring as a communication protocol between sensors. Cho et al. [53] used the Zigbee protocol to connect 70 sensor nodes, which covered the 484-meters-long Jindo Bridge in South Korea. Seventy sensors were divided into 2 sub-networks, where each was controlled by a separate base station.

Cellular communication is also used in SHM as demonstrated in [48, 50]. Niranjan and Rakesh [48] used a GSM SIM800A cellular module that interfaced with Arduino UNO and flex sensor. The data received from the sensor is transmitted to a ThinkSpeak server via cellular communication. Balestrieri et al. [50] proposed an SHM system that sent the sensors' data to the gateway via WiFi and transmitted the information from the gateway to the user over the internet via a cellular network. Cellular communication has a longer range but higher energy consumption. Communication protocols such as Narrowband-IoT (NB-IoT) handles the higher energy consumption issue in cellular communication. It is designed to be a low-power and long-range communication protocol built for IoT using a cellular network. Di Nuzzo et al. [49] proposed an SHM system that utilised the NB-IoT communication protocol.

5 Challenges of SHM and IoT

According to Lamonaca et al. [54], SHM and IoT bring many benefits such as cost efficiency and improved safety compared to the traditional SHM. However, the benefits also come with their own challenges. In this section, we discuss a few of the challenges and related literature.

5.1 Energy Consumption

Noel et al. [29] and Wang et al. [55] discussed in their paper that one of the challenges of SHM and IoT is energy consumption. Most devices do not have the access to power sockets. Also, being wirelessly connected means that each device has limited energy through the batteries. Further, the data transmission consumes considerable energy. Additionally, replacing depleted batteries for each node is not feasible since some sensors are difficult to access. Noel et al. [29] discussed that there are techniques to manage energy consumption such as energy harvesting, radio optimisation, data reduction and transmission duty cycle. Ghosh et al. [56] have proposed an event-based wake-up to optimise energy consumption for a railway bridge health monitoring system. The use of an event-based wake-up conserves the energy as the system sleeps if there is no train crossing the bridge. Aygün and Gungor [27] have discussed energy harvesting like solar panels to maintain continuous energy supply.

5.2 Scalability

IoT devices can be deployed easily due to their wireless connectivity. As the number of devices increases the amount of data increases too. This large amount of data then needs to be stored and processed. According to Noel et al. [29], traditional data processing systems are inefficient and expensive to handle a large amount of data. One solution to handle the large data is to use the cloud for storage and processing. Cloud computing platforms such as Amazon AWS, Google Cloud and Microsoft Azure etc. have now specific services to cater for IoT traffic. Further cloud services can scale much easier, more reliable and secure compared to on-site data processing systems.

5.3 Security

As with any other IoT systems, security is one of the challenges that need to be addressed. Alonso et al. [57] emphasize the proper security measures for the protection of sensitive SHM data. In IoT, devices' processing power, memory and energy are limited. Attackers can make use of these constraints. Mahmoud et al. [58] stated that each component of an IoT system is vulnerable to security attacks such as Denial of Service attacks (DoS), Replay attacks, Timing attacks, Node Capture attacks and Man-in-the-Middle attacks. The security in IoT is an open challenge and considerable research is being undertaken in this area.

5.4 Reliability

One of the benefits of the traditional wired approach is reliability. As everything is connected through a cable, data transmission is reliable and fast with a high data rate and throughput. With wireless connectivity, measures are needed to cater transmission to data loss or corruption. A communication protocol with retransmission will consume the energy of the devices, so a lightweight reliable communication protocol for IoT is needed. Kim et al. [21] designed and implemented the lightweight communication protocol STRAW (Scalable Thin and Rapid Amassment Without loss) to monitor structural health at Golden Gate Bridge.

Another challenge that needs to be addressed is data accuracy and noise from sensors. With the advancement in sensors technology, the sensors are smaller and cheaper. Sensors come differently with operational ranges and accuracy. Some sensors might be susceptible to noise and changes within the environment more than others. Mahmud et al. [7] in their paper mentioned several signal processing techniques to handle the noise in sensors with techniques like Wavelet denoising, Fast Fourier Transform (FFT), Wavelet transform and Cross-Correlation (CC).

6 Conclusion

We reviewed the published literature related to Structural Health Monitoring (SHM) using Internet of Things (IoT). The review demonstrated that IoT can bring many benefits to SHM, removing the limitations of the conventional time-based SHM approach. This will lead to cost reduction, wider and more sophisticated structural monitoring and real-time alerts. The powerful analysis tools will give insights that are presently not available. Thus, aiding in preemptive maintenance and consequently improved structural and human safety. The combination of SHM and IoT comes with its own challenges of data security, reliability, data denoising, reliable lightweight communication protocols and limitations attached with constrained devices. These challenges are in fact opportunities and the research community is continuously working on them. It is evident that the Structural Health Monitoring and Internet of Things will certainly lead to enhanced safety of structures and human lives.

Acknowledgment. This research is funded by the Planning and Transport Research Centre (PATREC) and the iMOVE CRC and supported by the Cooperative Research Centres program, an Australian Government initiative.

References

1. Burj khalifa - facts & figures (2021). www.burjkhalifa.ae/en/the-tower/facts-figures/
2. Britannica: Bridge (2021). www.britannica.com/technology/bridge-engineering/U-S-designs#ref1261381
3. Italy bridge collapse: Two drivers survive (2020). www.bbc.com/news/world-europe-52213898
4. Miami building collapse (2021). https://edition.cnn.com/2021/07/15/us/miami-dade-building-collapse-thursday/index.html
5. Humar, J., Bagchi, A., Xu, H.: Performance of vibration-based techniques for the identification of structural damage. Struct. Health Monit. **5**(3), 215–241 (2006)
6. Attar: What is destructive and non-destructive testing? (2020). www.attar.com.au/what-is-destructive-and-non-destructive-testing/
7. Mahmud, M.A., Bates, K., Wood, T., Abdelgawad, A., Yelamarthi, K.: A complete Internet of Things (IoT) platform for structural health monitoring (SHM). In: 2018 IEEE 4th World Forum on Internet of Things (WF-IoT), pp. 275–279 (2018)
8. Edwards, G.R., Tuncbilek, K., Walker, B.: Development of a multi-purpose wireless network for the structural health monitoring of a suspension bridge. In: IET Conference on Wireless Sensor Systems (WSS 2012), pp. 4B1–4B1 (2012)
9. Cao, J., Liu, X.: Structural health monitoring using wireless sensor networks. In: Mobile and Pervasive Computing in Construction, pp. 210–236 (2012)
10. Clark, J.: What is the internet of things, and how does it work? (2021). www.ibm.com/blogs/internet-of-things/what-is-the-iot/
11. What is the internet of things (IoT)? (2021). www.oracle.com/au/internet-of-things/what-is-iot/
12. 802.15.4 wireless for internet of things developers (2021). https://blog.helium.com/802-15-4-wireless-for-internet-of-things-developers-1948fc313b2e
13. Sonee, S.: Top IoT communication protocols updated 2021 (2020). https://hashstudioz.com/blog/top-iot-communication-protocols-2020/
14. Mobile base stations (2021). https://mobilenetworkguide.com.au/mobile_base_stations.html
15. Tudosa, I., Picariello, F., Balestrieri, E., Carnì, D.L., Lamonaca, F.: A flexible DAQ hardware architecture using SoCs for IoT based structural health monitoring systems. In: 2019 II Workshop on Metrology for Industry 4.0 and IoT (MetroInd4.0&IoT), pp. 291–295 (2019)
16. Lynch, J.P.: A summary review of wireless sensors and sensor networks for structural health monitoring. Shock Vibr. Digest **38**(2), 91–128 (2006)
17. Malekloo, A., Ozer, E., AlHamaydeh, M., Girolami, M.: Machine learning and structural health monitoring overview with emerging technology and high-dimensional data source highlights. Struct. Health Monit. **21**, 1906–1955 (2021)
18. Zhang, Z., Yang, G., Hu, K.: Prediction of fatigue crack growth in gas turbine engine blades using acoustic emission. Sensors (Basel, Switzerland) **18**(5), 1321 (2018)

19. Pierleoni, P., et al.: IoT solution based on MQTT protocol for real-time building monitoring. In: 2019 IEEE 23rd International Symposium on Consumer Technologies (ISCT), pp. 57–62 (2019)
20. Cusati, V., Corcione, S., Memmolo, V.: Impact of structural health monitoring on aircraft operating costs by multidisciplinary analysis. Sensors (Basel, Switzerland) **21**(20), 6938 (2021)
21. Kim, S., et al.: Health monitoring of civil infrastructures using wireless sensor networks. In: 2007 6th International Symposium on Information Processing in Sensor Networks, pp. 254–263 (2007)
22. Diamanti, K., Soutis, C.: Structural health monitoring techniques for aircraft composite structures. Progr. Aeros. Sci. **46**(8), 342–352 (2010)
23. Hodge, V.J., O'Keefe, S., Weeks, M., Moulds, A.: Wireless sensor networks for condition monitoring in the railway industry: a survey. IEEE Trans. Intell. Transp. Syst. **16**(3), 1088–1106 (2015)
24. Schubel, P., Crossley, R., Boateng, E., Hutchinson, J.: Review of structural health and cure monitoring techniques for large wind turbine blades. Renew. Energy **51**(C), 113–123 (2013)
25. Vestroni, F., De Sortis, A., Pau, A.: Measurements of the colosseum response to environmental actions. In: XI International Conference on Structural Dynamics (2020)
26. Pierdicca, A., Clementi, F., Isidori, D., Concettoni, E., Cristalli, C., Lenci, S.: Numerical model upgrading of a historical masonry palace monitored with a wireless sensor network. Int. J. Masonry Res. Innov. **1**(1), 74 (2016)
27. Aygün, B., Gungor, V.C.: Wireless sensor networks for structure health monitoring: recent advances and future research directions. Sensor Rev. **31**(3), 261–276 (2011)
28. Celebi, M., et al.: Seismic instrumentation of the bill emerson memorial mississippi river bridge at cape girardeau (mo): a cooperative effort. In: Proceedings of the 4th International Seismic Highway Conference (2004)
29. Noel, A.B., Abdaoui, A., Elfouly, T., Ahmed, M.H., Badawy, A., Shehata, M.S.: Structural health monitoring using wireless sensor networks: a comprehensive survey. IEEE Commun. Surv. Tutor. **19**(3), 1403–1423 (2017)
30. Muttillo, M., et al.: Structural health monitoring: an IoT sensor system for structural damage indicator evaluation. Sensors **20**(17), 4908 (2020)
31. Accelerometer sensors (2021). www.rohm.com/electronics-basics/sensor/accelerometer-sensor
32. Hanly, S.: Accelerometers: Taking the guesswork out of accelerometer selection (2021). https://blog.endaq.com/accelerometer-selection
33. Komarizadehasl, S., Mobaraki, B., Ma, H., Lozano-Galant, J.A., Turmo, J.: Development of a low-cost system for the accurate measurement of structural vibrations. Sensors **21**(18), 6191 (2021)
34. Villacorta, J.J., et al.: Design and validation of a scalable, reconfigurable and low-cost structural health monitoring system. Sensors **21**(2), 648 (2021)
35. Why mems accelerometers are becoming the designer's best choice for cbm applications (2021). www.analog.com/en/technical-articles/why-memes-acceler-are-best-choice-for-cbm-apps.html
36. Sabato, A., Niezrecki, C., Fortino, G.: Wireless MEMS-based accelerometer sensor boards for structural vibration monitoring: a review. IEEE Sens. J. **17**(2), 226–235 (2016)
37. Bassoli, E., Vincenzi, L., Bovo, M., Mazzotti, C.: Dynamic identification of an ancient masonry bell tower using a MEMS-based acquisition system. In: 2015

IEEE Workshop on Environmental, Energy, and Structural Monitoring Systems (EESMS) Proceedings, pp. 226–231 (2015)
38. Patil, P.K., Patil, S.R.: Structural health monitoring system using WSN for bridges. In: 2017 International Conference on Intelligent Computing and Control Systems (ICICCS), pp. 371–375 (2017)
39. Rice, J.A., Spencer, J.B.F.: Structural health monitoring sensor development for the Imote2 platform. In: Sensors and Smart Structures Technologies for Civil, Mechanical, and Aerospace Systems 2008, pp. 693234–693234-12 (2008)
40. Bedon, C., Bergamo, E., Izzi, M., Noè, S.: Prototyping and validation of MEMS accelerometers for structural health monitoring-the case study of the pietratagliata cable-stayed bridge. J. Sens. Actuator Netw. **7**(3), 30 (2018)
41. Hu, X., Wang, B., Ji, H.: A wireless sensor network-based structural health monitoring system for highway bridges. Comput.-Aided Civil Infrastruct. Eng. **28**(3), 193–209 (2013)
42. Chanv, B., Bakhru, S., Mehta, V.: Structural health monitoring system using IoT and wireless technologies. In: 2017 International Conference on Intelligent Communication and Computational Techniques (ICCT), pp. 151–157 (2017)
43. Naraharisetty, V., Talari, V.S., Neridu, S., Kalapatapu, P., Pasupuleti, V.D.K.: Cloud architecture for IoT based bridge monitoring applications. In: 2021 International Conference on Emerging Techniques in Computational Intelligence (ICETCI), pp. 39–42 (2021)
44. White paper: Optical fiber sensors vs. conventional electrical strain gauges for infrastructure monitoring applications (2021). www.hbm.com/en/6482/white-paper-optical-fiber-sensors-vs-conventional-electrical-strain-gauges/
45. Tennyson, R.C., Mufti, A.A., Rizkalla, S., Tadros, G., Benmokrane, B.: Structural health monitoring of innovative bridges in Canada with fiber optic sensors. Smart Mater. Struct. **10**(3), 560 (2001)
46. Dai, D., He, Q.: Structure damage localization with ultrasonic guided waves based on a time-frequency method. Signal Process. **96**, 21–28 (2014)
47. Paul, P., et al.: An internet of things (IoT) based system to analyze real-time collapsing probability of structures. In: 2018 IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), pp. 1070–1075 (2018)
48. Niranjan, D., Rakesh, N.: Early detection of building collapse using IoT. In: 2020 Second International Conference on Inventive Research in Computing Applications (ICIRCA), pp. 842–847 (2020)
49. Di Nuzzo, F., Brunelli, D., Polonelli, T., Benini, L.: Structural health monitoring system with narrowband IoT and mems sensors. IEEE Sens. J. **21**(14), 16371–16380 (2021)
50. Balestrieri, E., Vito, L.D., Picariello, F., Tudosa, I.: IoT system for remote monitoring of bridges: measurements for structural health and vehicular traffic load. In: 2019 II Workshop on Metrology for Industry 4.0 and IoT (MetroInd4.0&IoT), pp. 279–284 (2019)
51. Abdelgawad, A., Yelamarthi, K.: Internet of Things (IoT) platform for structure health monitoring. Wirel. Commun. Mob. Comput. **2017**, 1–10 (2017)
52. Why zigbee? (2021). https://zigbeealliance.org/why-zigbee
53. Cho, S., et al.: Structural health monitoring of a cable-stayed bridge using wireless smart sensor technology: data analyses. Smart Struct. Syst. **6**(5–6), 461–480 (2010)
54. Lamonaca, F., Sciammarella, P., Scuro, C., Carnì, D., Olivito, R.: Internet of Things for structural health monitoring. In: 2018 Workshop on Metrology for Industry 4.0 and IoT, pp. 95–100 (2018)

55. Wang, P., Yan, Y., Tian, G.Y., Bouzid, O., Ding, Z.: Investigation of wireless sensor networks for structural health monitoring. J. Sens. **2012**, 1–7 (2012)
56. Ghosh, S.K., Suman, M., Datta, R., Biswas, P.K.: Power efficient event detection scheme in wireless sensor networks for railway bridge health monitoring system. In: 2014 IEEE International Conference on Advanced Networks and Telecommuncations Systems (ANTS), pp. 1–6 (2014)
57. Alonso, L., Barbarán, J., Chen, J., Díaz, M., Llopis, L., Rubio, B.: Middleware and communication technologies for structural health monitoring of critical infrastructures: a survey. Comput. Stand. Interfaces **56**, 83–100 (2018)
58. Mahmoud, R., Yousuf, T., Aloul, F., Zualkernan, I.: Internet of things (IoT) security: current status, challenges and prospective measures. In: 2015 10th International Conference for Internet Technology and Secured Transactions (ICITST), pp. 336–341 (2015)

Semantic Interoperability Issues and Challenges in IoT: A Brief Review

Devamekalai Nagasundaram[1](✉), Selvakumar Manickam[2], and Shankar Karuppayah[2]

[1] National Advanced IPv6 Centre, University Sains Malaysia (USM), Penang, Malaysia
mekalai.deva@gmail.com
[2] National Advanced IPv6 Centre, University Sains Malaysia (USM), Penang, Malaysia
{selva,kshankar}@usm.my

Abstract. Semantic interoperability is one of the enormous challenges that need to be addressed to achieve the Internet of Things (IoT) vision. Accomplishing semantic interoperability in a heterogeneous IoT environment will allow a billion devices to exchange meaningful data in a form understandable by multiple devices. The paper presents the challenges faced by IoT due to the lack of semantic interoperability and the available method of achieving semantic interoperability in IoT. It also discusses the limitation of the current solution and recommendations on the future work needed.

Keywords: Internet of Things · Interoperability · Semantics · Semantic interoperability · Ontology · Semantic network

1 Introduction

IoT is a system of interconnected devices through the Internet to collect, share and communicate data with each other [1]. IoT technologies provide valuable benefits and significant inventions for society, and it is one of the pillars of the fourth industrial revolution [2]. Cisco has visioned that by 2030, around 500 billion smart devices are expected to be connected to the Internet globally [3]. IoT devices are expected to generate a large amount of data due to the exponential growth of IoT and increased adaptation [4]. According to IDC, the data collected by IoT will reach 73.1 ZB by 2025, which equals 422% of the 2019 output, when 17.3 ZB of data was produced [4].

IoT devices are highly heterogeneous, especially in data format; therefore, data management has always been an important topic [5]. Furthermore, no proper standard defined and availability of various data formats, cause data interoperability issue, also called semantic interoperability remains a substantial problem and unresolved for many years [6]. For example, a body temperature sensor records and transfers data in Degree Celsius in an IoT healthcare system, while the IoT healthcare controller system was developed to accept temperature in Fahrenheit. Therefore, the issue arises when the data from the temperature sensor need to be shared with the healthcare controller system. The

N.-T. Nguyen et al. (Eds.): ICIT 2022, LNDECT 148, pp. 16–31, 2022.
https://doi.org/10.1007/978-3-031-15063-0_2