SENSOR TECHNOLOGIES IN MONITORING OF CIVIL ENGINEERING STRUCTURES

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This project report submitted as a partial
fulfilment of the requirement for the award of the degree of
Master of Engineering (Civil-Structure)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

JULY, 2006

Special Dedicated to My Beloved Family

Zawawi bin Parjan

Rosni binti Ahmad

Adi bin Zawawi

Azfar Aizat bin Zawawi

Muhd Nooralfian bin Zawawi

Muhd Akmal bin Zawawi

Maria Munirah binti Zawawi

Mohd Adzmi bin Zawawi

Adam Irfan bin Zawawi

And

All my Friends

ACKNOWLEDGEMENT

I wishes to thank my supervisor, Professor Dr. Azlan bin Abdul Rahman for his valuable advice, constructive criticisms, stimulating discussions and valuable suggestions during the preparation of this project report.

I would like to express my thanks to all colleagues who are always ready to give their helping hands. Last but not least, no words can be used to express my deepest gratitude to my parent and family for their encouragement and love, which are forever indebted.

ABSTRACT

This paper describes and reviews various sensor technologies, particularly fiber-optic sensor, which are applicable to the monitoring of civil engineering structures. Aspects of review include technical requirement, design and fabrication, and instrumentation procedures for the sensors. A comparative study on the relative merits and selection criteria is carried out through an analysis of selected case studies on real applications of sensors in structures. The analysis provides some general guidelines on technical implementation of structural monitoring using those sensors for our local conditions. Finite Element Modelling (FEM) is carried out for case study III for comparison purpose. In general, it is found that the fiber optic sensors give a higher value of stress-strain compared to the conventional electrical resistance strain gauge. This is due to the properties of the electric strain gauge, which does not necessary capture the randomly developed crack or the steel reinforcement in the particular cracked zone. Fiber optic based sensors have superior properties for structural monitoring and are able to record strain readings even after member collapse.

ABSTRAK

Kajian ini dijalankan untuk membincangkan dan mengulas tentang kepelbagaian teknologi sensor khususnya sensor gentian optik, yang mana ia boleh digunakan dalam pemantauan terhadap struktur – struktur kejuruteraan awam. Aspek yang dibincangkan adalah termasuk rekaan dan pengeluaran, prosedur yang diperlukan semasa pemasangan sensor dan keperluan teknikal sensor tersebut. Perbandingan berhubung dengan kelebihan setiap sensor dan kriteria yang diperlukan semasa membuat pemilihan sensor dibuat berpandukan kajian kes yang dipilih. Kajian kes yang dipilih adalah berdasarkan aplikasi sebenar sensor tersebut dalam struktur kejuruteraan awam. Analisis yang dibuat membincangkan mengenai panduan umum teknik penggunaannya dalam mengawasi struktur serta penggunaannya pada stuktur tempatan. Kaedah unsur terhingga (FEM) telah digunakan untuk kajian kes yang ketiga untuk tujuan perbandingan. Secara umumnya, sensor gentian optik memberikan bacaan yang lebih tinggi dalam lengkung tegangan-terikan jika dibandingkan dengan penggunaan tolok terikan elektrik. Ini adalah disebabkan oleh ciri-ciri tolok terikan elektrik tersebut yang tidak dapat memberikan bacaan apabila sesuatu struktur mulai retak atau pada zon retak di sekitar tetulang keluli. Sensor gentian optik mempunyai ciri-ciri yang lebih baik untuk mengawasi struktur dan mampu memberikan rekod bacaan keterikan (strain) walaupun struktur tersebut telah runtuh atau musnah.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Civil Infrastructures, such as long span bridges, offshore structures, large dams and other hydraulic engineering, nuclear power stations, tall buildings, large space structures and geotechnical engineering etc. often have a long service period, maybe several decades or over one hundred years. During their service life, these structures inevitably suffer from environmental corrosion, long term loading or fatigue effects, material aging or their coupling effects with extreme loading. Consequently, the damage accumulates, performance degenerates or capacity resisting from disaster actions reduces. Intelligent health monitoring systems (HMSs) has become important technology to study the damage or even disaster evolving characteristics and laws and also become health-ensuring systems for infrastructures. This technology attracts immense research interests and active development interests of scientists and engineers in the whole world. (Jinping OU and Hui LI)

The concrete makes most of those civil infrastructures. Its long-term degradation is a major problem with the infrastructure of many developed countries.

Damage in a concrete structure may start very early in its life span. For example, in large structures such as dams, the high thermal gradients formed during early hydration may lead to cracking. Such thermal cracking can be avoided through feedback control, provided small strain changes of below 10 με can be measured (Habel and Hofmann 1994b). In the long run, loading environmental effects can also result in severe degradation. Highway bridges under heavy traffic and freezing/thawing are familiar examples. To properly maintain concrete structures in order to extend their service life, it is highly desirable to develop sensors that can monitor the structural condition throughout its life span. (Christopher K. Y. Leong et. al, 2000)

The sensing and measuring of various physical quantities such as displacement, strain, temperature, and pressure are an integral part of civil engineering. Prediction of failure and detection of defects are especially useful in structures such as dams, bridges, and nuclear waste containment vessels, and facilities where failure presents large safety and economical concerns. The cost of structural maintenance, repair, and upgrading would be reduced if appropriate sensors incorporated in structures provide an early warning of problems and data on the in situ performance of structures. The obtained in situ performance data could also help to reduce the cost of future construction of similar structures by increasing the degree of confidence and thereby reducing the degree of design conservation. Furthermore, the innovative application of fiber-reinforced polymers (FRP) in civil engineering structures necessitates long-term monitoring, not only to answer the safety concerns but also to generate valuable data for the research and development of FRP technology for more efficient and widespread use. (Burong Zhang et al, 2003)

Sensors have recently been embedded in various concrete structures such as buildings (Huston et al. 1992; Habel and Hofmann 1994a), dams (Holst and Habel 1992) and bridges (Maaskant et al. 1998) to monitor strain in the structure. The high resolution (below 1 με with interferometric techniques) makes them ideal for control applications. Since the sensor easily be embedded into concrete, they can be used for

the direct measurement of internal strain. Also, since a light signal rather than electric current is carried, sensors have very little loss and are immune to electromagnetic interference and lightning damages. For large structures in open areas (e.g., dams and bridges), or those carrying power lines (such as bridges with power lines underneath), sensors appear to be ideal. (Christopher K. Y. Leong et. al, 2000)

1.2 PROBLEM STATEMENT

All around us are living things that sense and react to their environment in sophisticated ways. Furthermore, they're so many cases of failure of the structure that has happened recently. Some of the symptoms of failure such as cracking, spalling, delamination, corrosion and even more worse when the structure failed. In Malaysia, the current issue about the failing of the structure is the MRR2 in Kepong, which is the crack occur along the beam. And the crack is identified as the life crack. As structures have become more complex and are being asked to perform ever more difficult missions, there has been increasing need to build intelligent into them so that they can sense and react to their environment. In order to build an intelligent or smart structure, sensors are provided in the structure.

The development of the vary sensor technologies make the choice of sensor in market higher. It sometime makes the engineer difficult to make the decision making in other to choose the best sensor that suitable for the structure. Sometimes wrong decision will make the thing even worse. So that this research is developed to identify the technology itself, technical requirement, and instrumentation and make the engineer or other bodies that involves can compare the differential between many types of sensor and make them can used it in correct condition.

1.3 OBJECTIVES AND SCOPES

There are a few objectives that have to be achieved at the end of this project. There are:

1. To study the development of strain/stress measurement sensor technology in structure.
2. To study the design, technical requirements and instrumentation of state-of-the-art sensors for structural monitoring.
3. To carry out comparative study of various sensor technologies applicable to structural monitoring.

1.4 SCOPES

This case study involves a review and analysis of case studies on sensor technologies used in mainly concrete structures, and in particular sensor based on fiber-optic materials. Fibre optics sensor are primarily used to sense displacement and temperature. Many techniques have been used including Bragg Grating, Intensity Sensors, Interferometric and optical time domain reflectometry (OTDR).

1.5 EXPECTED FINDINGS

At the end of this study, the author expected to know:

1. Information and data on various sensor technologies applicable to structural monitoring
2. Comparative study on different types of sensor and their relative merits.
3. Technical procedure for using sensors in monitoring of real structures.
4. General selection criteria for the applicable of sensors in structural monitoring.

1.6 RESEARCH METHODOLOGY

The general methodology for this study involves three main approaches:

i) Literature review for background study on the various sensor technologies applicable for structural monitoring
ii) Compilation and selection of case studies involving the use of sensor technologies in either real structure or experimental work
iii) Analysis of data from case studies to provide comparison between different sensors in various applications.
iv) Finite Element modelling for case study III for comparison purpose.

Finally, general guidelines are derived from the case study and recommendations are made for further work on the subject.

1.6.1 INTRODUCTION

This project mainly involves the study of information and findings from case studies due to limited time scale as well as the need for high technology equipment and expert's personnel. Besides, a sensor technology is construct to make the structure become intelligent which it can sense or detect any deterioration. This capability can help the engineer or any person in this area to take some action to investigate the best way to prevent it before it become worse.

General case study is preference when 'how' or 'why' questions are being posed. It also can be used when the investigators has little control over event and when the focus is on a temporary phenomenon within some real-life context or historical event (Yin, 1994).

According to Bell (1993), case study approach is particularly appropriate for individual researches because it gives an opportunity for one aspect of problem to be or a description of an event or state. As in all research, evidence is collected systematically, the relationship between variables is studied and the study is methodically planned.

The main advantage of the case study research is that it allows the researches to concentrate on a specific instance or situation and to identify or attempt to identify the various interactive processes at work (Bell, 1993).

Case study research covers a range of activities, literature review or the most common and important, which focus on the analysis of actual research findings from a number of different studies. Besides that, through observation and interviews are most frequently used in case study, no method is excluded. Method of collecting research information that is selected most is appropriate for the task.

1.6.2 LITERATURE SEARCHING

According to Moore (2000), no research project exists in isolation. Each piece of work relates in some way to the environmental within which the research take place, to the theories and concepts that has been developed to explain the environmental conditions. Therefore the researches must take full account of what has gone before and what is going on around. They must fully of all the relevant literature on the subject. It is essential that the researches aware the main issues and policies and able to cited the principal theories that other have developed.

A literature searching interpret and synthesis what has been researched and published in the area of interest. Literature searching or literature review involves reading what other people written about the area that a researcher interested, gathering suitable information to support or refute the arguments stated and writing out his findings. All research take into account previous work in the same area in order to prevent repeating other's mistake, duplicating a study already done. The goal of research is contributing to the knowledge of the field that may never be realized.

The literature itself consists of two types: data base research studies and non-data based writing. Data based research refers to studies that involve the collection and analysis of data gathered from people, organizations, documents and so on. Meanwhile, the non-data based writings reflect the writer's experiences or opinions and can be range from highly theoretical to popular testimonial (Meriam, 1988). In the field of engineering, there are a lot of data based researches but limited non-data based writings.

Indeed one function of literature searching is to provide the foundation of contributing to the knowledge base. This foundation can help in the formulation of the problem, in the selection of methodology and interpretation of research results.

Besides providing a foundation for the problem to be investigated, the literature searching can demonstrate how the present study ‘advances refines or revises what is already known’ (Meriam, 1988).

When planning the literature search, it is often helpful to think about of the types of material that can be used, such as books, journals, articles, thesis, seminar notes or conference papers, policy and etc to gather the theoretical aspects of the area study to avoid collected the useless material, it is essential to defined the boundaries of the research and identify the most suitable database to search for. Besides, the research information also can be collected through searching from indexes and abstracts of the journal, articles or look in the catalogue of a large or specialist library.

In this project, the main sources of the literature review are from books, journals, articles and some Internet searching. Since the subject of this project is about sensor technology in monitoring civil engineering structural and is quite new in Malaysia, they are limited published documents from the local authorities. Therefore, all the articles referred in this project are from overseas, mainly from Journal of Material in Civil Engineering, Journal of Engineering Mechanics and etc published by American Society of Civil Engineering (ASCE) in United State. Besides, for the basic theory for sensor technology is mainly refers from book.

While researching the research information, keywords are the important tool for searching and must be defined carefully in order to get the research information accurately. In order to search the information for this project, several keywords such as sensor, fiber optic, strain gauge and etc have been defined. These keywords are used in finding the related articles from ASCE and other database.

On the other hand, once the related documents or research reports have been identified, the bibliographies also can help to identify those other relates documents.

From the bibliographies stated, the important articles, books, journal papers and etc can help to improve the information about sensor technology in structure monitoring. The entire document referred must be recorded systematically for further reference.

When all the important documents have been collected, the case study research is carried on through reading and highlighting the important aspect in the technology of sensor technology in structure monitoring, types of fiber optic or non-fiber optic and the work of each sensor. Then the information obtained will be classified and analysed. The findings of literature searching hopefully will give a clear picture about the objective of this project.

1.6.3 DATA ANALYSIS

Unlike the experimental or surveying research, case study research does not claim any particular methods for data collection or data analysis. Therefore the data analysis for case study much depends on the researcher's own style thinking, along with the sufficient presentation of information and careful consideration of alternative interpretations (Yin, 1994). However the results from the analysis must be clear and reasonable.

Moore (2000) has suggested some principles that are common to analysis of all case study research. The principles are as follow:

1. The authorities and reliability of the information searched. When dealing with published material, one must know the authority that the published bring to the party and the steps that they have taken to ensure the research is worth published.

2. The researcher must be clear about the information that he is looking for. The relevant research information can be extracted from all the collected documents according to the research's aim and objectives.

3. The extracted information must be organized systematically into different categories in order to make the analysis easy and better. When using the material collected through literature search, all books, copies of journal must keep in easily accessible.

4. Document all the published sources and keep notes on each books, articles or report for further references.

5. Comparison is the key to data analysis in the case study research. The researchers must look for the similarities and the differences between the information collected.

6. When analysis is carried on, the collected information is break down into its component parts. Then, synthesis the results, bringing things together and noting where are significant differences. The eventual aims to produce something that can increase the public understanding on the issue investigate.

The process of data collection and data analysis is an ongoing process that can extend indetifinitely. There always more documents to be reviewed. This does not mean that the analysis is finished when all the data have been collected. Conversely, analysis became more intensive once all the data in, even though analysis has been an ongoing activity. The researcher should stop investigate or analyse the data when depleting of time and money allocated to the project or running out of mental energy (Meriam, 1988).

Data analysis consists of examining, categorising, tabulating or otherwise recombining the information to address the initial proposition of a study. Analysing case study information is difficult because the strategies and techniques have not been well developed in the past (Yin, 1994).

Analysing data collected in case study research is tedious and time-consuming work. Due to the constraints of time, not all the information collected us analysed. Only those information that are relevant and related to the fiber optic and sensor technology in monitoring structure will be analysed. The selection of information is started with reading through all the abstracts or the summary of the documents. After that, all the selected documents are read through some important information is noted carefully. Then the noted information is categorised into different titles or subtitles for report writing.

For further understanding in this topic, a few case studies have been selected. The case study is selected based on some criteria. The criteria are such as easy to understand, and it can show the usage of the different types of fiber optic sensor in the structure.

Discussion is made to compare the results obtain in the case study with the information stated in the literature review. All the similarities and differences are pointed out and discussed. Then the reasons are given to explain the differences discussed. Finally, the discussion is about the application of sensor in Malaysia.

1.6.4 SUMMARY

All the procedures of project's title definition, data collection, data analysis, discussion, conclusion and recommendation as stated before this are summarised in a flow chart below (Figure 5.1)

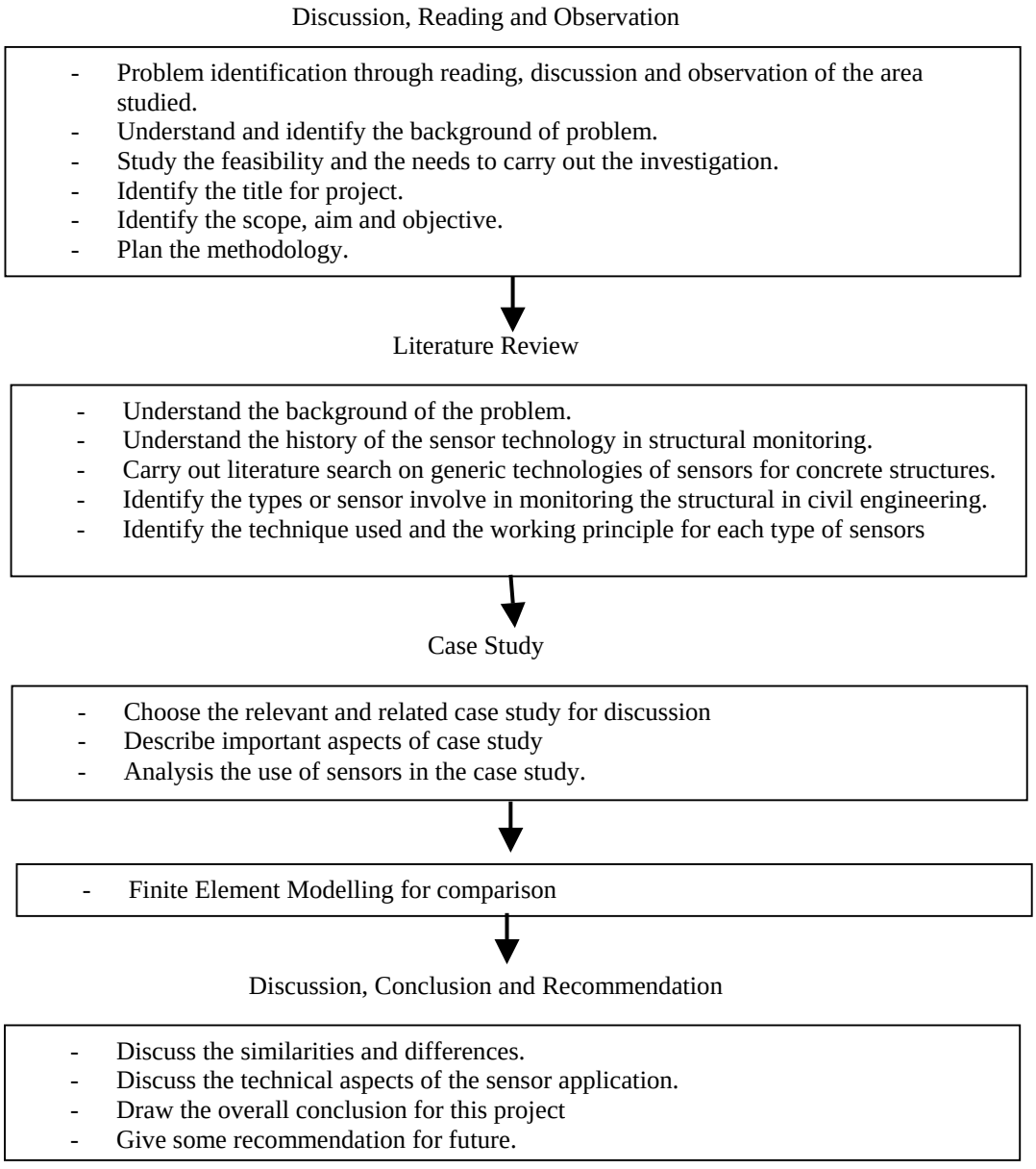

Figure 5.1: Summary of Project Procedure

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