OPTIMIZATION OF FIBER OPTIC FOR SENSING APPLICATIONS USING TAGUCHI APPROACH

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Supervisor Name	:	DR. HAZURA BINTI HAROON
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DEDICATION

This thesis is dedicated specially to my supervisor, DR. Hazura binti Haroon, for guiding me throughout my project and be with me in all ups and downs, my beloved family for moral support and finally my friends who have encouraged me and had a great teamwork in completing this research and thesis.

ABSTRACT

Taguchi approach is a method where statistical analysis is performed to improve the quality of manufactured goods. This method reduce time and cost and gives the optimized analysis same as thousands of experiments' results. In this project, a low cost sensor based on FBG sensor was designed and optimized by Taguchi method. The influence of design parameters variations was analysed and finally, the best setting of design parameters was obtained. This experiment was conducted under wavelength of 1550nm with the aim to studying the relationship of the design parameter to the wavelength shift and also the power received. The most optimized condition was identified and compared with the actual experiment. Confirmation test was performed to check the validity of the proposed optimized parameters and this result was implied using the Minitab Software. Upon completion, it was found to be the best parameter setting is 30°C, 60mm of bending and 1.3331 RI. The highest output power from confirmed experiment is 7.950 μW and wavelength shift of 1550.110nm. From this, the SNR is calculated which is 20.0189 while from the Taguchi, the expected SNR is 21.4346. Thus, the difference between the predicted value from Taguchi and from the actual experiment is 6.83%. Therefore, the Taguchi approach is proven as a great tool, giving great impact on economy, society and environment.

ABSTRAK

Pendekatan Taguchi adalah satu kaedah di mana analisis statistik dilakukan untuk meningkatkan kualiti barangan perkilangan. Kaedah ini mengurangkan masa dan kos dan memberikan analisis yang dioptimumkan dalam pelbagai hasil eksperimen. Dalam projek ini, sensor kos rendah berdasarkan sensor FBG direka dan dioptimumkan. Pengaruh variasi parameter reka bentuk dianalisis dan akhirnya, parameter reka bentuk terbaik diperolehi. Eksperimen ini dijalankan di bawah panjang gelombang 1550nm dengan matlamat untuk mengkaji hubungan antara parameter reka bentuk dengan peralihan panjang gelombang dan kuasa yang diterima. Ujian pengesahan telah dilakukan untuk memeriksa kesahihan parameter yang dioptimumkan yang dicadangkan dan hasil ini tersirat menggunakan Perisian Minitab. Selepas selesai, ia didapati sebagai parameter terbaik ialah 30 ℃, 60mm lenturan dan 1.3331 RI. Kuasa keluaran tertinggi daripada percubaan yang disahkan ialah 7.950 μW dan peralihan panjang gelombang 1550.110nm. Dari sini, SNR dikira iaitu 20.0189 manakala dari Taguchi, SNR yang dijangkakan ialah 21.4346. Oleh itu, perbezaan antara nilai ramalan dari Taguchi dan dari percubaan sebenar ialah 6.83%. Oleh itu, pendekatan Taguchi terbukti sebagai alat yang hebat dan memberi impak besar kepada ekonomi, masyarakat dan alam sekitar.

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LIST OF SYMBOLS AND ABBREVIATIONS

FBG	:	Fiber Bragg Grating
POF	:	Plastic Optical Fiber
EMI	:	Electromagnetic Interference
SRI	:	Surrounding Medium Refractive Index
UV	:	Ultraviolet
LED	:	Light Emitting Diode
LS	:	Light Source
BL	:	Bit-rate Length
PMMA	:	Polymethyl Methacrylate
NA	:	Numerical Aperture
LAN	:	Local Area Network
DOE	:	Design of Experiment
TMB	:	Tsing Ma Bridge
NASA	:	National Aeronautics and Space Administration
SNR	:	Signal to Noise Ratio
S/N	:	Signal to Noise
OSA	:	Optical Spectrum Analyzer
OS	:	Orthogonal Array
L	:	Level

OPM	:	Optical Power Meter
RI	:	Refractive Index
ANOVA	:	Analysis of Variance
dB	:	Decibels
μW	:	microWatt
%	:	Percentage
°C	:	Degree Celcius
λ	:	Wavelength Shift
B	:	Brix Scale
DUT	:	Device Under Test
SDM	:	Space-division Multiplexing
WDM	:	Wavelength-division Multiplexing

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

This chapter explains about the introduction of the project background, problem statement and objectives. In this chapter also, scope of work, significance and project outline have been explained briefly.

1.1 Introduction

The practice of trial-and-error approach is no longer sufficient in this volatile competitive international market to meet the challenges of globalization, especially when the disadvantages outweigh its benefits. Therefore, in optimizing the processing parameters which is the Taguchi Method, a systematic methodology is proposed to explore the connection between parameters and identify the optimal process conditions. Taguchi technique has been very successful in integrating powerful

applied statistical methods into engineering process for accomplishing greater capability and stability.

Taguchi technique is often referred to as the technique of Robust Design and is named after Dr. Genichi Taguchi. Genichi Taguchi, born in January 1924, was also an excellent engineer and statistician. Dr. Genichi believes the price is more vital than quality, but perhaps the value of quality will lower the cost automatically. The Taguchi method focuses primarily on increasing the productivity of engineering to develop new goods at lower rates, however. Indeed, it is the most powerful method available to minimize the cost of the product, improve quality and continuously increase the interval of development.

The Robust Design method helps to ensure customer satisfaction by consciously considering the noise factors which is the environmental variation throughout the use of the item, production variation, and component deterioration in the field. Robust Design concentrates on increasing the basic operation of the brand or process, thus facilitating flexible designs and concurrent engineering. Besides, the employment of fiber optics for such applications provides the same advantages as in communication, reduced cost, smaller size, better precision, greater flexibility and greater efficiency. Compared to conventional electrical sensors, fiber optic sensors are immune to external electromagnetic interference and can be used in potentially harmful and explosive environments.

The optic fiber can therefore be used as a parameter sensor but extends to certain limits as it can cause power loss as the value varies in the parameter selected. This is why optic fiber has been researched so that it can be optimized to identify which parameter chosen. During this project, Taguchi approach will be applied for

optimization of optical fiber based on few parameters. By achieving this, time and price were saved by reducing the number of experiment to few solely and the statistical data measured is same as efficient as hundreds of experiments research. Not only that, the optic fiber response will be measured under a few parameters to identify the most optimized condition for fiber optics to work the best.

1.2 Problem Statement

In the development of high potency fiber optic sensor system, the response of such sensors are subject to uncertainties due to variability in several hard-to-control noise factors, that embrace design parameters, material properties, and construction procedures. Efforts are emphasized by design engineers to optimize the design of the sensor itself since alternative uncertainties are internal uncontrollable factors in real condition. However, every design parameters have distinct contributions to the overall device performance. Therefore, the design trade-offs analysis and optimization is crucial in any device design process so as to satisfy design target. Conventional design optimization including trial-and-error and one-factor at a time approach do not seem to be solely long time-consuming, but contributes to higher development cost as many experiments must be conducted and plenty resources wasted. In this project, a structured experimental design by Taguchi were proposed for fiber optic sensor response optimization. The device parameters of interest are the temperature, the refractive index of the test samples and number of turns bending. All of these three design parameters will be optimized and therefore the best parameters setup for sensing applications will be disclosed.

1.3 Objectives

The objectives of this project are:

i. To design a low-cost intensity-based liquid concentration sensor based on Fiber Bragg Grating (FBG).

ii. To analyze the influence of design parameters variations on fiber optic sensor response.

iii. To optimize the fiber optic sensor design towards the Signal-to-Noise ratio of the sensor using Taguchi Approach.

1.4 Scope of Study

In this project, a method has been developed and implemented to conduct design of experiment using Taguchi technique for the analysis of optimization of optical fiber characteristics for sensing applications. The analysis was carried out using basic concept of Taguchi method, by analyzing the output data to find out the influence of each parameter which is temperature, fiber bending, and refractive index. Experiments and testing will be carried out using Fiber Bragg Grating (FBG). The temperature range that will be used is between 30°C to 100°C with an increment of 5°C per reading. For size of bending, bending diameter from 1mm to 60mm will be tested whereas for refractive index, 10 type of solutions will be selected within range of 1.33 and 1.54.

The response of the fiber will be investigated in terms of output power and wavelength shift. The collected data will be analyzed and need to find out inference for the upcoming results. The relationship between parameter and power loss and wavelength shift is recorded and plotted in graph form. Minitab software version 14 will be utilized to conduct the statistical analysis of the Taguchi method, where the response target for power loss is lower the better and for the sensitivity of the fiber,

higher the better. The experimental measurement will be carried at 1550 nm wavelength at 1 KHz frequency with several other condition according to parameter using FBG fiber. The percentage difference between the predicted value from Taguchi and the actual experimental value is finally calculated to verify the analysis.

1.5 Significance

Experiment design (DOE) under Taguchi Technique is truly an influential observational tool widely employed by engineers and researchers in all areas of study to predict the effects of input variables on output variables. It is the method of organizing experiments for obtaining information through the least series of experiments. That is why Taguchi Methodology seems more efficient than traditional method. How data collected is analyzed is the distinction between DOE using traditional and Taguchi methods. Average and variation of data are used in Taguchi technique whereas the average values of the response data are used in the traditional analysis. Therefore, Taguchi methodology was expected to deliver higher results as it guarantees the highest standards with minimal variance. The Taguchi method is simpler to enforce and does not require special statistical knowledge. Taguchi technique has been effectively used in many research and projects for quantitative analysis of various factors.

1.6 Project Outline

This report consists of five chapters. In Chapter 1, discussed about the introduction of the project with the objectives, problem statement, scope, significance and outline of the project. Chapter 2 discusses on theoretical, background and research knowledge in optimizing optical fiber and usage of Taguchi method. Meanwhile, Chapter 3