UNIVERSITI PUTRA MALAYSIA

OPTICAL FIBER VIBRATION SENSOR NETWORK BASED ON MULTI – SERVICE OPTICAL CODE- DIVISION MULTIPLE- ACCESS SYSTEM

DANJUMA KUJE

OPTICAL FIBER VIBRATION SENSOR NETWORK BASED ON MULTI – SERVICE OPTICAL CODE- DIVISION MULTIPLE- ACCESS SYSTEM

By

DANJUMA KUJE

Thesis Submitted to the School of Graduate Studies,Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

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DANJUMA KUJE

March 2016

Chairman : Ratna Kalos Zakiah Binti Sahbudin, PhD
Faculty : Engineering

Optical fiber sensors are used in the measurements of a number of different physical properties. Some areas of application of sensors include harsh and electromagnetic interference prone environments where electronics cannot survive and in distributed detection. Recent advancement in fiber optics technology has brought about the need for distributed vibration monitory in structures and equipment. This is essential in order to predict the unusual behaviors and forestall unforeseen corrective maintenance that may require total overhaul of such structures and equipment.

Different multiplexing techniques have been used in distributed sensing which include Time Division Multiplexing (TDM), Wavelength Division Multiplexing (WDM) and Optical Code Division Multiplexing (OCDM). Some either suffered from low scanning speed such as in TDM or high cost of the multi-wavelength light source in WDM. OCDM is limited by Multiple Access Interference (MAI) which makes it difficult to differentiate the correct signal from the noise. Intensity modulated fiber vibration sensor multiplexing using Multi-Service (MS) code in Spectral Amplitude Coding- Optical Code Division Multiple Access (SAC-OCDMA) with Spectral Direct Decoding (SDD) was investigated in this work in order to reduce MAI impact with low cross correlation. The proposed work was implemented using a simulation tool to compare MS code with Khazani-Syed (KS) and Modified Quadratic Congruence (MQC) codes while laboratory experimental design was used to implement and compare the system with using MS and KS codes based on the level of power received. Due to cost of components and availability constrains, the MQC code was not implemented in the experiment. Results show frequency response being received at slightly higher peak power in vibration sensor multiplexing using MS code with power levels of 3.61dB and 10.43dB above noise level in back to back and over 25km fiber systems with average percentage improvement of 6.59% and 24.16%, 7.85% and 11.71% compared to 2.45dB and 4.81dB respectively obtained using KS code. The range of 0Hz - 212.1Hz frequency obtained from both system using MS and KS codes show the possibility of remote vibration monitoring in structures that exhibit low frequency such as bridges, transformers and pipelines.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk Ijazah Master Sains

RANGKAIAN PENDERIA GETARAN GENTIAN OPTIK BERASASKAN PELBAGAI – PERKHIDMATAN AKSES PELBAGAI PEMBAHAGIAN KOD OPTIK SISTEM

Oleh

DANJUMA KUJE

Mac 2016

Pengerusi : Ratna Kalos Zakiah Binti Sahbudin, PhD
Fakulti : Kejuruteraan

Penderia gentian optik digunakan dalam pengukuran beberapa ciri fizikal yang berbeza. Beberapa kawasan aplikasi penderia termasuk dalam persekitaran yang terdedah kepade gangguan elektromagnet di mana elektronik tidak dapat bertahan dan dalam pengesanan teragih. Kemajuan terkini dalam teknologi gentian optik telah membawa kepada keperluan pemantauan getaran teragih dalam struktur dan peralatan. Ini adalah penting untuk meramalkan tingkah laku yang luar biasa dan mencegah penyelenggaraan pembetulan yang tidak diduga yang mungkin memerlukan baik pulih keseluruhan struktur dan peralatan tersebut.

Teknik pemultipleksan yang berbeza telah digunakan dalam penderiaan teragih termasuk pemultipleksan pembahagian masa (TDM), pemultipleksan pembahagian panjang gelombang (WDM) dan pemultipleksan pembahagian kod optik (OCDM). Terdapat teknik yang sama ada mengalami kelajuan pengimbasan rendah seperti dalam TDM atau kos sumber cahaya yang tinggi pelbagai panjang gelombang dalam WDM. OCDM adalah terhad kepada gangguan akses pelbagai (MAI) yang menjadikan ia sukar untuk dibezakan isyarat yang betul dari hingar. Keamatan termodulat pemultipleksan penderia getaran gentian menggunakan kod pelbagai perkhidmatan (MS) dalam spektrum amplitud pengekodan akses pelbagai pembahagian kod optik (SAC-OCDMA) dengan penyahkodan terus spektrum (SDD) telah disiasat dalam kerja ini untuk mengurangkan kesan MAI dengan sekaitan silang yang rendah. Kerja yang dicadangkan dilaksanakan menggunakan alat simulasi untuk membandingkan kod MS dengan kod Khazani-Syed (KS) dan kesesuaian kuadratik terubah (MQC) manakala reka bentuk eksperimen di makmal telah dijalankan untuk melaksanakan dan membandingkan sistem menggunakan kod MS dan KS berdasarkan tahap kuasa yang diterima. Oleh kerana kos komponen dan kekangan ketersediaan, kod MQC yang tidak dilaksanakan dalam eksperimen. Keputusan menunjukkan sambutan frekuensi yang diterima di puncak kuasa lebih tinggi dalam pemultipleksan penderia getaran apabila menggunakan kod MS dengan tahap kuasa 3.61dB dan 10.43dB atas paras hingar dalam keadaan belakang ke belakang dan lebih 25km sistem gentian dengan purata peningkatan peratusan sebanyak 6.59% dan 24.16%, 7.85% dan 11.71% berbanding dengan 2.45dB dan 4.81dB masing-masing diperolehi dengan menggunakan kod KS. Julat frekuensi 0Hz – 212.1Hz yang diperolehi daripada kedua-dua sistem menggunakan kod MS dan KS menunjukkan kemungkinan

pemantauan getaran jauh dalam struktur yang mempamerkan frekuensi rendah seperti jambatan, transformer dan saluran paip.

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Finally, I would like to express my deepest gratitude to my late parents who did their best in shaping me to be somebody today. May their souls continue to rest in the bosom of the Lord.

I certify that a Thesis Examination Committee has met on 24 March 2016 to conduct the final examination of Danjuma Kuje on his thesis entitled "Optical Fiber Vibration Sensor Network Based on Multi-Service Optical Code-Division Multiple-Access System" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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Shaiful Jahari bin Hashim, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Siti Barirah binti Ahmad Anas, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Zulfadzli Yusoff, PhD
Associate Professor
Multimedia University
Malaysia
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 25 May 2016

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Ratna Kalos Zakiah Binti Sahbudin, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Makhfudzah Binti Mokhtar, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohd Hanif Bin Yaacob, PhD
Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

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Signature: ______________________
Name of Member of Supervisory Committee: Makhfudzah Binti Mokhtar, PhD

Signature: ______________________
Name of Member of Supervisory Committee: Mohd Hanif Bin Yaacob, PhD

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LIST OF ABBREVIATIONS

ASE	Amplified Spontaneous Emission
CDM	Code Division Multiplexing
CSD	Complementary Subtraction Decoding
DWDM	Dense Wavelength Division Multiplexing
EMI	Electromagnetic Interference
FBG	Fiber Bragg Gratings
FFT	Fast Fourier Transform
FMCW	Frequency Modulated Carrier Waves
FPI	Fabry-Perot Interferometer
GS/S	Giga Samples Per Second
ITU	International Telecommunication Union
KS	Khazani-Syed
LPFBG	Long Period Fiber Bragg Gratings
MS	Multi-Service
MAI	Multiple Access Interference
MQC	Modified Quadratic Congruence
MFH	Modified Frequency Hopping
NA	Numerical Aperture
OCDMA	Optical Code Division Multiple Access
OSA	Optical Spectrum Analyzer
OFDR	Optical Frequency Domain Reflectometer
OTDR	Optical Time Domain Reflectometer
OOC	Optical Orthogonal Code
PIN	Pseudo-Noise
PIIN	Phase Induced Intensity Noise

PIN	Positive Intrinsic Negative
PRBS	Pseudo Random Bit Sequence
RF	Radio Frequency
RD	Random Diagonal
SAC	Spectral Amplitude Coding
SDD	Spectral Direct Decoding
SNR	Signal to Noise Ratio
SMF	Single Mode Fiber
SOA	Semiconductor Optical Amplifier
SDM	Space Division Multiplexing
TDM	Time Division Multiplexing
WDM	Wavelength Division Multiplexing
ZCC	Zero Cross-Correlation

CHAPTER ONE

INTRODUCTION

1.1 Introduction

This chapter presents the background, rationale and the impetus that leads to this research. It also includes objectives and scope of the study. The organization of the thesis is also presented in this chapter.

1.2 Background of the Study

Since the emergence and development of optical fiber some decades back, there has been an increasing interest in research on its various applications. This is due to the potentials and fascinating benefits offered by optical fiber over the conventional electrical media among which include data security and high data rate [1], high sensitivity, resistance to electromagnetic interference, corrosion and shock, durability, withstand high temperature and harsh environment due to glass composition of the fiber, chemically inactive, ease of multiplexing, low loss which permits remote sensing [2, 3] and several others. These are viewed in its applications in teleconferencing and various telecommunication system implementations. These ever growing applications of fiber optics have also been employed in various sensing systems.

Sensors produce electrical output regardless of the energy input. They monitor and record changes of physical phenomenon in an environment and convert it to electrical which could easily be explained and utilized by the onlooker. This helps in eliminating the need for physical presence by human in monitoring of such changes. Besides, the phenomena to be sensed might be quite insignificant and beyond human intuition or may be, some of the measurands might not be easily accessed by the human. Generally, sensor systems can be classified under either of these categories: electrical, mechanical, optical or chemical sensors. The highlighted benefits offered by fiber optics provide the advantages of fiber based optical sensors. This has helped in boosting their applications in numerous fields. One important application area of fiber sensor is in mitigation of frequent disaster related to the collapsing of building without any early warning system. This has led to loss of many lives and properties, hence better monitoring system which includes sensors are being used. The ease of multiplexing benefit of fiber based sensors provide access to the system bandwidth, make them suitable for distributed and remote sensing, reduction in the physical size of the sensor system and cost of the components. Fiber optic based sensing involves modulating the properties of the light beam by the phenomena that is being measured or changing the properties of the light by the quantity being measured. Light may change in its five optical properties which are intensity, phase, polarization, wavelength and spectral distribution as depicted in Figure 1.1. The modulation process employed in fiber based sensing may take place within the fiber itself, which acts as a sensing element (intrinsic sensing) [4]. Here, phase modulation techniques are often used. The modulation may also take place outside the fiber, in which the fiber acts only as a medium for transmitting the probing light or signal (extrinsic sensing). Intensity modulation is often used here. From the previous view points, fiber optic sensors have attracted a lot of attention due to their unique advantages and have displaced traditional sensors for temperature, strain, pressure, displacement, real time monitoring of the physical health of structures, acoustics, viscosity, rotation, electric and magnetic fields, humidity, linear and angular position, chemical, gas, velocity and vibration measurements.

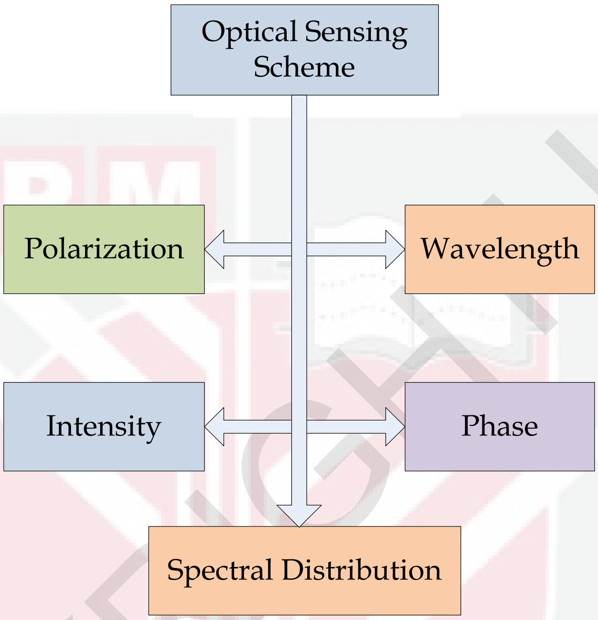

Figure 1.1. Categories of optical fiber sensor

Recent advancement in fiber optics technology has brought about vibration sensing which helped in providing the necessary and timely information about the physical health state of buildings, bridges, dams structures, pipelines, electromechanical equipment such as machines, transformers, and vehicles in order to prevent unforeseen collapse. Hitherto, traditional vibration sensors such as piezoelectric or accelerometer, magnetoelectric, eddy current sensors which convert their measurands directly into electrical signal have been used in vibration amplitude measurements [5]. These sensors are limited due to evident of defects - short transmission distance, weak output signal, and easily interfered by electromagnetism.

Fiber vibration sensors have since replaced the traditional types. They can be used both as single point or multipoint sensors for distributed or quasi-distributed sensing, depending on the magnitude of the measurand. Considerable number of the past works were only concentrated on the utilization of distributed sensors for temperature, pressure and static strain measurements with little on the dynamic strain or vibration detection which is suitable for quasi-distributed remote vibration sensing [6]. Quasi-distributed (multipoint) vibration sensing can be utilized in big structures that show low vibration like dams, bridges, tunnels, tall buildings, power generator, transformers and also can be applied in those ones that exhibit high frequency such as crack, deformation detection and abnormalities in engines.

1.3 Problem Statement

Several multiplexing techniques have been previously employed in order to effectively utilize the bandwidth opportunity in optical fiber such as WDM, TDM and CDM. The complex and high cost of multiple wavelength light source in WDM and the low scanning speed, low signal to noise ratio (SNR) limitations in TDM which make it less favorable for real time remote vibration sensing have been considered as impediments to the applications of these techniques. CDM notable for asynchronous access, transmission security, large bandwidth and low attenuation is limited by MAI or crosstalk from other users.

SAC-OCDMA has received a lot of attention mainly due to its ability to take out the impact of MAI at less cost and complexity [7]. Compare to other coding techniques like the Spectral Phase Coding OCDMA (SPC-OCDMA), SAC-OCDMA is less expensive due to incoherent broadband source used. Besides, for access environment where cost is one of the most effective factors, SAC-OCDMA seems better option [8]. Several SAC-OCDMA codes families have been developed such as Optical Orthogonal Code (OOC), Modified Frequency Hopping (MFH), Random Diagonal (RD) and others. Most of the proposed codes are either limited by high cross correlation, long code length or complicated code design. In [9], M-sequence code in Wavelength Division Multiplexing/Spectral Amplitude Coding (WDM/SAC) for vibration sensor systems was proposed. However, the technique is limited by high cross correlation in the code which may increase the level of crosstalk in the network. Besides, the technique uses complementary decoding which increase the cost and complexity as the sensor points increase. A more recent research work [2] proposed Khazani-Syed (KS) code SAC-OCDMA in fiber vibration sensor multiplexing to eliminate MAI. Based on the research, the system was able to reduce MAI impact at less cost and complexity. Though, KS is a code with cross correlation of one but it is only limited to even number of code weight which limits the flexibility in choosing the weight and number of users. The development of suitable SAC-OCDMA codes has seen many newly proposed codes. Multi-Service (MS) code is one of the latest which shows considerable improvements than the earlier ones in terms of received power and other advantages [10, 11] and it has not been employed in any vibration sensor system before. The code design is such that it supports more users with same weight and provides flexibility of choosing any number of basic user ($N_B = W$) and any weight with minimum code length. Moreover, the non-overlapping chips in the codeword of MS code are well positioned or spaced from the overlapping chips as compared to KS and MQC codes. Thus, the interference effect emanating from the overlapping chips which may cause interference at the receiver has less effect on the non-overlapping chips hence; the possibility for MS to perform slightly better in terms of power deliver to the receiver. Therefore, in this study, MS code SAC-OCDMA fiber vibration sensor multiplexing is proposed to manage MAI. It is hypothesized that the advantages of MS code can be taken opportunity of towards improving the transmission of signals in fiber vibration sensor networks.

1.4 Aim and Objectives

This research work is aimed at multiplexing light intensity modulation based fiber optic vibration sensors for distributed remote vibration sensing at reduced MAI deploying SAC-OCDMA system with Spectral Direct Decoding (SDD) technique.
The following are the objectives of the study:

- To implement a SAC-OCDMA based fiber vibration sensor multiplexing system for vibration detection utilizing SDD technique.
- To investigate the performance of Multi-Service (MS), Khazani-Syed (KS) and Modified Quadratic Congruence (MQC) codes in SAC-OCDMA vibration sensor multiplexing using simulation tools.
- To investigate through experimental demonstration, performance of MS and KS codes in back to back and over fiber systems using SDD detection technique based on power level, noise level and MAI cancellation.
- To investigate the linearity, sensitivity and stability of both system using MS and KS codes.

1.5 Scope of the Study

This research work is to be restricted to fiber optic vibration sensor multiplexing deploying SAC - OCDMA system with MS code. The practicability of the proposed system is to be initially checked in simulation to observe the fiber length that can be supported and the received signal power level. Fiber Bragg Gratings (FBG) together with optical circulator was used in the system to form both the encoder and decoder while SDD technique is used. The sensor head in the experimental implementation consists of two coupled optical collimators which work as the light intensity modulation based sensors. Performance assessment of the proposed system is based on different design and performance parameters such as input and received vibration signals, fiber length, power level, and noise level. The frequency response of the signal is monitored and obtained from the oscilloscope by getting the Fast Fourier Transform (FFT) of the time domain signals obtained. It is anticipated that the proposed system will have better interference cancellation, low noise level and hence be a better alternative for distributed vibration sensing as highlighted in Section 1.3. Figure 1.2 shows the elaborated scope of the study. The highlighted boxes are the main focus areas. The design parameters include number of users, code weight, code length, fiber length and applied vibration frequency while signal power level, supported fiber length, noise level, stability, sensitivity and linearity are performance parameters.

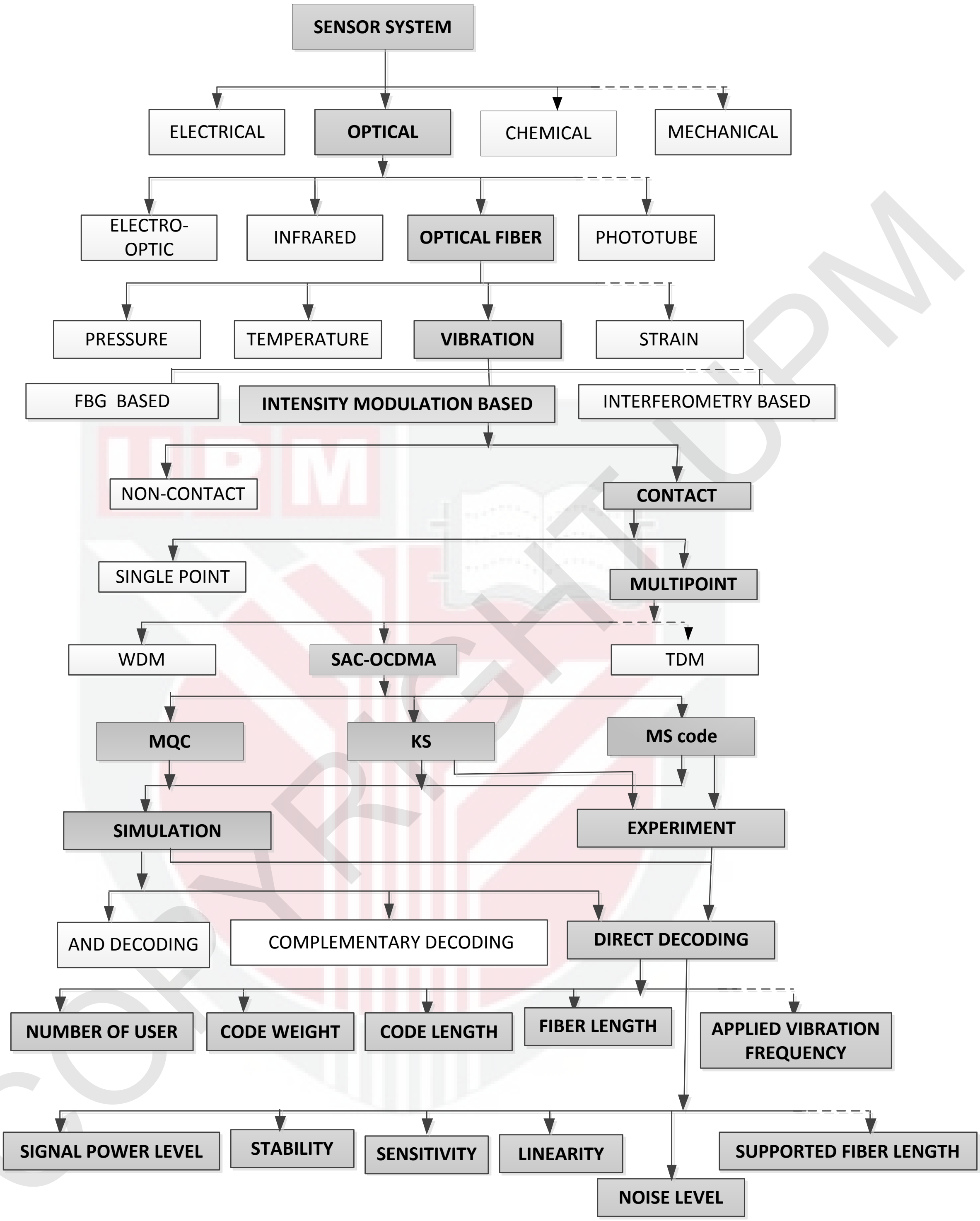

Figure 1.2. Chart showing scope of the study

1.6 Thesis Organization

This thesis is organized into five chapters.

Chapter one is the introductory chapter that expound the background of study, problem statement, objectives of study, as well as the scope of work.

Chapter two deals with the literature reviews that explain the reason behind the study including some of the challenges that require attention. This chapter presents reviews on optical fiber communication, optical fiber sensors, optical fiber vibration sensors, classification of vibration sensors as well as multiplexing and decoding techniques.

Chapter three is the methodology that includes the procedures and methods adopted both in simulation and experimentation of the work.

Chapter four presents the results from both simulation and the experiment as well as the discussion that mentions about the outcomes of the research work and its findings.

Chapter five presents the conclusion of the research work and also recommendations for future works.

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