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Mechanism of Structural Health Monitoring in Construction

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ABSTRACT: The objectives of this thesis is to have better understanding of the Structural Health Monitoring(SHM), which is new era technology or field which correlate Civil Engineering with Electronics Engineering. Structural health monitoring is promising field for upcoming generation. It opens the doors to enter into new galaxy of inter departmental research programs. Structural health monitoring is constantly growing and innovative field. It is a term increasingly used in the last decade to describe a range of systems implemented on full-scale civil infrastructures and whose purposes are to assist and inform operators about continued _fitness for purpose ‘of structures under gradual or sudden changes to their state, to learn about either or both of the load and response mechanisms. Arguably, various forms of SHM have been employed in civil infrastructure for at least half a century, but it is only in the last decade or two that computer-based systems are being designed for the purpose of assisting owners/operators of ageing infrastructure with timely information for their continued safe and economic operation. In this study we have devised some capacitance-based sensor; by the help of it we can actually identify the minor crack in structures before it can subject to a failure (brittle or ductile). This paper describes the motivations for and recent history of SHM applications to various forms of civil infrastructure and provides case studies on specific types of structure. It ends with a discussion of the present state-of-the-art and future developments in terms of instrumentation, data acquisition, communication systems and data mining and presentation procedures for diagnosis of infrastructural health’.

KEYWORDS: Wireless Sensor Networks, Ambient Health Monitoring, Structural Health Monitoring in Construction Management, Technical Challenges, Acoustic emission, Monitoring, MEMS, Structures.

I. INTRODUCTION

1.1 INTRODUCTION

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. In terms of length-scales, all damage begins at the material level. Although not necessarily a universally accepted terminology, such damage is referred to as a defect or flaw and is present to some degree in all materials. Under appropriate loading scenarios, the defects or flaws grow and coalesce at various rates to cause component and then system-level damage. The term damage does not necessarily imply a total loss of system functionality, but rather that the system is no longer operating in its optimal manner. As the damage grows, it will reach a point where it affects the system operation to a point that is no longer acceptable to the user. This point is referred to as failure. In terms of time-scales, damage can accumulate incrementally over long periods of time such as that associated with fatigue or corrosion damage accumulation. On relatively shorter time-scales, damage can also result from scheduled discrete events such as aircraft landings and from unscheduled discrete events such as enemy fire on a military vehicle or natural phenomena hazards such as earthquakes. The process of implementing a damage identification strategy for aerospace, civil and mechanical engineering infrastructure is referred to as structural health

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monitoring (SHM). This process involves the observation of a structure or mechanical system over time using periodically spaced measurements, the extraction of damage-sensitive features the current state of system health. For long-term SHM, the output of this process is periodically updated information regarding the ability of the structure to continue to perform its intended function in light of the inevitable aging and damage accumulation resulting from the operational environments. Under an extreme event, such as an earthquake or unanticipated blast loading, SHM is used for rapid condition screening. This screening is intended to provide, in near real-time, reliable information about system performance during such extreme events and the subsequent integrity of the system.

Damage identification is carried out in conjunction with five closely related disciplines that include SHM, condition monitoring, non-destructive evaluation statistical process control and damage prognosis. Typically, SHM is associated with online-global damage identification in structural systems such as aircraft and buildings. CM is analogous to SHM, but addresses damage identification in rotating and reciprocating machinery, such as those used in manufacturing and power generation. NDE is usually carried out off-line in a local manner after the damage has been located. There are exceptions to this rule, as NDE is also used as a monitoring tool for in situ structures such as pressure vessels and rails. NDE is therefore primarily used for damage characterization and as a severity check when there is a priori knowledge of the damage location. SPC is process-based rather than structure-based and uses a variety of sensors to monitor changes in a process, one cause of which can result from structural damage. Once damage has been detected, DP is used to predict the remaining useful life of a system.

1.2 BRIEF HISTORICAL OVERVIEW

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. 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. 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
- (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.

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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, fuselage 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. 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 delaminating 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 fiber 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.

In summary, the review of the technical literature presented by Doebling et al. (1996) and Sohn et al. (2003) shows an increasing number of research studies related to damage identification. These 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.

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1.3 THE STATISTICAL PATTERN RECOGNITION PARADIGM

There are many ways by which one can organize a discussion of SHM. We have chosen that defines the SHM process in terms of a four-step statistical pattern recognition paradigm. This following four-step process includes:

- i. operational evaluation,
- ii. data acquisition, normalization and cleansing,
- iii. feature selection and information condensation, and
- iv. Statistical model development for feature discrimination.

II. LITERATURE REVIEW

2.1 METHODS OF STRUCTURAL HEALTH MONITORING

ORIGIN

Qualitative and non-continuous methods have long been used to evaluate structures for their capacity to serve their intended purpose. Since the beginning of the 19th century, railroad wheel-tappers have used the sound of a hammer striking the train wheel to evaluate if damage was present. In rotating machinery, vibration monitoring has been used for decades as a performance evaluation technique. In the last ten to fifteen years, SHM technologies have emerged creating an exciting new field within various branches of engineering. These technologies are currently becoming increasingly common.

2.2 STATISTICAL PATTERN RECOGNITION PARADIGM APPROACH

The SHM problem can be addressed in the context of a statistical pattern appreciation model.

This model can be broken down into four parts:

- (1) Operational Evaluation
- (2) Data Acquisition and Cleansing
- (3) Feature Extraction and Data Compression
- (4) Statistical Model Development for Feature Discrimination.

When one attempts to apply this paradigm to data from real world structures, it quickly becomes apparent that the ability to cleanse, compress, normalize and fuse data to account for operational and environmental variability is a key implementation issue when addressing Parts 2-4 of this paradigm. These processes can be implemented through hardware or software and, in general, some combination of these two approaches will be used.

2.3 OPERATIONAL EVALUATION

Operational evaluation attempts to answer four questions regarding the implementation of a damage identification capability:

- i) What are the life-safety and/or economic justification for performing the SHM?

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- ii) How is damage defined for the system being investigated and, for multiple damage possibilities, which cases are of the most concern?
- iii) What are the conditions, both operational and environmental, under which the system to be monitored functions?
- iv) What are the limitations on acquiring data in the operational environment?

2.4 ECONOMIC AND/OR LIFE-SAFETY ISSUES

Economic and life-safety issues are the primary driving force behind the development of structural health-monitoring technology. Garibaldi and Gorman (1999) state the need for accurate numerical models for bridge applications in which some modal frequencies are closely spaced. The authors note that the closely spaced frequencies can get obscured during the modal analysis of measurement data from limited measurements on the bridge-span sides and can lead to poor analysis results. Furthermore, because of the inaccessibility of the bridges under deck or the cost of closing the bridge to instrument measurements on the roadway, it is difficult to take dynamic measurements under the bridge or in the middle of a lane traversing the bridge.

Sikorsky and Stubbs (1997) discuss the goals of bridge management systems including SHM that the American Association of State Highway and Transportation Officials (AASHTO) intend to implement. In particular, the authors advocate a quality-management initiative directed toward the construction stage of bridge structures coupled with modal-based nondestructive damage evaluation (NDE) throughout the lifespan of the bridges. These goals are to help engineers and decision makers determine when and where to spend funds so that structural safety is enhanced, the existing infrastructure is preserved, and the needs of commerce and the motoring public are satisfied.

2.5 DEFINITION OF DAMAGE

Doebeling and Farrar (1997), damage has been intentionally introduced into a structure in an effort to simulate damage without having to wait for such a damage to occur. In other cases, the authors postulate a damage-sensitive feature and then develop an experiment to demonstrate the effectiveness of this feature. In these cases, there is no need to formally define damage. Most laboratory investigations fall into this category. When a SHM system is deployed on an in situ structure, it is imperative that the investigators first clearly define and quantify the damage that they are looking for; then, that they can increase the likelihood that the damage will be detected with sufficient warning, and to make optimal use of their sensing resources.

Rytter and Kirkegaard (1997), define damage simply as reduction in a bending stiffness, EI. Here, I is the moment of inertia of the beam's cross section, and E is the elastic modulus. They analyze the time history data from a four-story structure subjected to earthquake loading in the laboratory. The stiffness reduction of beams and columns are investigated in this study.

2.6 ENVIRONMENTAL AND/OR OPERATIONAL CONSTRAINTS

Using an analytical model of a cantilever beam, Cawley (1997) compares the effect of crack formation on the resonant frequency to that of the beam's length. In this study, the crack is introduced at the fixed end of the cantilever beam, and the length of the beam is varied. This study is part of a general discussion on the limitations of using modal properties for damage diagnosis. His results demonstrate that the resonance-frequency change caused by a crack, which is 2% cut through the depth of the beam, is 40 times smaller than caused by a 2% increase in the beam's length. The implication here is that changes in the structure's surroundings or boundary conditions such as thermal expansion can produce more significant changes in resonant frequencies than damage. Then, the authors propose to use the Lamb waves instead of vibration measurements to discern damage from a change in the boundary condition. In Lamb wave testing, the measurements are limited to the short time period between the generation of the wave and the onset of the first

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reflection signal at the boundaries. For an example of a beam, a wave is generated at one end of the beam, and the first echoes from the other end of the beam are monitored. Therefore, the sensitivity to the boundary conditions is reduced by excluding multiple reflections signals from the boundaries. Any additional reflection signals arriving before the boundary reflection would indicate the presence of damage. This Lamb wave testing is applied to detect delamination in a composite plate.

Pirner and Fischer (1997) separate mechanically induced loadings from thermally induced ones in a TV tower in Prague, Czechoslovakia. The researchers note that it is impossible to directly distinguish these loadings using time histories alone. They note, however, that temperature changes produce major and slowly changing stresses, while wind loads produce faster changes. The authors are then able to infer the temperature-induced loadings from a curve relating the number of stress cycles to the stress magnitude.

2.7 DATA MANAGEMENT

Seeing a deficiency in modern management methods in the bridge and highway infrastructure, Aktan et al. (2000) set out to present and discuss the issues prerequisite to creating a meaningful and successful health-monitoring system. His proposal entailed the implementation of an integrated-asset management that would facilitate a cost-effective optimization of operational performance and life-cycle preservation with an encompassing data network. The data components would include event-based, intermittent and on-line monitoring, and would combine temporal data collection and spatial-position-based data. A management system would diagnose the useful life only in collaboration with sensing damaged and undamaged states of systems.

The author adds that inventories of existing structure and infrastructure safety-related information are limited in detail. For example, critical welds may be monitored and determined to be damaged, but with accurate information regarding the bridge safety values, the bearing load of a bridge is found to be within safety values. As such, the authors suggest that the infrastructures be reevaluated with appropriate system identification allowing for effective health monitoring

Operational evaluation begins to set the limitations on what will be monitored and how the monitoring will be accomplished. This evaluation starts to tailor the damage identification process to features that are unique to the system being monitored and tries to take advantage of unique features of the damage that is to be detected.

2.8 DATA ACQUISITION AND SIGNAL PROCESSING

The data acquisition portion of the SHM process involves selecting the excitation methods, the sensor types, number and locations, and the data acquisition/storage/transmittal hardware. Again, this process will be application specific. Economic considerations will play a major role in making these decisions. The intervals at which data should be collected are another consideration that must be addressed. Because data can be measured under varying conditions, the ability to normalize the data becomes very important to the damage identification process. For instance, the measured fundamental frequency of the Alamosa Canyon Bridge in New Mexico varied approximately 5% during a 24-hour test period. Because the bridge is approximately aligned in the north and south direction, there was a large temperature gradient between the west and east sides of the bridge deck throughout the day.

2.9 EXCITATION METHODS

The excitation methods fall into the two general categories of ambient and forced excitation methods. During ambient excitation, the input to a system is not generally measured. In contrast, excitation forces are usually applied in a controlled manner and measured when the forced excitation method is employed. In this review, local excitations such as an excitation using a piezoelectric actuator is addressed in an independent section separated from the conventional forced excitation.

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2.10 FORCED EXCITATION

In the forced-excitation testing of structures, a wide variety of forcing techniques is used, including actuators, shakers, step relaxation, and various methods of measured impact (see Figure). For most of the forced-vibration tests, the input-forcing function is well characterized and system-identification techniques for determining the modal characteristics (resonant frequencies, mode shapes, and modal-damping ratios) of the structures subjected to measured inputs are well established. One advantage of the forced-vibration test is that the input force is typically strong enough to dominate other noise disturbance, resulting in a strong signal to noise ratio.

III. INSTRUMENTS USED IN STRUCTURAL HEALTH MONITORING

1. SENSOR

A sensor is a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument. In order to fulfill the purpose of structural health monitoring the following primary criteria for selecting the right type of sensors are considered: advance, sensitivity, precision, proper operating environmental conditions, low cost, high reliability, high durability, high stability, easy installation, replace ability, rehabilitation & expansibility. Now we will discuss about the type of sensors related to it

2. ANEMOMETER



FIGURE 1: ANEMOMETER

An anemometer is a device for measuring wind speed, it can work properly under bad weather such as windy and rainy, and temperature variation range in winter & summer. There are several types of anemometer, such as ultrasonic, turbine and so on. Ultrasonic anemometer can measure speed, direction and angle, so the performance is absolutely better than other types of anemometers.

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3. WEIGHBRIDGES



FIGURE 2: WEIGHBRIDGES

The weight and speed of vehicles are measured by weighbridges or weight-in-motion. The weighbridges are embedded underground in pavement, and thus the replacement cost is inexpensive. The short life due to bad durability is the main defect of this instrument. The weighbridge is made in steel-concrete composite structure, which has the same life with bridge itself. The weighbridge provides a good candidate for measuring traffic loads.

4. TEMPERATURE SENSORS



FIGURE 3: TEMPERATURE SENSORS

The temperature sensor measurement range is determined according to the highest & lowest temperatures of historical records. For concrete structure, temperature sensors are usually embedded into concrete, the replacement and

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rehabilitation are difficult and haven burden-in-labor. Thermocouples are typical type of sensors to record temperature. There are many kinds of thermocouples at present, such as contact-type, infrared-type and so on.

5. STRAIN SENSORS

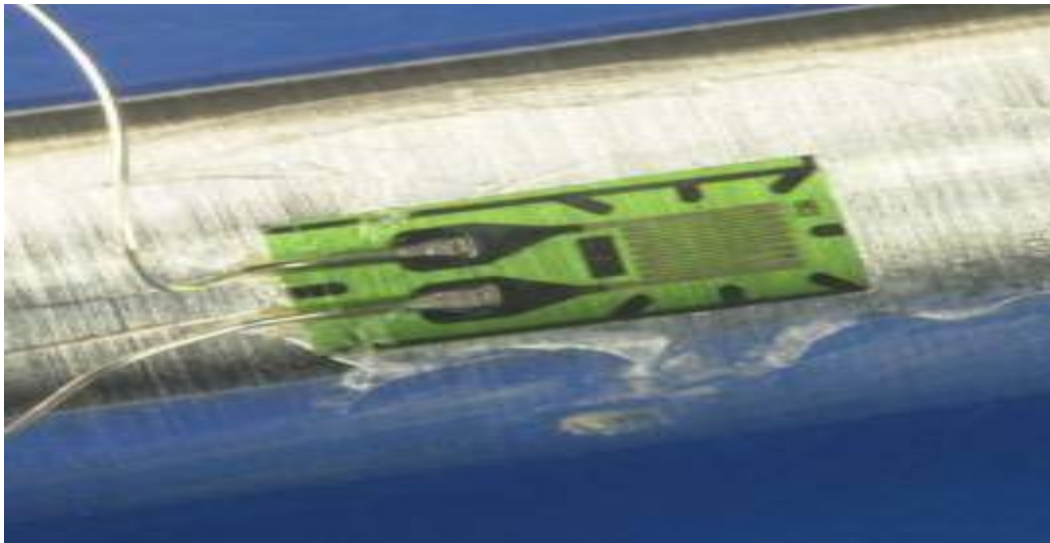


FIGURE 4: STRAIN SENSORS

Precision, sensitivity, stability and durability are primary criteria to be considered for selecting strain sensors. Dynamic and static properties of sensors are also criteria for some cases. The precision and sensitivity demand on strain sensors can be determined based on strain level induced by dead loads and live loads. Generally, the materials of strain sensor itself have high durability. However, if the strain sensor is mounted onto the specimen by inserter adhesive between strain sensor and specimen, the creep of adhesive will affect precision and durability of strain sensors. There is a wide variety of strain sensors, such as strain gauge, measuring vibrating wire strain gauges, optical fiber strain sensors. Strain gauge has been widely used in measurement of strain in the past decades. However, the adhesive which is used to mount strain gauge onto specimen, has disadvantage impact on precision and durability. This factor limits the application of health monitoring system in civil infrastructure. Measuring vibrating wire strain gauges can mount specimen via weld, which extend the life of gauges. However, this type of sensors cannot measure dynamic strain, only appreciation for static state response. Various optical fiber strain sensors are well developed in recent years.

6. ACCELEROMETERS

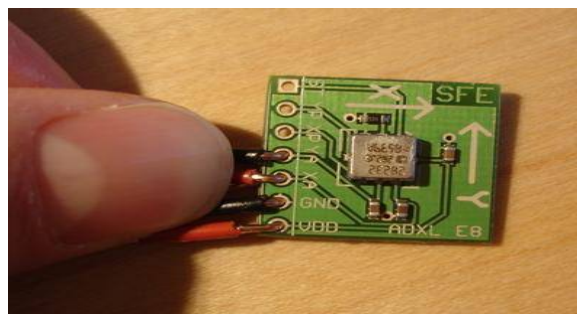


FIGURE 5: ACCELEROMETER

High precision, a wide range of frequency, suitable measurement range, operating environment condition, high stability and decay of signal with increasing distance are the factors to be considered for selecting accelerometers. Acceleration

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is more readily to measure. There are many types of accelerometers at present. For bridge, the natural modal frequency is much low, and thus the accelerometers with DC frequency is the first candidate to choose.

7. DISPLACEMENT TRANSDUCERS

High precision, a wide range of frequency, measurement range high stability and easy installation are the primary criteria to be considered for selecting displacement transducer. It is still very difficult to measure absolute displacement or deflection of bridge so far. There is wide variety of displacement transducer. Contact and un-contact are the main two categories. For un-contact CCD is the typical sensor to measure absolute displacement or deflection. GPS is the ideal sensor to measure displacement or deflection due to the advantages of high precision, convenient installation, automatization operation and so on. There are other sensors available for health monitoring system, such as magneto-elastic sensor for measuring tension force of cable, acoustic emission technology for detection of breakage, crack and so on.

8. DATA ACQUISITION SYSTEM

Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be operated by a computer. Data acquisition systems (abbreviated with the acronym DAS or DAQ) typically convert analog waveforms into digital values for processing. The components of data acquisition systems include:

- Sensors that convert physical parameters to electrical signals.
- Signal conditioning circuitry to convert sensor signals into a form that can be converted to digital values.
- Analog-to-digital converters, which convert conditioned sensor signals to digital values.

Data acquisition applications are controlled by software programs developed using various general purpose programming languages such as BASIC, C, Fortran, Java, Lisp, Pascal.

Specialized software tools used for building large-scale data acquisition systems include EPICS. Graphical programming environments include ladder logic, Visual C++, Visual Basic, MATLAB and Lab VIEW.

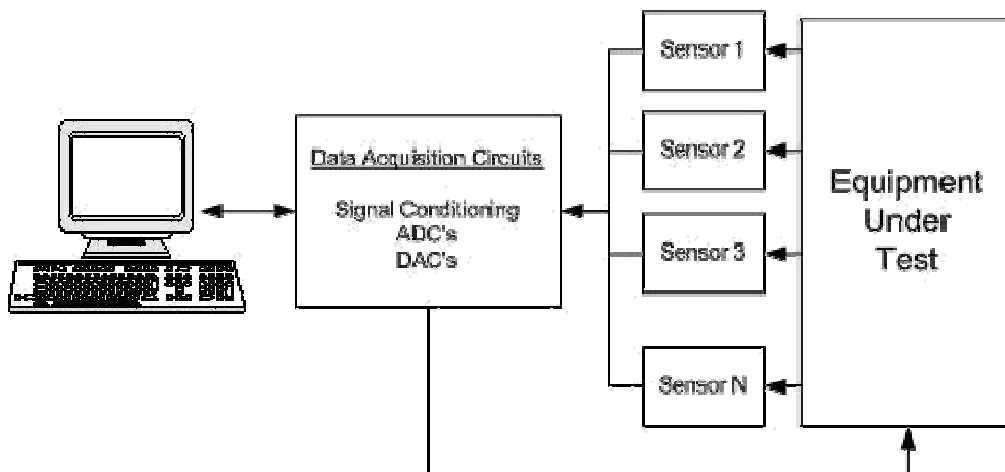


FIGURE 6: DATA ACQUISITION SYSTEM

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Data acquisition begins with the physical phenomenon or physical property to be measured. Examples of this include temperature, light intensity, fluid flow, and force. Regardless of the type of physical property to be measured, the physical state that is to be measured must first be transformed into a unified form that can be sampled by a data acquisition system. The task of performing such transformations falls on devices called sensors.

A sensor, which is a type of transducer, is a device that converts a physical property into a corresponding electrical signal (e.g. a voltage or current) or, in many cases, into a corresponding electrical characteristic (e.g. resistance or capacitance) that can easily be converted to electrical signal.

The ability of a data acquisition system to measure differing properties depends on having sensors that are suited to detect the various properties to be measured. There are specific sensors for many different applications. DAQ systems also employ various signal conditioning techniques to adequately modify various different electrical signals into voltage that can then be digitized using an Analog-to-digital converter (ADC).

Signals may be digital (also called logic signals sometimes) or analog depending on the transducer used.

Signal conditioning may be necessary if the signal from the transducer is not suitable for the DAQ hardware being used. The signal may need to be amplified, filtered or demodulated. Various other examples of signal conditioning might be bridge completion, providing current or voltage excitation to the sensor, isolation, linearization. For transmission purposes, single ended analog signals, which are more susceptible to noise can be converted to differential signals. Once digitized, the signal can be encoded to reduce and correct transmission errors.

9. STRUCTURAL HEALTH MONITORING FOR BRIDGES

Health monitoring of large bridges shall be performed by simultaneous measurement of loads on the bridge and effects of these loads. It typically includes monitoring of:

- Wind and weather
- Traffic
- Prestressing and stay cables
- Deck
- Pylons
- Ground

Provided with this knowledge, the engineer can:

- Estimate the loads and their effects
- Estimate the state of fatigue
- Forecast the probable evolution of the bridge

Integrated SHM system has the following advantages over existing methods to inspect and assess the structural integrity of buildings:

- Real-time assessment of structural stability and impending collapse

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- Stand-off mode, allowing safer operation with less risk to emergency response personnel
- Map of structural damage and temperature, to identify and locate hot spots
- Reduced cost and time spent on structural inspections
- Improved structural reliability
- Minimized catastrophic structural failure
- Convenience and automation of inspection

IV. STRUCTURAL HEALTH MONITORING APPLICATIONS

1. Multimodal sensor systems
2. Robust, precision signal conditioning
3. Distributed measurement systems
4. Software technologies

V. CONCLUSIONS

The results obtained in the form of graphical representation confirms that the capacitance based sensor effectively detect the micro cracks in the structure. This sensing device is new era technology, which is relatively cheaper but accurate. By employing this technique we can effectively forecast the development of the cracks in the structure and will be in the state to provide remedies well before collapse of the structure. Such technology plays vital role in the rehabilitation of the structures and makes structural health monitoring easier. Another important feature of this sensor is, as this technology help us to know the development of crack in anticipation, this will certainly minimize the role of F.O.S, which will ultimately make the structure much cheaper by using the ultimate strengths of the materials. Significant future developments of this technology will, in all likelihood, come by way of multi-disciplinary research efforts encompassing fields such as structural dynamics, signal processing, motion and environmental sensing hardware, computational hardware, data telemetry, smart materials and statistical pattern recognition, as well as other fields yet to be defined. These topics are the focus of significant discipline-specific research efforts, and to date not all technologies from these fields that are relevant to the SHM problem have been explored by the SHM research community. Furthermore, there are few efforts that try to advance and integrate these technologies with the specific focus of developing SHM solutions. Without such a focus in mind, these technologies may not evolve in a manner that is not necessarily optimal for solving the SHM problem. Finally, the problem of global SHM is significantly complex and diverse that it will not be solved in the immediate future. Like so many other technology fields, advancements in SHM will most likely come in small increments requiring diligent, focused and coordinated research efforts over long periods of time.

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