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A Review on Structural Health Monitoring in Wireless Sensor Networks

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Abstract—* Wireless Sensor Networks have gained popularity due to their real time applications and low-cost nature. These networks provide solutions to scenarios that are critical, complicated and sensitive like military fields, habitat monitoring, and disaster management. The nodes in wireless sensor networks are highly resource constrained. Routing protocols are designed to make efficient utilization of the available resources in communicating a message from source to destination. "Smart" sensors with embedded microprocessors and wireless communication links have the potential to fundamentally change the way civil infrastructure systems are monitored, controlled, and maintained. A structural health monitoring system is designed, implemented, and tested using Wireless Sensor Networks (WSN). Structural health monitoring (SHM) is an emerging field in civil engineering, offering the potential for continuous and periodic assessment of the safety and integrity of civil infrastructure. Based on knowledge of the condition of the structure, certain preventive measures can be taken to prolong the service life of the structure and prevent catastrophic failure. Damage detection strategies can ultimately reduce life-cycle cost. Thus most of the industrialized countries are on the verge of increasing their budget for SHM of their major civil infrastructure. The SHM system often offers an opportunity to reduce the cost for the maintenance, repair and retrofit throughout the life of the structure. In this paper, a survey on various SHM systems is presented.
Keywords—* smart, sensors, embedded, microprocessors, networks.

I. INTRODUCTION

Wireless sensor networks have recently emerged as a premier research topic. They have great long term economic potential, ability to transform our lives, and pose many new system-building challenges [1]. Sensor networks also pose a number of new conceptual and optimization problems. Some, such as location, deployment, and tracking, are fundamental issues, in that many applications rely on them for needed information. Coverage in general, answers the questions about quality of service (surveillance) that can be provided by a particular sensor network. The integration of multiple types of sensors such as seismic, acoustic, optical, etc. in one network platform and the study of the overall coverage of the system also presents several interesting challenges. Wireless sensors have become an excellent tool for military applications involving intrusion detection, perimeter monitoring, information gathering and smart logistics support in an unknown deployed area. Some other applications: sensor based personal health monitor, location detection with sensor networks and movement detection [2].

A SHM system refers to the process of damage detection of civil structures [1, 2]. Traditionally a Structural Health Monitoring system periodically collects the measured output from the sensor modules installed in the structures and updates the health condition of a structure. The sensor modules must be wireless to reduce installation costs, must operate with a low power consumption to reduce servicing costs of replacing batteries. Re-chargeable battery is used for sensor module and an alternative renewable energy - Solar source has been employed to increase the life time of the battery by charging the battery. The data collected from the sensor modules are transported to the base station through Wireless Sensor Network and from the base station the health of the building is informed to the end user via SMS alert by using GSM. End user is primarily Civil engineers and architects responsible for the building and they are expected to take appropriate action based on the alert. Wireless sensor network based monitoring systems can potentially enhance the resolution of sensing and provide information at unprecedented levels of granularity. Recently there has been an immense amount of research examining various aspects and issues pertaining to such monitoring networks [3].

Structural Health Monitoring (SHM) focuses on developing technologies and systems for assessing the integrity of structures such as buildings, bridges (figure 1), aerospace structures and off-shore oil rigs. Most existing SHM implementations use wired data acquisition systems to collect vibration data from various locations in the structure induced by ambient sources (e.g., moving vehicles, wind, waves and earthquakes) and analyze it at a central location. A structural health monitoring system is designed, implemented, and tested using Wireless Sensor Networks (WSN). With WSN, low cost monitoring is possible without interfering with the operation of the structure.

SHM utilizes wireless sensor networks to detect the presence, location, severity, and consequence of damage. In many monitoring allocations, the conventional usages of WSNs are cases with low data rate, small data size, low duty cycle, and low power consumption. However, structural health monitoring requires high data rate, large data size, and a relatively high duty cycle [1,3].

Fig. 1 Structural Health Monitoring with sensors on a Bridge

In the most general terms, damage can be defined as changes introduced into a system that adversely affects its current or future performance. Implicit in this definition is the concept that damage is not meaningful without a comparison between two different states of the system, one of which is assumed to represent the initial, and often undamaged, state. This theme issue is focused on the study of damage identification in structural and mechanical systems. Therefore, the definition of damage will be limited to changes to the material and/or geometric properties of these systems, including changes to the boundary conditions and system connectivity, which adversely affect the current or future performance of these systems. This paper is organized as follows: Section 2 elaborates the brief history of SHM, Section 3 portrays on Principles, Organization of SHM and also differentiates the types of monitoring in SHM, Section 4 illustrates the Operations and furthermore lists the Challenges of SHM, the survey and related work are presented in Section 5. Finally, the paper is concluded in Section 6.

II. BRIEF HISTORICAL OVERVIEW

The damage identification, as determined by changes in the dynamic response of systems, has been practiced in a qualitative manner, using acoustic techniques (e.g. tap tests on train wheels), since modern man has used tools. More recently, the development of quantifiable SHM approaches has been closely coupled with the evolution, miniaturization and cost reductions of digital computing hardware. In conjunction with these developments, SHM has received considerable attention in the technical literature and a brief summary of the developments in this technology over the last 30 years is presented below [2]. To date, the most successful application of SHM technology has been for CM of rotating machinery. The rotating machinery application has taken an almost exclusive non-model based approach to damage identification. The identification process is based on pattern recognition applied to displacement, velocity or acceleration time histories (or spectra) generally measured at a single point on the housing or shafts of the machinery during normal operating conditions and start up or shut down transients. Often this pattern recognition is performed only in a qualitative manner based on a visual comparison of the spectra obtained from the system at different times. Databases have been developed that allow specific types of damage to be identified from particular features of the vibration signature. For rotating machinery systems, the approximate damage location is generally known making a single-channel fast Fourier transform analyzer sufficient for most periodic monitoring activities. Typical damage that can be identified includes loose or damaged bearings, misaligned shafts and chipped gear teeth. Today, commercial software integrated with measurement hardware is marketed to help the user systematically apply this technology to the operating equipment [4].

The success of CM is due in part to (i) minimal operational and environmental variability associated with this type of monitoring, (ii) well-defined damage types that occur at known locations, (iii) large databases that include data from damaged systems, (iv) well-established correlation between damage and features extracted from the measured data, and (v) clear and quantifiable economic benefits that this technology can provide. These factors have allowed this application of SHM to have made the transition from a research topic to industry practice several decades ago resulting in comprehensive condition management systems such as the US Navy's Integrated Condition Assessment System [5]. During the 1970s and 1980s, the oil industry made considerable efforts to develop vibration-based damage identification methods for offshore platforms. This damage identification problem is fundamentally different from that of rotating machinery because the damage location is unknown and because the majority of the structure is not readily accessible for measurement. To circumvent these difficulties, a common methodology adopted by this industry was to simulate candidate damage scenarios with numerical models, examine the changes in resonant frequencies that were produced by these simulated changes, and correlate these changes with those measured on a platform.

A number of very practical problems were encountered including measurement difficulties caused by platform machine noise, instrumentation difficulties in hostile environments, changing mass caused by marine growth, varying fluid storage levels, temporal variability of foundation conditions and the inability of wave motion to excite higher vibration modes. These issues prevented adaptation of this technology and efforts at further developing this technology for offshore platforms were largely abandoned in the early 1980s. The aerospace community began to study the use of vibration-based damage identification during the late 1970s and early 1980s in conjunction with the development of the space shuttle. This work has continued with current applications being investigated for the National Aeronautics and Space Administration's space station and future reusable launch vehicle designs. The shuttle modal inspection system (SMIS) was developed to identify fatigue damage in components such as control surfaces, uselage panels and lifting surfaces. These areas were covered with a thermal protection system making them inaccessible and, hence, impractical for conventional local non-destructive examination methods [6].

The SMIS has been successful in locating damaged components that are covered by the thermal protection system. All orbiter vehicles have been periodically subjected to SMIS testing since 1987. Space station applications have primarily driven the development of experimental/analytical methods aimed at identifying damage to truss elements caused by space debris impact. These approaches are based on correlating analytical models of the undamaged structure with measured modal properties from both the undamaged and damaged structures. Changes in stiffness indices as assessed from the two model updates are used to locate and quantify the damage. Since the mid-1990s, studies of damage identification for composite materials have been motivated by the development of a composite fuel tank for a reusable launch vehicle. The failure mechanisms, such as delamination caused by debris impacts, and corresponding material response for composite fuel tanks are significantly different to those associated with metallic structures. Moreover, the composite fuel tank problem presents challenges because the sensing systems must not provide a spark source. This challenge has led to the development of SHM based on fibre optic sensing systems.

The civil engineering community has studied vibration-based damage assessment of bridge structures and buildings since the early 1980s. Modal properties and quantities derived from these properties, such as mode shape curvature and dynamic flexibility matrix indices, have been the primary features used to identify damage in bridge structures. Environmental and operating condition variability presents significant challenges to the bridge monitoring application. The physical size of the structure also presents many practical challenges for vibration-based damage assessment. Regulatory requirements in Asian countries, which mandate that the companies that construct the bridges periodically certify their structural health, are driving current research and commercial development of bridge SHM systems. The studies identify many technical challenges to the adaptation of SHM that are common to all applications of this technology. These challenges include the development of methods to optimally define the number and location of the sensors; identification of the features sensitive to small damage levels; the ability to discriminate changes in these features caused by damage from those caused by changing environmental and/or test conditions; the development of statistical methods to discriminate features from undamaged and damaged structures; and performance of comparative studies of different damage identification methods applied to common datasets. These topics are currently the focus of various research efforts by many industries including defense, civil infrastructure, automotive and semiconductor manufacturing where multi-disciplinary approaches are being used to advance the current capabilities of SHM and CM [7].

III. PRINCIPLES, ORGANIZATION AND MONITORING OF SHM

A. Principles and Organization of a SHM system

In Figure 2, the organization of a typical SHM system is given in detail. The first part of the system, which corresponds to the structural integrity monitoring function, can be defined by: i) the type of physical phenomenon, closely related to the damage, which is monitored by the sensor, ii) the type of physical phenomenon that is used by the sensor to produce a signal (generally electric) sent to the acquisition and storage sub-system. Several sensors of the same type, constituting a network, can be multiplexed and their data merged with those from other types of sensors [8]. Possibly, other sensors, monitoring the environmental conditions, make

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it possible to perform the usage monitoring function. The signal delivered by the integrity monitoring sub-system, in parallel with the previously registered data, is used by the controller to create a diagnostic. Mixing the information of the integrity monitoring sub-system with that of the usage monitoring sub-system and with the knowledge based on damage mechanics and behavior laws makes it possible to determine the prognosis (residual life) and the health management of the structure (organization of maintenance, repair operations, etc.). Finally, similar structure management systems related to other structures which constitute a type of super system (a fleet of aircraft, a group of power stations, etc.) make possible the health management of the super system.

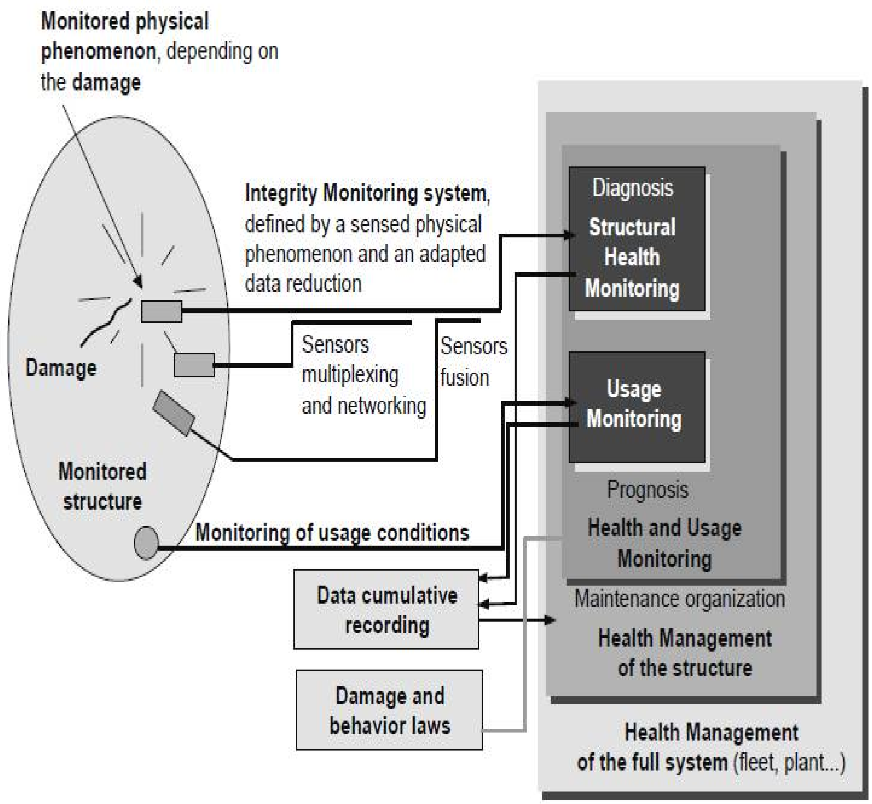

Fig. 2 Principles and Organization of a SHM system

Knowing the integrity of in-service structures on a continuous real-time basis is a very important objective for manufacturers, end-users and maintenance teams. In effect, SHM:

1) allows an optimal use of the structure, a minimized downtime, and the avoidance of catastrophic failures,
2) gives the constructor an improvement in his products,
3) drastically changes the work organization of maintenance services:
   a) By aiming to replace scheduled and periodic maintenance inspection with performance-based (or condition-based) maintenance (long term) or at least (short term) by reducing the present maintenance labor, in particular by avoiding dismounting parts where there is no hidden defect
   b) By drastically minimizing the human involvement, and consequently reducing labor, downtime and human errors, and thus improving safety and reliability.

B. Monitoring in SHM: Passive and Active

SHM, can be passive or active. Figure 3 presents the possible situations in which both experimenter and examined structure are involved. The structure is equipped with sensors and interacts with the surrounding environment; in such a way that it's state and its physical parameters is evolving [8].

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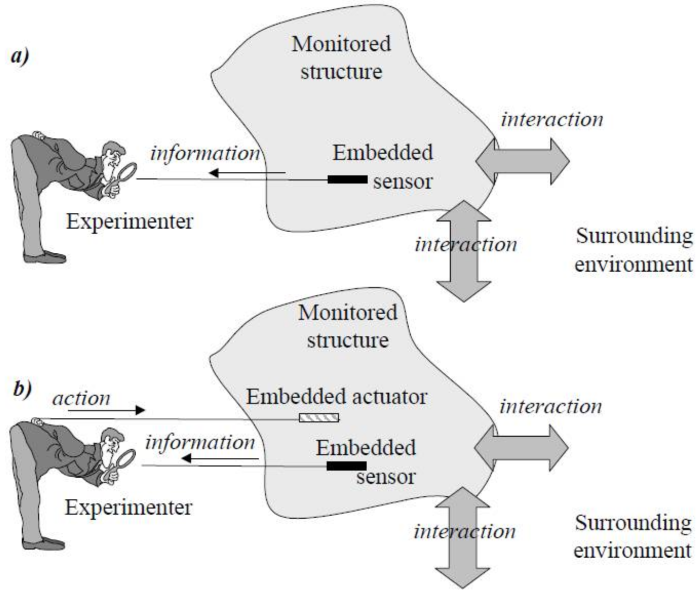

Fig. 3 The two possible attitudes of the experimenter defining: (a) Passive and (b) Active monitoring in SHM.

If the experimenter is just monitoring this evolution (uses embedded sensors), this action is called as "passive monitoring". For SHM, this sort of situation is encountered with acoustic emission techniques detecting, for example, the progression of damage in a loaded structure or the occurrence of a damaging impact. If the experimenter has equipped the structure with both sensors and actuators, he or she can generate perturbations in the structure, thanks to actuators, and then, use sensors to monitor the response of the structure. In such a case, the action of the experimenter is "active monitoring".

In the aforementioned example, the monitoring becomes active, by adding to the first piezoelectric patch, which is used as an acoustic emission detector, a second patch, which is used as an emitter of ultrasonic waves. The receiver, here, is registering signals, resulting from the interaction of these waves with a possible damage site, allowing its detection the examined structure, but the philosophy is the same. In SHM, the actuator and the sensor can be different or identical in nature, for instance, excitation by a piezoelectric patch and detection of the waves, by a fiber-optic sensor or another piezoelectric patch. In the case of piezoelectric transducers, it is worth noting that the same device can work as both emitter and receiver, which gives flexibility to the monitoring system, by alternating their roles. With piezoelectric patches, a unique transducer can even perform the two functions at the same time, as in the electromechanical impedance technique [8, 9].

IV. OPERATIONS AND CHALLENGES OF SHM

This section portrays on the operation of SHM and the major challenges in Structural Health Monitoring [7].

A. SHM Operations

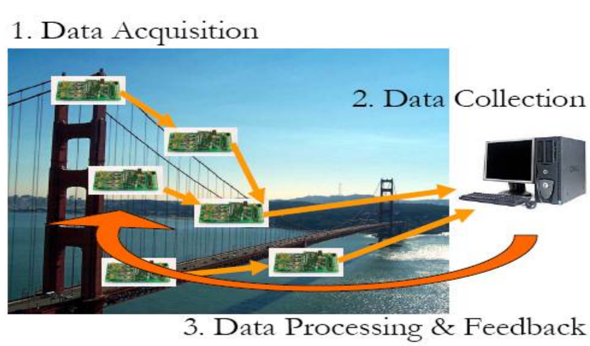

Fig. 4 Operation in Structural Health Monitorning.

Operation can be decomposed into three phases (figure 4).

1) Data sampling: sample the vibration data of the structure.
2) Data collection: transfers data reliably to an external computing resource.
3) Data Analysis: runs analysis algorithm, and determines health status. Sends feedback to nodes if needed

B. Challenges for SHM

The basic premise of SHM feature selection is that damage will significantly alter the stiffness, mass or energy dissipation properties of a system, which, in turn, alter the measured dynamic response of that system. Although the basis for feature selection appears intuitive, its actual application poses many significant technical challenges. The most fundamental challenge is the fact that damage is typically a local phenomenon and may not significantly influence the lower-frequency global response of structures that is normally measured during system operation. Stated another way, this fundamental challenge is similar to that in many engineering fields where the ability to capture the system response on widely varying length- and time-scales, as is needed to model turbulence or to develop phenomenological models of energy dissipation, has proven difficult. Another fundamental challenge is that in many situations feature selection and damage identification must be performed in an unsupervised learning mode. That is, data from damaged systems are not available. Damage can accumulate over widely varying time-scales, which poses significant challenges for the SHM sensing system [9]. This challenge is supplemented by many practical issues associated with making accurate and repeatable measurements over long periods of time at a limited number of locations on complex structures often operating in adverse environments.

Finally, a significant challenge for SHM is to develop the capability to define the required sensing system properties before field deployment and, if possible, to demonstrate that the sensor system itself will not be damaged when deployed in the field. If the possibility of sensor damage exists, it will be necessary to monitor the sensors themselves. This monitoring can be accomplished either by developing appropriate self-validating sensors or by using the sensors to report on each other's condition. Sensor networks should also be 'fail-safe'. If a sensor fails, the damage identification algorithms must be able to adapt to the new network. This adaptive capability implies that a certain amount of redundancy must be built into the sensor network. In addition to the challenges described above, there are other non-technical issues that must be addressed before SHM technology can make the transition from a research topic to actual practice. These issues include convincing structural system owners that the SHM technology provides an economic benefit over their current maintenance approaches and convincing regulatory agencies that this technology provides a significant life-safety benefit. All these challenges lead to the current state of SHM technology [10], where outside of condition monitoring for rotating machinery applications SHM remains a research topic that is still making the transition to field demonstrations and subsequent field deployment. There are lots of ongoing and new structural monitoring activities, but these systems have been put in place without a predefined damage to be detected and without the corresponding data interrogation procedure. As such, these monitoring activities do not represent a fully integrated hardware/software SHM system with pre-defined damage identification goals [11].

V. RELATED WORK AND DISCUSSIONS

This section presents the survey made on Structural Health Monitoring. Various authors have presented their illustrations on the applications of SHM.

Qing Ling and et al., presented a localized information processing approach for long-term, online structural health monitoring (SHM) using wireless sensor networks (WSNs). Each sensor independently calculates a statistical damage-sensitive coefficient using the measured acceleration data during each monitoring period. A nonlinear programming formulation is developed to identify damage presence, localize damage position, and quantify damage severity from the damage-sensitive coefficients in the whole sensing field. By limiting each sensor to exchange information among its neighboring sensors only, a localized near-optimal algorithm is proposed to reduce communication costs, thus alleviating the channel interference and prolonging the network lifetime. Simulation results on a steel frame structure prove the effectiveness of the proposed algorithm [12].

J.A. Rice and et al., elaborated on SHM, which is an important tool for the ongoing maintenance of aging infrastructure. The ultimate goals of implementing an SHM system are to improve infrastructure maintenance, increase public safety, and minimize the economic impact of an extreme loading event by streamlining repair and retrofit measures. Networks of wireless smart sensors offer tremendous promise for accurate and continuous structural monitoring using a dense array of inexpensive sensors; however, hurdles still remain. While smart sensors have been commercially available for nearly a decade, full-scale implementation for civil infrastructure has been lacking with the exception of a few short-term demonstration projects. This slow progress is due in part to the fact that programming smart sensors is extremely complex, putting the use of these devices for all but the simplest tasks out of the reach of most engineers. This paper presents an enabling, open source framework for structural health monitoring using networks of wireless smart sensors. The framework is based on a service-oriented architecture that is modular, reusable, and extensible, thus allowing engineers to more readily realize the potential of smart sensing technology. To demonstrate the efficacy of the proposed framework, an example SHM application is provided [13].

A. Ravinagarajan and et al., proposed that the task scheduler of an energy harvesting wireless sensor node (WSN) must adapt the task complexity and maximize the accuracy of the tasks within the constraint of limited energy reserves. Structural Health Monitoring (SHM) represents a great example of such an application comprising of both steady state operations and sporadic externally triggered events. To this end, we propose a task scheduler based on a Linear Regression Model embedded with Dynamic Voltage and Frequency Scaling (DVFS) functionality. Our results show an improvement in the average accuracy of a SHM measurement, setting it at 80% of the maximum achievable accuracy. There is also an increase of 50% in the number of SHM measurements [14].

Shamim N. Pakzad and et al., described an integrated hardware and software system for a scalable wireless sensor network (WSN) is designed and developed for structural health monitoring. An accelerometer sensor node is designed, developed, and calibrated to meet the requirements for structural vibration monitoring and modal identification. The nodes have four channels of accelerometers in two directions and a microcontroller for processing and wireless communication in a multihop network. Software components have been implemented within the TinyOS operating system to provide a flexible software platform and scalable performance for structural health monitoring applications. These components include a protocol for reliable command dissemination through the network and data collection, and improvements to software components for data pipelining, jitter control, and high-frequency sampling. The prototype WSN was deployed on a long-span bridge with 64 nodes. The data acquired from the test-bed were used to examine the scalability of the network and the data quality. Robust and scalable performance was demonstrated even with a large number of hops required for communication. The results showed that the WSN provides spatially dense and accurate ambient vibration data for identifying vibration modes of a bridge [15].

G. Anastasi, G. Lo Re, M. Ortolani, described on the Monitoring structural health of historical heritage buildings may be a daunting task for civil engineers due to the lack of a pre-existing model for the building stability, and to the presence of strict constraints on monitoring device deployment. This paper reports on the experience maturated during a project regarding the design and implementation of an innovative technological framework for monitoring critical structures in Sicily, Italy. The usage of Wireless Sensor Networks allows for a pervasive observation over the sites of interest in order to minimize the potential damages that natural phenomena may cause to architectural or engineering works. Moreover, the system provides real-time feedback to the civil engineer that may promptly steer the functioning of the monitoring network, also remotely accessing sensed data via web interfaces [16].

Charles R. Farrar, Keith Worden, elaborated the process of implementing a damage identification strategy for aerospace, civil and mechanical engineering infrastructure is referred to as structural health monitoring (SHM). Here, damage is defined as changes to the material and/or geometric properties of these systems, including changes to the boundary conditions and system connectivity, which adversely affect the system’s performance. A wide variety of highly effective local non-destructive evaluation tools are available for such monitoring. However, the majority of SHM research conducted over the last 30 years has attempted to identify damage in structures on a more global basis. The past 10 years have seen a rapid increase in the amount of research related to SHM as quantified by the significant escalation in papers published on this subject. The increased interest in SHM and its associated potential for significant life-safety and economic benefits has motivated the need for this theme issue. This introduction begins with a brief history of SHM technology development. Recent research has begun to recognize that the SHM problem is fundamentally one of the statistical pattern recognition (SPR) and a paradigm to address such a problem is described in detail herein as it forms the basis for organization of this theme issue. In the process of providing the historical overview and summarizing the SPR paradigm, the subsequent articles in this theme issue are cited in an effort to show how they fit into this overview of SHM. In conclusion, technical challenges that must be addressed if SHM is to gain wider application are discussed in a general manner [17].

Xuefeng Liu and et al., depicted that in recent years, using wireless sensor networks (WSNs) for structural health monitoring (SHM) has attracted increasing attention. Traditional centralized SHM algorithms developed by civil engineers can achieve the highest

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damage detection quality since they have the raw data from all the sensor nodes. However, directly implementing these algorithms in a typical WSN is impractical considering the large amount of data transmissions and extensive computations required. Correspondingly, many SHM algorithms have been tailored for WSNs to become distributed and less complicated. However, the modified algorithms usually cannot achieve the same damage detection quality of the original centralized counterparts. In this paper, we select a classical SHM algorithm: the eigen-system realization algorithm (ERA), and propose a distributed version for WSNs. In this approach, the required computations in the ERA are updated incrementally along a path constructed from the deployed sensor nodes. The efficacy of the proposed approach is demonstrated through both simulation and experiment [18].

Md Zakirul Alam Bhuiyan and et al., represented an integrated hardware and software system for a scalable wireless sensor network (WSN) is designed and developed for structural health monitoring. An accelerometer sensor node is designed, developed, and calibrated to meet the requirements for structural vibration monitoring and modal identification. The nodes have four channels of accelerometers in two directions and a microcontroller for processing and wireless communication in a multihop network. Software components have been implemented within the TinyOS operating system to provide a flexible software platform and scalable performance for structural health monitoring applications. These components include a protocol for reliable command dissemination through the network and data collection, and improvements to software components for data pipelining, jitter control, and high-frequency sampling [19].

Boyle, David and and et al., documented the design, implementation and characterization of a wireless sensor node (GENESI Node v1.0), applicable to long-term structural health monitoring. Presented is a three layer abstraction of the hardware platform; consisting of a Sensor Layer, a Main Layer and a Power Layer. Extended operational lifetime is one of the primary design goals, necessitating the inclusion of supplemental energy sources, energy awareness, and the implementation of optimal components (microcontroller(s), RF transceiver, etc.) to achieve lowest-possible power consumption, whilst ensuring that the functional requirements of the intended application area are satisfied. A novel Smart Power Unit has been developed; including intelligence, ambient available energy harvesting (EH), storage, electrochemical fuel cell integration, and recharging capability, which acts as the Power Layer for the node. The functional node has been prototyped, demonstrated and characterized in a variety of operational modes. It is demonstrable via simulation that, under normal operating conditions within a structural health monitoring application, the node may operate perpetually [20].

TAN Zhong-ji and et al., discussed that the health monitoring management system has prominent function to improve the security and dependability of the aircraft, can also shortens the maintain cycle by a large margin, improves the sortie rate at the same time. They explained the concept, the development in domestic and international and the key technology of the health monitoring management system of aircraft; Construct the structure of the aircraft health monitoring management system, and has carried on analysis and research to its implementation method [21].

LI Hui, OU Jinping portrayed that the sensing technologies are developed for monitoring of fatigue, corrosion, score and seismic damages by using integrating piezo-electric ceramic array with optical fiber Bragg Grating sensor array and ultrasonic monitoring technology. The approaches of health diagnosis for civil structures have been proposed byauthors and their group. The damage detection approaches considering the uncertainties of civil structures and environmental factors are proposed, such as probabilistic damage identification approach based on dynamic sensitivity analysis and damage detection approach by using information fusion techniques. A multi-scale finite element model (FEM) updating approach is presented for conducting safety evaluation. The modeling approaches for various loads and responses using SHM data are proposed and the framework of SHM-based structure safety evaluation is established. Finally, the role of SHM in developing smart earth in the future is also put forwarded [22].

Even though wireless sensing technologies continue to advance in lockstep with the rapid evolution of related embedded systems technologies, in many regards, wireless structural monitoring systems are still in their infancy. Opportunities still exist to improve the hardware and software features of existing wireless sensing unit prototypes. With power consumption still a major challenge, work is needed to produce wireless sensors whose hardware designs allow them to be employed in long-term field deployments. Power harvesting technologies, under development in academia, could offer opportunities to replenish battery energy by harvesting power from ambient structural vibrations. With computational responsibility spatially distributed throughout the wireless structural monitoring system, new approaches to interrogating structural response data for signs of damage are also needed. The development of future damage detection algorithms intended for embedment in the wireless monitoring system would greatly benefit if the architecture (e.g. a decentralized computing grid) and limitations (e.g. power constrained) of the wireless system architecture are taken into account a priori. Greater emphasis should be placed upon the use of real civil structures for validation of wireless monitoring systems.

VI. CONCLUSION

A major challenge facing our society is the rapidly aging infrastructure. The funds needed to reconstruct infrastructure systems and to maintain their service at a level that is considered satisfactory are prohibitive. Therefore, it is imperative that any planning for reconstruction should specifically look into a prioritization scheme. The availability of a versatile and smart monitoring system, with ability to provide information on structural health conditions on a routine basis, will substantially enhance the capabilities of various agencies when they plan for prioritizing their infrastructure systems for maintenance. Many structural health monitoring systems that are available today are only applicable to specific structures and lack the versatility needed to cover a whole host of distress conditions. To address these shortcomings, implementation of structural health monitoring systems should include:

A. Design and realization of application oriented network for wireless communication.

B. Design and realization of smart computing engines in the sensor nodes for on-going real-time monitoring.

C. Design and realization of power harvesting and power usage optimization for self-sustainable operation.

D. Design and synthesis of advanced signal processing algorithms for defect detection and characterization.

E. Data archiving and analysis for damage assessment and maintenance scheduling.

This paper has presented a study on some of the current applications and scenario of SHM.

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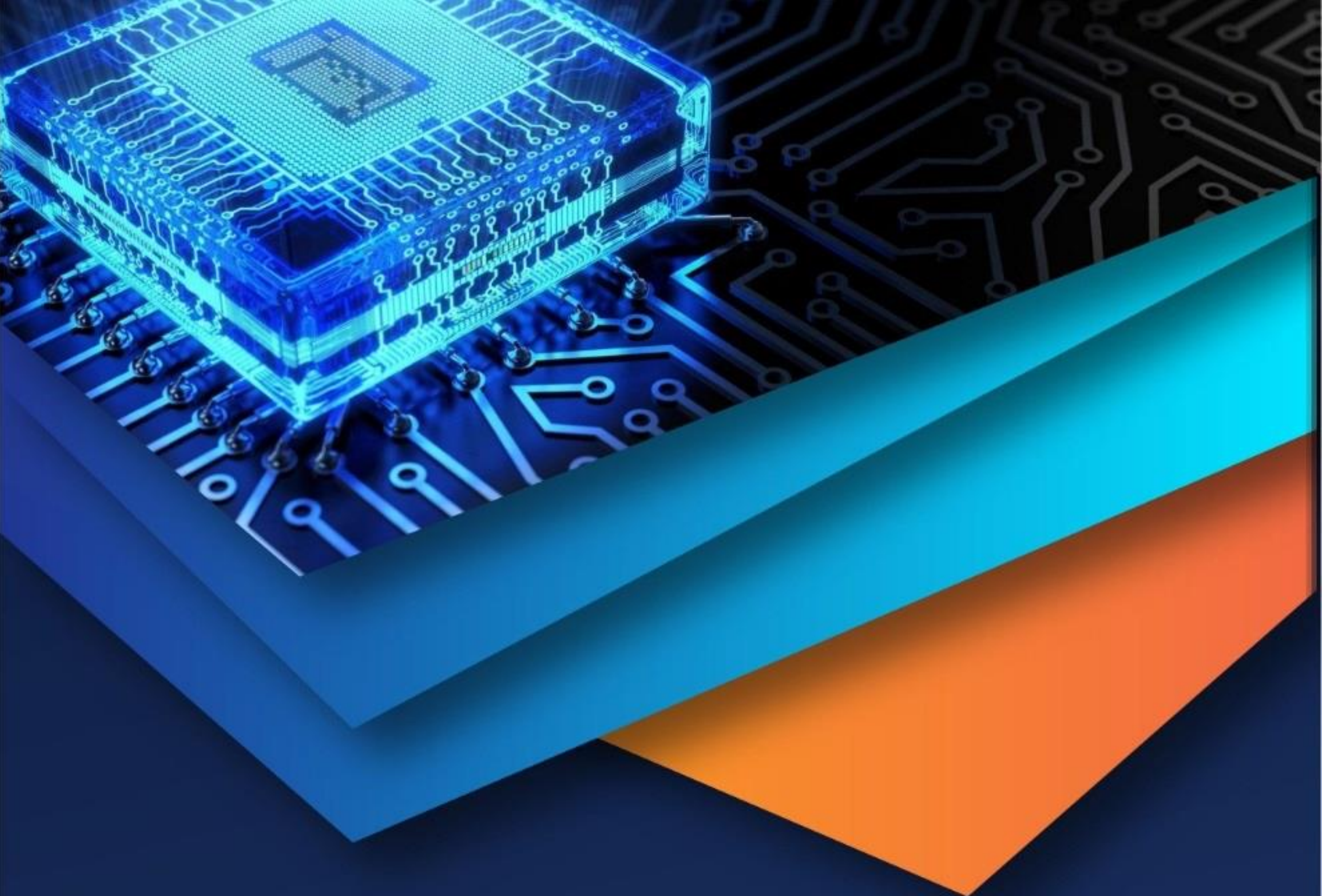

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