Faculty of Electronics and Computer Technology and Engineering

DEVELOPMENT OF MICROFIBER SENSOR IN DETECTING GLUCOSE CONDITION USING A BOX BEHNKEN DESIGN (BBD) APPROACH AND DESIGN EXPERT

SITI MAISARAH BT ZUALKELFI

Bachelor of Electronics Engineering Technology (Telecommunications) with Honours

2024

Development Of Microfiber Sensor In Detecting Glucose Condition Using A Box Behnken Design (BBD) Approach And Design Expert

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A project report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Electronics Engineering Technology with Honours

Faculty of Electronics and Computer Technology and Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI TEKNOLOGI DAN KEJUTERAAN ELEKTRONIK DAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : Development Of Microfiber Sensor In Detecting Glucose Condition Using A Box Behnken Design (BBD) Approach And Design Expert

Sesi Pengajian: Sesi 2023/2024

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DEDICATION

This project is dedicated to my mother, Noorain ,and father,Zualkefli and family members, whose unwavering support and encouragement have been my anchor throughout this journey. Your belief in me has fueled my determination, and this accomplishment is a testament to the strength derived from your love. Thank you for being my constant source of inspiration.

ABSTRACT

This study developed a microfiber sensor for detecting glucose levels. In recent years, microfiber sensors for detecting and analyzing glucose have become increasingly popular. Microfiber optical sensors have been shown great potential in this field, and wearable optical microfiber sensors for glucose monitoring have recently gained interest. These sensors offer advantages such as high sensitivity, small size, flexibility, and non-invasiveness, making them suitable for wearable applications.Various input parameters were considered when optimizing the sensor performance to enhance sensitivity, including wavelength, microfiber diameter, glucose concentration, and microfiber types. These optimization approaches were obtained using the Design of Experiments, with the expectation of improving the development of optical microfiber sensors for glucose detection. The application of Design Expert Software and the Box-Behnken Design optimization approach played a crucial role in systematically planning and analyzing trials, resulting in a deeper understanding of the correlations between variables and responses.The findings presented the solution of the best parameter to detect the glucose condition and it is the optimal solution for the given criteria.

ABSTRAK

Kajian ini telah membangunkan sensor mikrofiber untuk mengesan tahap glukosa. Pada tahun-tahun terkini, sensor mikrofiber untuk mengesan dan menganalisis glukosa telah menjadi semakin popular. Sensor optik mikrofiber telah menunjukkan potensi besar dalam bidang ini, dan sensor optik mikrofiber yang boleh dipakai untuk pemantauan glukosa baru-baru ini telah menarik minat. Sensor ini menawarkan kelebihan seperti sensitiviti yang tinggi, saiz yang kecil, fleksibiliti, dan keadaan yang tidak invasif, menjadikannya sesuai untuk aplikasi yang boleh dipakai. Pelbagai parameter input telah dipertimbangkan semasa mengoptimumkan prestasi sensor untuk meningkatkan sensitiviti, termasuk panjang gelombang, diameter mikrofiber, kepekatan glukosa, dan jenis mikrofiber. Pendekatan pengoptimuman ini diperoleh menggunakan Reka Bentuk Eksperimen, dengan harapan meningkatkan pembangunan sensor optik mikrofiber untuk pengesanan glukosa. Aplikasi Perisian Design Expert dan pendekatan pengoptimuman Reka Bentuk Box-Behnken memainkan peranan penting dalam merancang dan menganalisis ujian secara sistematik, yang menghasilkan pemahaman yang lebih mendalam tentang korelasi antara pembolehubah dan respons. Penemuan menyajikan penyelesaian parameter terbaik untuk mengesan keadaan glukosa dan ia adalah penyelesaian optimal untuk kriteria yang diberikan.

ACKNOWLEDGEMENTS

First and foremost, I wish to extend my sincere gratitude to my supervisor, Puan Rahaini Binti Mohd Said , for her invaluable guidance, words of wisdom, and patience throughout the entirety of this project. Her mentorship has been instrumental in shaping the course of my research journey.

I am profoundly indebted to Universiti Teknikal Malaysia Melaka (UTeM) for the generous financial support provided through lab equipment for the experiment process. This support played a pivotal role in enabling the successful completion of the project. I also express my gratitude to my fellow colleague, Nur Izzaty Balqhis,Najihah and Nurafiqah , for willingly sharing his thoughts and ideas, contributing to the depth and richness of the project.

My highest appreciation is reserved for my parents and family members for their unwavering love and prayers during the course of my study. Their support has been a source of strength and motivation.

Finally, I extend my gratitude to all the staff at the University Teknikal Malaysia Melaka, fellow colleagues, and classmates, as well as the Faculty members. Additionally, I appreciate the cooperation and assistance received from other individuals not explicitly mentioned here. The collaborative and helpful spirit demonstrated by everyone involved has contributed significantly to the successful realization of this project.

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LIST OF ABBREVIATIONS

DoE	-	Design of Experiment
MSR	-	Micro-sphere Resonator
MFOS	-	microfiber optic sensors
SMF	-	single-mode fiber
GOD	-	oxidation of glucose
MLR	-	microfibre loop resonator
FPG	-	fasting blood plasma glucose
RSM	-	response surface methodology
IPA	-	isopropyl alcohol
BBD	-	Box-Behnken Design

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CHAPTER 1

INTRODUCTION

1.1 Background

Glucose is a sugar that provides energy for living organisms and is found in many foods. Sugar can be found in many aspects of life (Marzuki et al., 2018). It plays a key role in processes like metabolism and glycogen synthesis. Glucose is water-soluble, tastes sweet, and has different forms. The concentration of glucose in the blood can cause diabetes, which is common worldwide, and is the leading cause of metabolic disorders due to its high glucose concentration (Colmegna et al., 2016). According to the International Diabetes Federation (IDF), the World Health Organization (WHO) , 422 million people worldwide suffer from diabetes, and this number is expected to reach 642 million by 2030. It is important to monitor glucose concentration for several medical reasons, especially to monitor blood sugar levels in diabetic (Shendurse et al., 2016).One of the monitoring tools for glucose condition is a microfiber optic sensor.

The fiber optical sensing sector has been one of the most successful uses of fiber optics and sensing. A current trend in fiber optics sensors is the rapid advancement of micro/nanotechnology and the demand for optical sensors with increasing performance and versatility. Therefore, to improve the sensor's performance and spatial resolution, reducing the size of the sensing structure is usually an essential step. A microfiber optical sensor is one of the most potential sensor for this purpose due to its high sensitivity and low power consumption. Because of its unique optical and sensing characteristic, microfiber sensors have garnered a lot of interest in recent years. The unique properties of microfibers, such as their strong optical confinement, flexibility, large evanescent field, and configurability, maket them ideal for applications such as ultrasensitive surface absorption spectroscopy (Warken et al., 2007) , humidity (Irawati et al., 2017) , hydrogen detection(Kien et al., 1999), temperature(Aisyah M. Aris, 2017), rotation and the most rampant refractive index sensor(Tang et al., 2017). Normally, the sensing performance is determined by the loss of light energy or the change in the phase of the light (Ong et al., 2015) . Besides that, the unique features of microfiber have also attracted considerable attention from optical sensings, such as its configurability, compact size, strong evanescent fields, large abnormal waveguide dispersion, strong near-field interaction with its surroundings, and good evanescent coupling between it and other waveguides (Wu & Tong, 2013). There are two types of fiber optic which are single mode, and multi-mode. Microfiber is made by stretching optical fibers until they reach the desired waist diameter while maintaining their input and output dimensions.Optical fibers of standard sizes can be interconnected easily with this method, resulting in low-loss splicing. As well, the device could be bent into a small radius to make it more compact (Brambilla, 2010).

Recently, there has been a lot of research and development n in terms of microfiber sensors for detecting glucose levels and monitoring diabetics (Rghioui et al., 2020). One of the most significant application of microfiber sensors in the biomedical industry is glucose level detection. In the pharmaceutical industry, monitoring glucose levels in real time is vital to patient care because it is crucial for the accuracy and timeliness of treatment. This study aims to improve the accuracy of glucose measurement by developing a highly sensitive and selective glucose sensor. Existing methods for glucose detection, such as enzymatic assays and electrochemical sensors, have limitations in terms of their sensitivity, selectivity, and stability(Amor-Gutiérrez et al., 2022; Durakovic, 2017).

Moreover, in the development of a microfiber sensor to detect glucose, a key challenge is optimizing its performance parameters, including sensitivity, selectivity, and response time., The design of the experiment is one of the methods used employing statistical design of experiments i to systematically vary experimental parameters to determine the optimal conditions for maximizing sensor performance.The Design of Experiments (DOE) is a mathematical methodology that can be used to plan and carry out experiments, analyze the data obtained from these experiments, and interpret the results of these experiments (Durakovic, 2017). Additionally,adjusting the thickness and refractive index of the sensor layers can further optimize performance. By developing microfiber sensors for glucose detection using optimization approaches, the pharmaceutical industry can provide a highly accurate and reliable tool for monitoring glucose levels in diabetics.

1.2 Addressing global issue through microfiber sensing in detecting glucose project

The microfiber sensing project, specifically targeting glucose detection, introduces a unique context with implications for healthcare and potential contributions to global challenges. Developing efficient and accurate microfiber-based sensors for glucose monitoring can significantly improve healthcare outcomes, especially in the managing diabetes and other metabolic disorders on a global scale. The project's primary focus is on Providing accessible and affordable glucose monitoring technologies, aiming to promote sustainable practices in healthcare while addressing the pressing need for glucose monitoring devices.

Additionally, microfiber-based glucose sensors can drive technological advancements beyond healthcare. Innovative sensor designs developed in this project may have broader implications, including potential applications in environmental monitoring. New opportunities may arise from cross-disciplinary collaborations, involving experts in environmental science, materials science, and engineering. The integration of microfiber sensor technology into monitoring systems for example, could contribute to global efforts addressing environmental challenges by facilitating the detection of specific chemical pollutants and contaminants.

1.3 Problem Statement

Microfiber optic sensor parameters are being modeled and optimized for detecting glucose conditions in the pharmaceutical industry, particularly in application related to diabetes. Glucose plays a critical role in diabetes management, and its accurate measurement is vital for monitoring and controlling blood glucose levels in individuals with diabetes. Existing glucose detection methods often lack accuracy and reliability, leading to inconsistent readings and compromised glucose management (Michael et.al, 2016). This poses a significant challenge in effectively monitoring glucose levels and making informed treatment decisions for individuals with glucose-related conditions. Therefore, the development of efficient glucose sensing technologies, such as microfiber optic sensors (MFOS), holds great potential for diabetes management.

Microfiber sensors can address the challenge of accuracy and reliability in glucose detection, providing precise and dependable measurements for improved glucose management. By optimizing parameters such as fiber diameter and length, core and cladding refractive index, and the sensing material, MFOS can be tailored to provide accurate and reliable measurements of glucose levels. Various method can be employed to optimize the parameters of a microfiber sensor, one of which is the Design of Experiments (DOE),. This method involves systematically varying the parameters while measuring the corresponding responses. By analyzing the results, the optimal combination of parameters that yields the best sensor performance can be identified.

These sensors can be integrated into wearable devices or other monitoring systems, enabling continuous and real-time glucose monitoring for individuals with diabetes. The goal of developing microfiber optic sensors for glucose detection in diabetes-related applications is to improve the quality of glucose monitoring, enhance patient convenience, and empower individuals with diabetes to manage their condition effectively.

1.4 Project Objective

The primary project of this project to develop microfiber sensor to detecting glucose condition using optimization approach. Specifically, the objectives are as follows:

a) To identify the significant effect of microfiber sensor parameter

b) To develop a mathematical regression model for the microfiber sensor to measure glucose conditions using Box Behnken Design (BBD)

c) To design a sensor detector capable of detecting glucose by optimizing the parameters of the microfiber sensor.

1.5 Scope of Project

The scope of this project is as follows:

a) Identify parameters to optimize the microfiber sensor for accurate and reliable glucose monitoring, including fiber type, diameter, wavelength, and glucose concentration.

b) Utilize both single-mode fiber and multi-mode fiber in the experiment..

c) develop and test a prototype of the microfiber sensor using a design of experiment software.

d) Consider Four aspects of microfiber need to be considered: wavelength, diameter, fiber type, and glucose concentration.

e) Implement the sensor to detect the glucose level using two types of glucose concentration. Once the glucose level is detected, the output will switch to power.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter briefly discusses and gives an overview of several topics about reviews on existing systems and literature studies that are related to this project. This literature review will examine previous systems created for similar purposes and analyze their strengths and weaknesses. In conclusion, this chapter provides a strong basis and provides important information that will be helpful to this project.

2.2 Understanding [Global/Current Issue] in the Literature

Through a review of the literature on the development of microfiber sensor for detecting glucose conditions, this section will explore the ways in which these technologies can contribute to our understanding of glucose levels and inform strategies for managing diabetes. Research has demonstrated that microfiber-based sensors offer the potential for accurate and real-time glucose monitoring, enabling individuals to monitor their glucose levels more effectively. Studies have focused on microfiber-based glucose sensing, including sensor design and fabrication methods. Researchers have explored various materials and sensing modalities to improve the sensitivity, selectivity, and reliability of microfiber sensors. Literature reviews provide information on microfiber-based glucose detection advancements and challenges.

By integrating microfiber-based glucose sensing with data analysis techniques and digital health platforms, healthcare providers and patients can access valuable insights into glucose conditions. Further, microfiber-based glucose detection may enable continuous monitoring and better patient outcomes through wearable devices and implants. A literature review of microfiber-based glucose detection systems provides valuable insights into the advancements and challenges in this field. Monitoring glucose and managing diabetes could be revolutionized by these technologies.

2.3 Fiber Optic Sensor

A fiber optic sensor is a device that measures physical quantities or parameters using optical fibers as the sensing element. Optical fiber sensors, also referred to as fiber optic sensors, are used in a variety of industries, including the medical, pharmaceutical, bioprocessing, defense, food industries, and environmental, for sensing via optical fiber or sensing element (Kumar et al., 2018). Fiber sensors can be designed using one or several optical parameters of guided light, such as phase, intensity, wavelength, and polarization. (Pendão & Silva, 2022). The basic structure of a fiber optic sensor consists of an optical fiber, a light source, and a detector. The optical fiber acts as a conduit for transmitting light between the source and the detector. The sensing element of the fiber optic sensor is designed to interact with the external environment or the parameter being measured. This interaction causes changes in the transmitted light, which are then detected and analyzed to determine the desired parameter. Fiber optic sensors can be based on different sensing principles, including intensity modulation, phase modulation, wavelength modulation, and polarization modulation. These principles allow the measurement of various physical quantities such as temperature, strain, vibration, humidity, pressure, chemical concentrations, and more. One of the key advantages of fiber optic sensors is their immunity to electromagnetic interference. Unlike traditional electronic sensors, fiber optic sensors do not use electrical signals for measurement, making them highly resistant to electromagnetic fields.

Additionally, optical fibers can be very small in diameter, flexible, and capable of transmitting light over long distances, enabling remote sensing and distributed sensing applications. Fiber optic sensors find applications in a wide range of industries and fields. They are used in structural health monitoring of buildings, bridges, and pipelines, where they can detect strain and deformation. They are also used in environmental monitoring, biomedical applications, aerospace, telecommunications, and many other areas where accurate and reliable sensing is required. Overall, fiber optic sensors provide a versatile and effective means of measuring physical parameters. Due to their unique properties, they are well-suited to applications that require high sensitivity, immunity to electromagnetic interference, and harsh environmental performance.

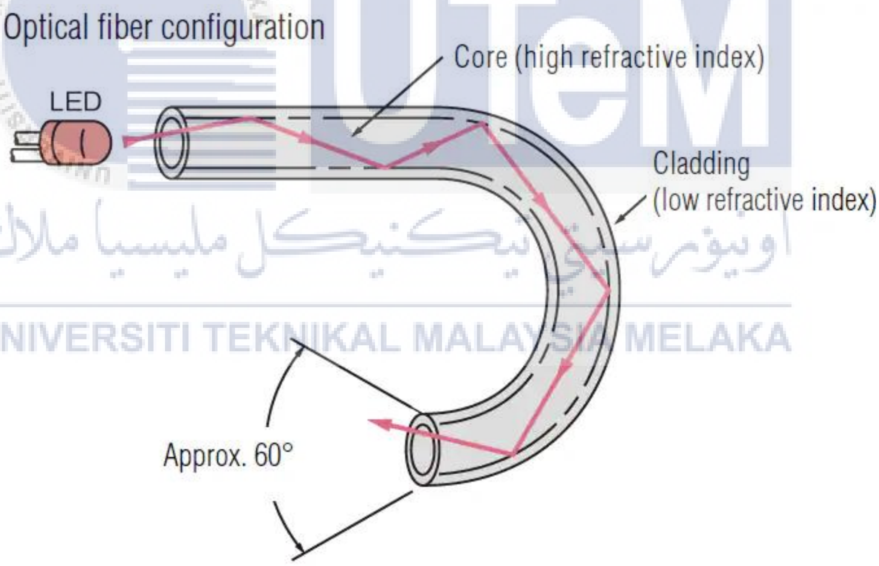


Figure 2.1 Optical Fiber Configuration

2.3.1 Optical Microfiber Sensor

The paper "Optical Microfiber Sensor: A Review" discusses the working principle and fabrication methods of optical microfiber sensors(Jali et al., 2021). Based on the principle of light transmission through the microfibers, the optic microfiber sensor works under the principle of light transmission through the microfibers. Microfibers are thin, glass, or plastic fibers that have a diameter that is typically in the range of 1-100 microns and are made of either glass or plastic. Microfibers are coated with a thin layer of material that reacts with the target analyte, which changes the refractive index of the coating material and alters light transmission. In this paper, different fabrication methods of optical microfiber sensors are described, such as the tapered fiber method, fiber drawing method, and chemical etching method. Tapered fibers can be produced by heating the fiber and pulling it to produce a tapered shape, whereas fibers can be drawn from preforms using a drawing tower instead of heating the fiber and pulling it. A chemical etching method removes material from the fiber selectively to create the desired shape.

Additionally, the paper discusses temperature sensors, strain sensors, pressure sensors, and chemical sensors. The advantages of optical microfiber sensors include their high sensitivity, low cost, and small size which make them suitable for a wide range of applications in the field of environmental monitoring, biomedical sensing, and structural health monitoring. These features, as well as others, make them effective for a variety of applications. Microfiber sensors have high sensitivity and accuracy, making them ideal for use in various sensing applications, including temperature, pressure, and chemical sensing. They are also highly robust and can withstand harsh environmental conditions, making them suitable for use in harsh environments such as aerospace and military applications. Besides that, because of its tiny mass, microfibre is extremely sensitive to changes in the momentum of photons guided by mechanical displacement or vibration.

Furthermore, microfiber sensors can be fabricated using various low-cost fabrication methods such as flame brushing, tapering, and etching, which make them an attractive option for commercial and industrial applications. The paper also discusses the potential applications of microfiber sensors in various fields such as telecommunications, environmental monitoring, and biomedical sensing. Overall, the advantages of microfiber sensors make them a promising technology for various sensing applications, including the detection of glucose conditions in the pharmaceutical industry using optimization approaches.(Jali et al., 2021)

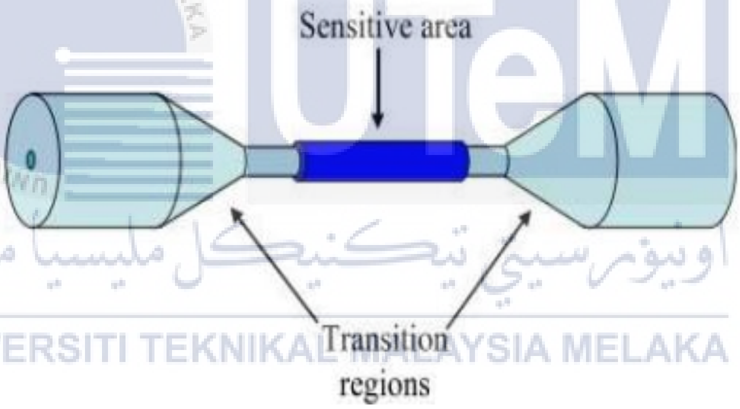


Figure 2.2 Sensitive area has a large fraction of power propagating

2.3.2 Microfiber Optical Sensors: A Review

In this paper, the authors focus on microfiber optical sensors and provide a detailed explanation of their fabrication, waveguide properties, sensing applications, and the advantages they offer over conventional optical fiber sensors(Lou et al., 2014). One notable advantage highlighted is the low optical power consumption of microfiber sensors. The low optical power consumption of microfiber sensors is attributed to the unique waveguide properties of microfibers. The tight confinement and surface enhancement of the probing light waveguided along a microfiber, due to its small diameter and high index contrast, allow for efficient light propagation and interaction with the surrounding environment. Despite using low optical power, microfiber sensors can achieve high sensitivity in detecting changes in the measured parameter. The low power consumption of microfiber sensors is beneficial in various ways. It enables the minimization of energy requirements in sensing applications, making them suitable for scenarios where power efficiency is critical (Lou et al., 2014). Additionally, the use of low optical power can be advantageous when high-power light sources are not readily available or when power conservation is important. The combination of small size, high sensitivity, fast response, flexibility, and low power consumption makes microfiber optical sensors highly desirable for a wide range of applications. They offer the potential for miniaturized and efficient sensing systems while maintaining sensitivity and accuracy. Overall, the low optical power consumption of microfiber optical sensors contributes to their practicality and suitability for various applications. It allows for energy-efficient sensing without compromising on performance, making microfiber sensors a promising choice in the field of optical sensing.

2.3.3 Type of Optical Fiber

Single Mode

It is also known as SMF and is used for long-distance communication. A singlemode fibre cable is a single piece of glass fibre with a diameter ranging from 8.3 to 10 microns, with a common size of 9 um and only one mode of transmission. Single mode fibres have a smaller core diameter than multimode fibres.(Rekha et al).Because of the tiny core and single light-wave, there is almost no distortion caused by overlapping light pulses, resulting in the least signal attenuation and highest transmission speeds of any fibre cable type. Singlemode fibre has a relatively low diameter through which only one mode can propagate, often in the 1310 or 1550 band wavelength, and has a higher bandwidth than multimode fibre, which we shall describe later; nonetheless, singlemode fibre requires a light source with a restricted spectral width. Singlemode fibre is also known as mono-mode optical fibre, singlemode optical waveguide, and uni-mode fibre.

Singlemode fibre is used in a variety of applications where data is supplied at many frequencies (WDM Wave-Division-Multiplexing) and only one connection is required: singlemode on a single fibre.A singlemode optical fibre can only propagate the lowest order bound mode at the wavelength of interest, which is typically 1300 to 1320m.

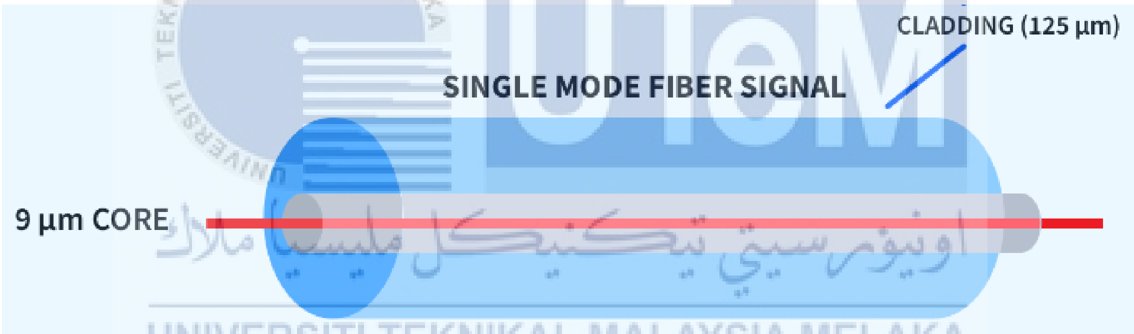


Figure 2.3 Single Mode Fiber

Multimode

It is known as MMF and is used for short distances of less than 500 metres. Based on specification and, in a nutshell, bandwidth performance, multimode fibres are classified as OM1, OM2, OM3, and OM4. Each multimode type has changeable transmission data rates, link length, and bandwidth for various protocols, applications, and transceiver types. Typical multimode fibre core widths are 62.5um (OM1) and 50pm (OM2/OM3/OM4). Multiple routes of light can cause signal distortion at the receiving end, resulting in an undear and full data transmission, therefore designers are now advocating for singlemode fibre in new Gigabit and beyond applications.

Multimode fibre cable has a somewhat greater diameter than singlemode fibre cable, with the light carry component typically measuring 50 to 100 microns in diameter. Multimode fibre enables high bandwidth over short distances (10 to 100MBS - Gigabit to 275m to 2km) (Datatronix, n.d.). As light waves pass through the core of the cable, which is typically 850m or 1310nm in length, they are separated into multiple paths, or modes.

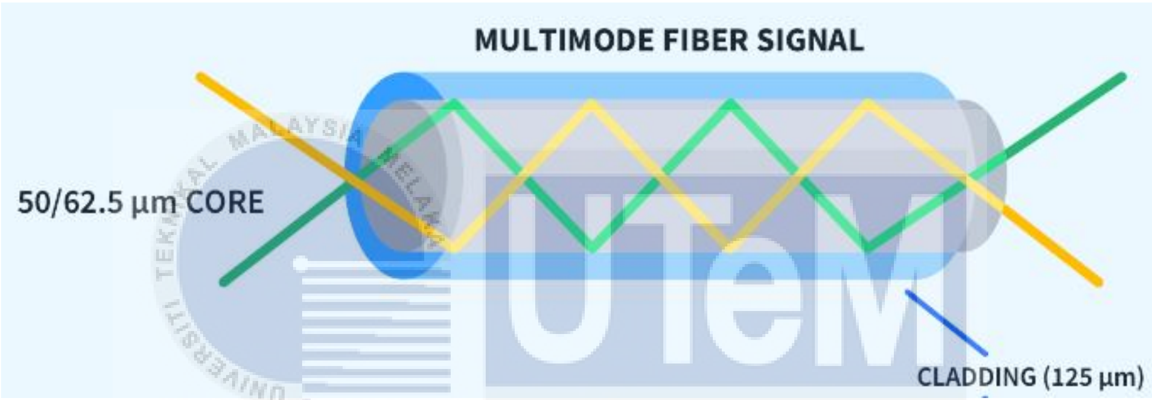


Figure 2.4 Multimode Fiber

2.3.4 Microfiber Diameters

Microfibers, characterized by their diminutive size, typically with diameters in the micrometer or sub-micrometer range, play a crucial role in various technological applications. The fabrication of microfibers involves precise control of their diameters, often achieved through tapering or drawing techniques. This controlled diameter is a defining factor influencing the optical, mechanical, and sensing properties of microfibers. In optical applications, microfibers exhibit unique characteristics owing to their small size. The diameter of a microfiber is particularly relevant in sensing applications, where it can impact the sensitivity and responsiveness of the sensor. For instance, microfiber sensors designed for temperature sensing leverage changes in refractive index influenced by temperature variations, with the diameter influencing the sensor's response. Similarly, in strain sensing applications, the mechanical properties of microfibers, including their diameter, are critical. One of the key advantages of microfibers lies in their ability to support guided modes and interact with their surrounding environment through evanescent field interactions. The diameter of the microfiber directly affects the extent of the evanescent field, influencing the sensor's capability to detect changes in the environment. Microfibers are often employed in evanescent wave sensing, where the interaction of the evanescent field with external mediums is harnessed for various sensing purposes.

Based on the research paper titled "Effect of Microfiber Diameters on Micro-sphere Resonator Based Humidity Sensor" explores the impact of microfiber diameter on the performance of a humidity sensor based on micro-sphere resonators (MSRs) (Mohamad Ali et al., 2022). In the study, it was demonstrated that MSRs coupled with microfibers of 5 um diameter exhibit the highest linearity (99.16%) and sensitivity (0.5039 dB/% RH) among diameters tested. It has been determined that smaller microfiber diameters result in stronger evanescent fields and improve the interaction of light with the sensor's surroundings due to their smaller diameter. The 10 µm diameter microfiber was used in an MSR-based humidity sensor experiment. The larger diameter of the microfiber compared to the 5 µm microfiber resulted in a slightly lower sensitivity. This is because the evanescent field from the larger microfiber interacts less strongly with the microsphere resonator, leading to a smaller change in the output power as humidity varies. Although the microfiber was 10 µm diameter, the linearity was still high, suggesting a reliable and consistent response to humidity changes. To summarize, this study emphasizes the importance of the diameter of microfibers as well as their performance. According to the findings, smaller microfiber diameters improve the sensing capabilities.

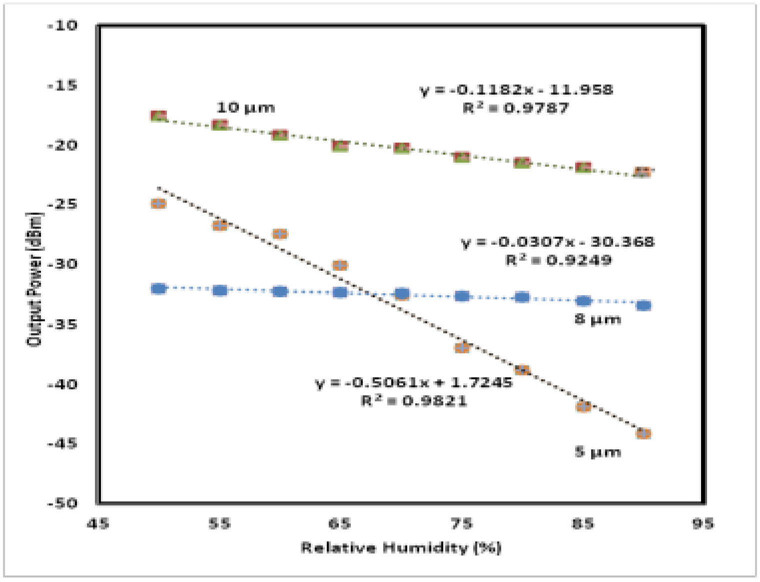


Figure 2.5 Humidity sensing response of MSRs

2.3.5 Microfiber Wavelength

In fiber optics, the wavelength of light refers to the specific length of the optical wave transmitted through the optical fiber. The two predominant wavelength windows used in optical communication are centered around 1310 nm and 1550 nm, known as the first and second windows, respectively. The wavelengths used for the optical fibers are very small; which are 1,550 nm and 1,310 nm are used mostly for long-distance communication because of the less attenuation(Nandhakumar & Kumar, 2021).The 1310 nm wavelength, situated in the first window, is characterized by relatively low attenuation and dispersion, making it suitable for shorter-distance applications such as local area networks (LANs), metropolitan area networks (MANs), and Fiber to the Home (FTTH). However, it is important to note that this wavelength experiences some water absorption, which can impact underwater optical communication. On the other hand, the 1550 nm wavelength, positioned in the second window, is renowned for its low attenuation and efficiency in optical amplification. This makes it ideal for long-distance communication, including transcontinental links and undersea cables. The use of Erbium-Doped Fiber Amplifiers (EDFAs) at 1550 nm facilitates effective optical signal amplification. Despite its higher dispersion, dispersion compensation techniques are commonly employed for managing long-distance transmissions. In addition to these primary windows, other wavelengths, such as 850 nm for short-distance communication within buildings, are utilized, especially in conjunction with multimode fibers. Moreover, wavelength bands like the C band (1530 nm to 1625 nm) and L band (1625 nm to 1675 nm) play specific roles in optical communication systems. The implementation of Wavelength Division Multiplexing (WDM) further enhances system capacity by allowing the simultaneous transmission of multiple wavelengths over a single optical fiber. The selection of a particular wavelength is contingent on factors such as the type of optical fiber, communication distance, the availability of optical components, and the specific demands of the application.

2.4 Glucose Concentration

Fasting blood glucose concentrations are estimated to be between 70 mg/dL (3.9 mmol/L) and 100 mg/dL (5.6 mmol/L). It is recommended to monitor glycemia and change lifestyle when fasting blood glucose is between 100 and 125 mg/dL (5.6 and 6.9 mmol/L). It is possible to diagnose diabetes if fasting blood glucose levels are 126 mg/dL (7 mmol/L) or higher on two separate tests. Also, individuals with low fasting blood glucose concentrations (hypoglycemia) - below 70 mg/dL (3.9 mmol/L) - often experience dizziness, sweating, palpitations, and blurred vision (world health organization & Leanne Riley, n.d.). An increase in fasting blood glucose level (hyperglycemia) is a higher risk factor for diabetes. In diabetics, fasting blood plasma glucose (FPG) may remain within the normal range because the glucose-lowering medication is effective in treating their condition. As a proxy for both promoting healthy diets and behaviors as well as treating diabetes, the mean FPG at the national level is used.

2.4.1 Normal blood Glucose

The paper "What is a normal blood glucose?" published in Archives of Disease in Childhood in September 2015 is a review article that aimed to provide an overview of the current understanding of blood glucose levels in children and adolescents (Güemes et al., n.d.; Klonoff, 2012). The authors emphasized the significance of controlling blood glucose in maintaining health and avoiding complications such as diabetes mellitus. They highlighted that the definition of normal blood glucose levels can vary depending on factors such as age, sex, and race and that the diagnostic criteria for diabetes also differ for children and adults. The paper presented data from various studies to provide a reference range of normal blood glucose levels in children and adolescents. The authors noted that fasting blood glucose levels below 5.6 mmol/L (100 mg/dL) are considered normal, while levels between 5.6-6.9 mmol/L (100-125 mg/dL) may indicate impaired glucose tolerance or pre-diabetes. A diagnosis of diabetes is typically made when the fasting blood glucose level is 7.0 mmol/L (126 mg/dL) or higher, or when a random blood glucose level is 11.1 mmol/L (200 mg/dL) or higher. The paper also discussed the significance of blood glucose monitoring in adolescents with diabetes and children and emphasized the need for individualized management plans to achieve optimal blood glucose control. The authors highlighted the potential short-term and long-term consequences of poor blood glucose control, such as hypoglycemia, hyperglycemia, and diabetic complications affecting various organs and systems in the body. Overall, the paper provided valuable insights into the current understanding of normal blood glucose levels in children and adolescents and the importance of monitoring blood glucose levels for maintaining health and preventing complications.

2.5 Glucose Detection Method using Fiber Optic.

Glucose monitoring is a critical aspect of diabetes management, and current methods involve invasive procedures such as finger pricks to obtain blood samples for testing (Multar et al., 2020). Fiber optic sensors offer a potential solution for non-invasive glucose monitoring by using light to detect glucose levels. In this study, the researchers developed a functionalized fiber optic sensor for glucose detection. They used a single-mode fiber (SMF) and tapered it employing a flame-brushing technique to enhance sensitivity and limit detection of the sensor. They then used covalent interaction to immobilize glucose oxidase (GOD) on the tapering area of the SMF.

2.5.1 Fluorescence Glucose Sensing

The article "Overview of Fluorescence Glucose Sensing: A Technology with a Bright Future," explores the potential of fluorescence glucose sensing for diabetes management (Arif et al., 2020; Klonoff, 2012). Accurate and frequent glucose monitoring is crucial, but traditional methods have limitations. Fluorescence glucose sensing uses fluorescent molecules that interact with glucose, allowing for its measurement. The key advantage is its non-invasiveness, offering continuous monitoring and integration with wearable devices or smartphones. Challenges include calibration, probe stability, interference, and cost-effectiveness. However, the article ends optimistically, envisioning fluorescence glucose sensing transforming diabetes management with patient-friendly and reliable glucose data. Further research is needed for widespread use. Overall, the article provides an in-depth overview of the benefits and challenges of fluorescence glucose sensing, highlighting its promising future in glucose monitoring for diabetes management.

2.5.2 A Non-enzymatic Electrochemical Sensor for Glucose Detection Based on Ag@TiO2@ Metal-Organic Framework (ZIF-67) Nanocomposite

The paper titled "A Non-enzymatic Electrochemical Sensor for Glucose Detection Based on Ag@TiO2@ Metal-Organic Framework (ZIF-67) Nanocomposite" (Arif et al., 2020)proposes a novel approach for glucose detection using a non-enzymatic electrochemical sensor. The sensor design incorporates a nanocomposite material consisting of Ag@TiO2@ Metal-Organic Framework (ZIF-67). The primary goal of the study is to develop a highly sensitive and selective sensor for glucose detection without relying on enzymes. Enzyme-based sensors often face issues such as limited stability, high cost, and complex fabrication processes. The proposed sensor aims to overcome these limitations. The nanocomposite material, Ag@TiO2@ZIF-67, is synthesized by depositing silver nanoparticles (Ag) onto titanium dioxide (TiO2) nanoparticles, followed by the growth of a metal-organic framework (ZIF-67) on the surface. This unique combination of materials enhances the sensor's performance by providing a large surface area, improved conductivity, and enhanced electrocatalytic properties. The electrochemical behavior of the nanocomposite sensor is extensively characterized using techniques such as cyclic voltammetry and chronoamperometry. The sensor demonstrates excellent electrochemical activity towards glucose oxidation, resulting in a measurable current response proportional to the glucose concentration. The performance of the sensor is evaluated in terms of sensitivity, selectivity, and stability. The results show that the nanocomposite-based sensor exhibits high sensitivity, low detection limit, wide linear range, and good selectivity for glucose detection. Additionally, the sensor demonstrates good stability over an extended period, making it suitable for practical applications.

2.5.3 A Smart Glucose Monitoring System for Diabetic Patient

The paper "A Smart Glucose Monitoring System for Diabetic Patients" presents the development of a smart glucose monitoring system for diabetic patients (Rghioui et al., 2020). This system consists of a non-invasive microfiber sensor that detects changes in the refractive index of sweat, a microcontroller based on Arduino, and a smartphone application to interface with the sensor. This microfiber sensor is coated with graphene oxide and molecularly imprinted polymers so that its sensitivity and selectivity for glucose detection will be enhanced. An Arduino-based microcontroller is used to connect the sensor to the microcontroller, which then processes the sensor data and transmits it wirelessly via Bluetooth to a smartphone application. In the application, glucose levels are monitored in real time, alerts the user whenever there are abnormal readings, and the data is stored for later analysis.

This paper describes how the sensor and the electronic circuits of the system were designed and built, in addition to how the smartphone application was developed. Also, the authors conducted a number of experiments in order to evaluate the performance of the system, including how accurate and precise the sensor measurements were, how stable the system was over time, and how user-friendly the smartphone application was. According to the authors, there is a high correlation between the measurements obtained from their system and the measurements obtained from a commercial glucose meter, demonstrating the potential of the microfiber sensor for non-invasive glucose monitoring. Moreover, the authors also highlighted the advantages of the smart monitoring system, such as its portability, non-invasiveness, and ability to monitor patients in real time, as well as its advantages over conventional monitoring systems. In summary, this study presents a promising development for non-invasive glucose monitoring services for diabetic patients and indicates their potential application in healthcare and the monitoring of individual health.

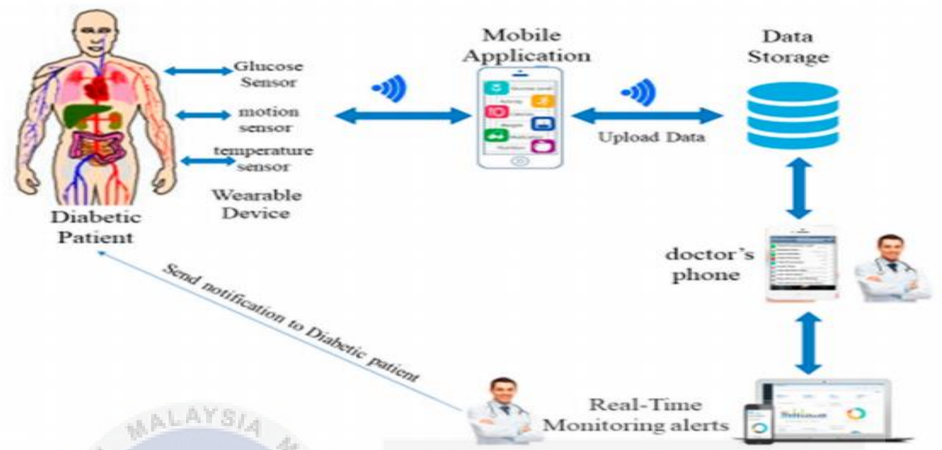


Figure 2.6 Architecture for diabetic monitoring

2.5.4 Design and Development of Infrared LED Based Non-Invasive Blood Glucometer

The article "Design and Development of Infrared LED Based Non-Invasive Blood Glucometer" describes the design and development of a noninvasive blood glucometer that uses infrared LED technology (Komal Lawand et al., n.d.). According to the authors, the glucometer measures blood sugar levels by using near-infrared light to measure levels of glucose in the blood. The light is transmitted through the skin and interacts with glucose molecules in the blood, causing changes in the light that are measured by the glucometer. As the glucometer is designed to be held against the skin, it makes it completely painless and noninvasive for you to monitor the level of your blood glucose. The article describes the development and testing of the glucometer, including laboratory testing and clinical trials involving human subjects. Based on the authors' findings, the glucometer showed promising results in terms of accuracy and reliability. Glucometers may also improve diabetes management and reduce healthcare costs, according to the authors. The glucometer may be particularly useful for people with diabetes who need to monitor their glucose levels frequently, as it provides a noninvasive and painless method. The article presents an approach to noninvasive glucose monitoring that uses infrared LED technology to provide accurate and reliable glucose monitoring of blood glucose levels that uses a new approach to noninvasive glucose monitoring. The authors suggest that further research and development are needed to ensure the accuracy and reliability of the glucometer for wider use in clinical settings.

Figure 2.7 Infrared LED Based Non Invasive Blood Glucometer

2.6 Design OF Experiments (DOE)

Design of Experiments (DoE) is a statistical tool for designing experiments and analyzing the results to optimize the performance of a product or process (Ranga et al., n.d.). It is a method that involves manipulating input variables, or factors, at different levels to observe their effects on the output response variable, or the outcome. By varying the factors at different levels, a relationship between the input and output variables can be established, which can help to identify the optimal settings for the factors to achieve the desired performance. This paper reviews factors, levels, experimental designs, and results analysis for DoE. A factor is merely an input variable that affects the output response variable, while a level is an indication of the range of values that can be applied to a factor. Experimental designs are the systematic plans for conducting experiments by varying the factors at different levels. Different types of experimental designs, including response surface methodology (RSM), fractional factorial, and full factorial are discussed.

This paper also highlights the benefits of DoE, such as reducing the number of experiments needed to identify optimal conditions, providing a systematic approach to experimentation, and identifying important factors. It can also help to reduce variability and improve product quality, process efficiency, and yield. Although the authors acknowledge the challenges associated with DoE, such as the need to carefully plan and execute experiments, and the difficulty of determining the appropriate experimental design and statistical analysis. There are several case studies included in the paper that demonstrate the application of DoE in various industries, such as pharmaceuticals, automotive, and manufacturing, for instance. The authors provide examples of how DoE can be applied to improve product quality, reduce variability, and optimize process parameters, as well as how it has led to significant cost savings and increased productivity as a result of improved DoE. Overall, this paper provides a useful overview of DoE methodology and its application in various industries. In addition to highlighting the importance of using statistical tools to optimize product or process performance, this book can be a useful resource for researchers, engineers, and managers who are interested in using statistical tools to improve the quality and efficiency of their products and processes.

Screening Design (S.D)	Screening designs are effective way to identified significant main effects. The term "Screening design" refers to an experimental plan i.e. indented to find a few significant factors from a list of many potential ones.
Response Screening Design	Response screening design involves just the main effects & interactions or they may also have quadratic & possibly cubic terms to account for curvature model which may be appropriate to described a response
Fractional Factorial Design	Full factorial experiments can requires may runs. The solution to this problem is to use only a fraction of the runs specified by the full factorial design. In general, we pick a fraction such ½, ¼ etc. of the runs called for by the full factorial.
Placket – Burmam Design	These designs have run numbers that are in multiple of 4.placket Burmam (PB) designs are used for screening experiments because in PB designs, main effects are, heavenly confounded with two – factor interactions.
Box- Behnken Design	The Box- Behnken Design is an independent quadratic design which does not contain an embedded factorial or fractional factorial design. These designs are rotatable (or near rotatable) & requires 3 levels of each factors.

Figure 2.8 Types of Design of Experiments commonly used

2.6.1 Box-Behnken Design

The Box-Behnken Design (BBD) is a statistical experimental design method that is particularly useful in optimizing processes and systems by systematically exploring the effects of multiple variables at different levels. Named after statisticians George E.P. Box and Donald W. Behnken, BBD provides an efficient way to study the response of a system to changes in various factors while minimizing the number of experiments needed. In the context of developing a microfiber sensor for detecting glucose conditions, BBD can be applied to optimize the sensor's parameters such as fiber diameter, length, core and cladding refractive index, and sensing material. The design involves selecting three levels for each variable, creating a series of experimental runs that cover a range of conditions. The advantage of the BBD is its ability to model quadratic response surfaces, allowing for the identification of optimal parameter combinations without exhaustively testing every possible combination. During BBD experimentation, the responses to different combinations of parameters are measured, and the collected data are then used to fit a mathematical model. This model helps identify the main effects of each parameter and any potential interactions between them. Through statistical analysis, the optimal set of parameters that yields the best sensor performance can be determined, contributing to the efficient and effective development of the microfiber sensor for glucose detection. The BBD approach streamlines the optimization process, saving time and resources while providing valuable insights into the relationships between variables, ultimately contributing to the successful development of an accurate and reliable glucose monitoring sensor. The goal of employing the BBD in this study was to find the optimal levels of the independent variables that would result in desirable responses.(Venkata et al., n.d.)

2.7 Comparison of Previous Study

Table 2.1 Comparison previous study

Parameter	**Design and Development of Infrared LED Based Non Invasive Blood Glucometer** (Komal Lawand et al., n.d.)	**Electrochemical Sensor Based on Ag@TiO2@ZIF-67** (Arif et al., 2020)	**A Smart Glucose Monitoring System for Diabetic Patients** (Rghioui et al., 2020)
Sensor Used	Infrared LED	Ag@TiO2@ZIF-67 electrochemical sensor	Microfiber sensor
Sensing Method	Infrared absorption	Non-enzymatic electrochemical oxidation	Refractive index measurement in sweat
Invasiveness	Non-invasive	Invasive	Non-invasive
Sensitivity	Moderate to high	High	High
Enzyme Requirement	Enzyme-based	Enzyme-based	Non-enzymatic
Sample Type	Blood	Blood	Sweat
Cost	Moderate	Moderate	Moderate
Calibration	Required	Required for accurate quantification	Required
Applications	Glucose monitoring through blood testing	Glucose monitoring through blood testing	Glucose monitoring for diabetic patients

2.8 Summary

Given the critical importance of accurate detection of glucose conditions in the pharmaceutical industry, developing a microfiber sensor that can effectively and efficiently perform this task is of utmost significance. However, designing a sensor that can precisely and reliably detect glucose levels in pharmaceutical processes requires an optimization approach that can achieve the desired performance characteristics while minimizing the associated costs. Unfortunately, there is no widely accepted method for optimizing the design of microfiber sensors for glucose detection in the pharmaceutical industry due to the lack of a comprehensive understanding of the underlying scientific principles and the complex interplay between the sensor's design parameters and its performance. As a result, the development of a microfiber sensor that meets the industry's needs necessitates a robust and innovative approach that takes into account the unique requirements and constraints of the pharmaceutical industry while optimizing the sensor's design parameters.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discusses the methodology implemented in this study. This methodology discusses the project at an early stage in detail and also explains the schematic diagram of the project. Moreover, it will also explain the flowchart to explain how this project works.The objective of this research is to proposed a development microfiber optic.

3.2 Methodology

This project proposes an innovative method for the development of a microfiber sensor that can be used to detect glucose conditions in the pharmaceutical industry, as well as a systematic approach to the development of the microfiber sensor. Based on the proposed methodology, the microfiber sensor will be developed using the optimization parameters approach, which involves using the design of experiments software to identify the optimal combination of input parameters that are going to produce the highest levels of sensitivity, accuracy, and durability for the microfiber sensor. In order to determine the sensor's performance in detecting the glucose condition in the pharmaceutical industry.

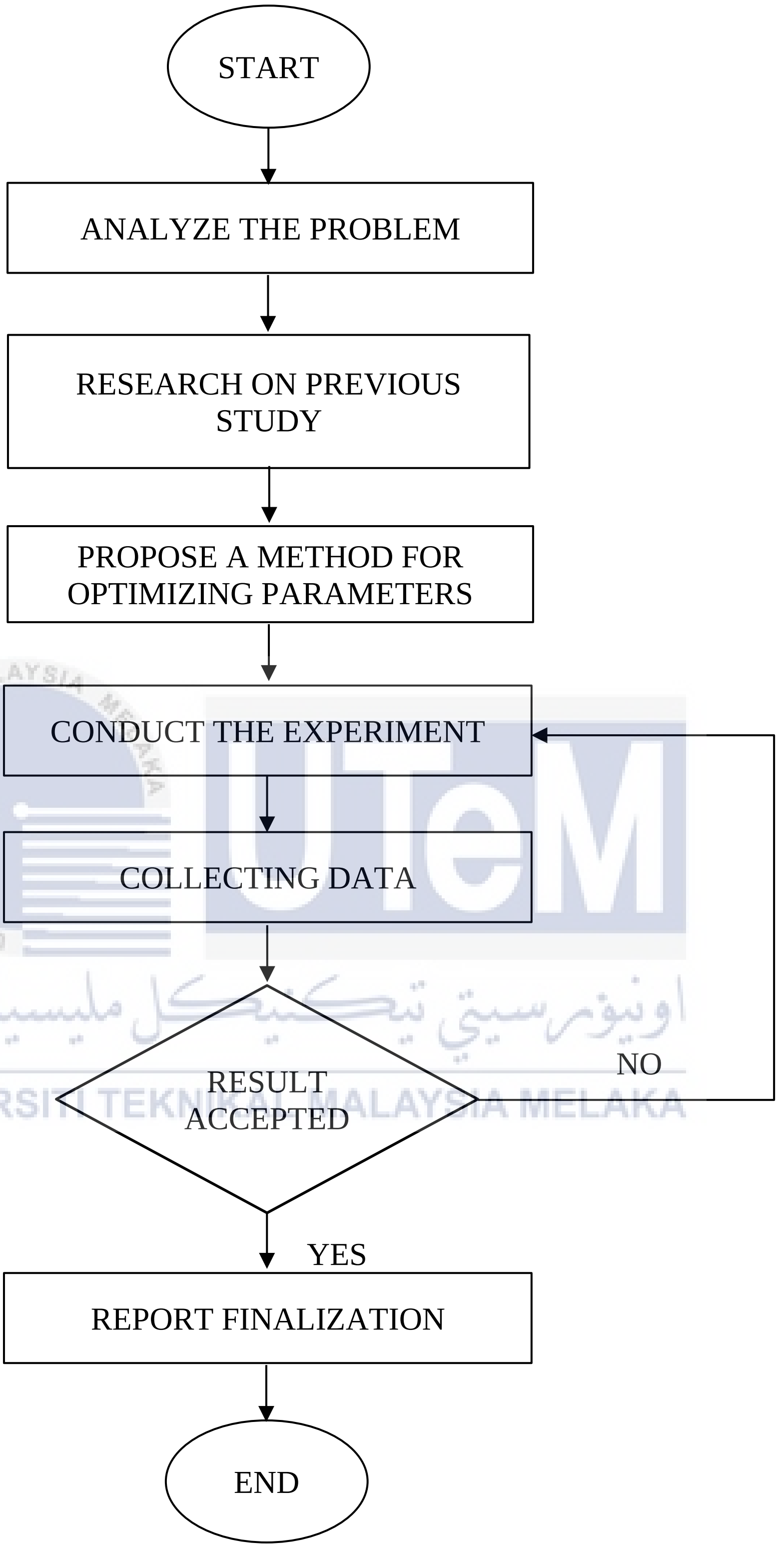


Figure 3.1 Work process flow

3.2.1 Experimental setup

An experimental setup would involve several steps to developing a microfiber sensor for detecting glucose conditions. Firstly, a suitable optical fiber with a cladding and core material that can interact with glucose needs to be obtained. The fiber is then prepared by stripping off the protective coating and cleaning it to remove any contaminants. Next, the fiber is tapered using a fiber tapering setup to create a microfiber with a waist region. Then, the ends of the microfiber are connected to optical connectors or fibers for light input and output by applying the fusion splicing process. Besides that, for the sensing material, a suitable material that selectively interacts with glucose is sugar water. The sensing material is prepared by dropping it onto the surface of the microfiber-tapered area. The sensor's performance and accuracy are then validated using glucose samples of two levels of concentration. The sensor's accuracy, precision, and reliability are validated through statistical analysis and comparison with reference methods or samples. The results are presented and interpreted, highlighting the sensor's capabilities, limitations, and potential applications.

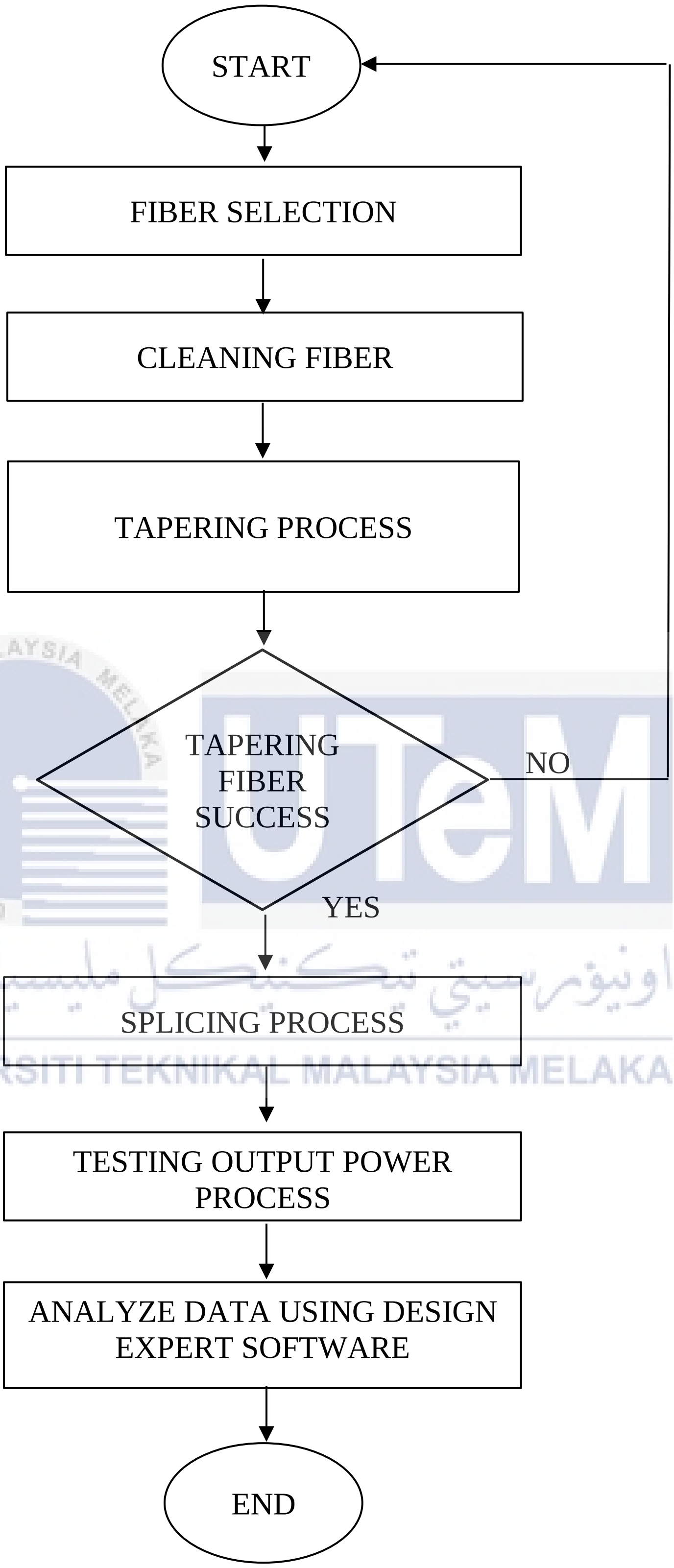


Figure 3.2 Experimental Process

3.2.1.1 Parameters

1. **Wavelength**

The interaction of glucose with the microfiber can result in changes in the wavelength of light transmitted through the fiber, which can be measured and correlated to glucose concentration. The choice of wavelength depends on the type of microfiber and the sensing mechanism. For example, if optical fibers are used, the wavelength can be in the visible or near-infrared range, where glucose has absorption bands. In the visible range, glucose has absorption bands at around 540 nm, 580 nm, and 620 nm. In the near-infrared range, glucose has absorption bands at around 1100 nm, 1200 nm, and 1400 nm. At wavelengths between 1420 and 1480 nm and 1630 and 1730 nm, glucose absorbance is the most significant (Yadav et al., n.d.)

2. **Microfiber Diameter**

The diameter of the microfiber can affect the sensor's sensitivity and selectivity to glucose, as well as its mechanical and optical properties. Microfibers are often fabricated by taper-drawing glass or polymer materials, for example, glass optical fibers. Their diameter ranges from hundreds of nanometers to several micrometers, and their sidewalls are very smooth. (Tong et al., 2003). Smaller diameter microfibers are more sensitive to glucose interactions, as they provide a higher surface area for glucose to interact with the sensing material. For example, as stated by (Ujah et al., 2023) micron-sized waist diameters of (TOF) RI sensors can significantly improve sensor sensitivity by lowering mode volume over long distances. However, smaller-diameter fibers may be more susceptible to mechanical damage and may require more delicate handling during fabrication and use. In this study, the diameter of the microfiber used is less than 10um and greater than 10um.

3. Types of microfibers

One commonly used type of microfiber for biosensors is optical fiber. Optical fibers are tiny fibers composed of glass or plastic that can transfer light signals over long distances with minimal signal loss. Single-mode fiber and multi-mode fiber are two types of fiber. Single-mode optical fiber propagates one light mode at a time. However, multiple modes can be propagated by multi-mode fiber cable (S.Panzer, 2021). They can be coated with various matericoncentration. Whenymes or polymers are sensitive to glucose concentration. When glucose molecules come in contact with the coating, they can change the optical properties of the fiber, resulting in a measurable signal.

4. Concentration of glucose

The microfiber sensor can be fabricated using materials that are sensitive to changes in glucose concentration, such as enzymes or polymers (Li et al., 2018). Microfiber can be designed to interact with the glucose molecules and generate a signal that is proportional to the glucose concentration. Two levels of concentration of glucose can be used in this glucose detection which is for normal individuals and diabetes patients. Blood glucose concentrations during normal fasting range between 70 mg/dL (3.9 mmol/L) and 100 mg/dL (5.6 mmol/L). Then, for diabetes patients is 126 mg/dL (7 mmol/L) or higher. An optimization approach can be used to determine the optimal concentration range of glucose that the sensor can accurately detect. This can be achieved by testing the sensor's response to different concentrations of glucose and analyzing the resulting data.

3.2.1.2 Parameter Used

Table 3.1 Parameter Used

Parameter		
Type of Fiber	Single Mode	Multimode
Wavelength	1310nm	1550nm
Diameter	9µm	13µm
Concentration	4.8 mmol/L (86mg/dL)	9 mmol/L (162mg/dL)

3.2.1.3 Equipment

Various pieces of equipment that can be used in the tapering process for optical fibers. Some of the most commonly used equipment include:

1. Tapering machine: This is a specialized machine that is designed specifically for tapering optical fibers. It typically consists of a motorized pulling mechanism, a heat source, and a control system that can adjust the pulling speed, temperature, and other parameters.

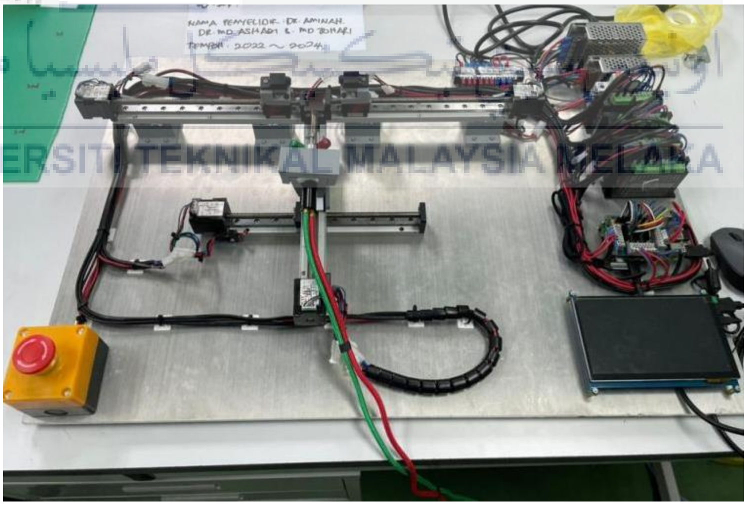


Figure 3.3 Tapering Machine

2. Fiber holder: The fiber to be tapered needs to be held securely during the tapering process to prevent it from moving or bending. A fiber holder can be a simple clamp or a more sophisticated chuck that can grip the fiber without damaging it.

Figure 3.4 Fiber Holder

3. Heat source: A heat source is required to soften the glass during the tapering process. This can be a flame, a laser, or an electric heater. The choice of heat source will depend on the specific requirements of the application.

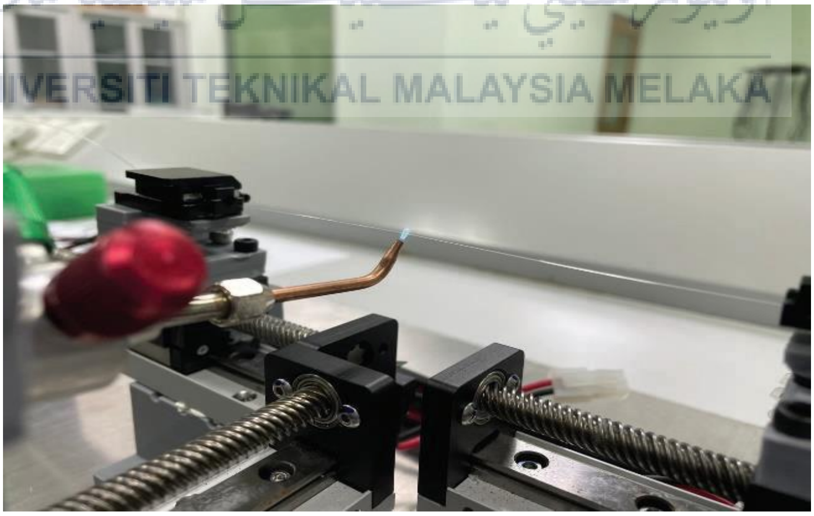


Figure 3.5 Heat Source

Next are various pieces of equipment fusion splicing process for optical fiber:

1. Fiber stripper: remove the protective coating or buffer layer from an optical fiber without damaging the fiber itself

Figure 3.6 Fiber stripper

2. Fiber cleaver: A fiber cleaver is a specialized tool used in fiber optic installations and maintenance to cut or cleave optical fibers with high precision and create a clean and flat end face

Figure 3.7 Fiber Cleaver

3. Alcohol for fiber cleaning: Cleaning optical fibers with alcohol is a frequent practice. Its purpose is to remove any dirt, dust, oils, or pollutants from the fiber surface. To clean the fiber, alcohol, such as isopropyl alcohol (IPA), is put to a lint-free cloth or cleaning swab and gently rubbed over it.

Figure 3.8 Alcohol

4. Fusion splicer: A specialized tool used in fiber optic installations and maintenance to join two optical fibers together through a fusion process

Figure 3.9 Fusion Splicer

5. Optical Time-Domain Reflectometer: Device that tests the integrity of a fiber cable and is used for the building, certifying, maintaining, and troubleshooting fiber optic systems.

Figure 3.10 OTDR

6. Light source : Used to measured power and loss using the dual-wavelength testing feature, in which 1310 nm and 1550 nm. These wavelength can be transmitted simultaneously.

Figure 3.11 Light Source

3.2.1.4 Fabrication Techniques

i. Tapering

Tapering an SMF involves pulling the fiber's end while heating the fiber's waist to decrease the diameter of the cladding (together with the core) (Zibaii et al., 2010). It is commonly used in fiber optics technology to couple light between fibers of different diameters or to improve the optical properties of fibers by reducing their diameter. Surface smoothness and geometric uniformity are critical throughout the microfiber production process for achieving a high signal-to-noise ratio and low optical loss criteria (Wu & Tong, 2013). There are various methods for tapering, including chemical etching, flame brushing, and mechanical stretching. The flame brushing method is used for this experiment. Generally, the fiber is heated at a certain point and then pulled to gradually reduce its diameter. Tapered fibers are used in optical fiber optics for a variety of applications, including optical sensing, telecommunications, and fiber lasers. They can be used to enhance light coupling efficiency, reduce loss, and improve the optical properties of the fiber. The process of tapering fiber involves reducing the diameter of a section of the fiber by gradually pulling it while it is heated. Several different techniques can be used to accomplish this, but the basic principles are similar. Here are the steps involved in the general process:

1. The fiber to be tapered is cleaned and stripped of any protective coating or buffer material. This is typically done using chemical solutions or mechanical stripping tools.
2. The section of the fiber to be tapered is heated using a heat source such as a flame, laser, or electric heater. The heat softens the glass, making it easier to deform.
3. The heated section of the fiber is stretched and pulled using a specialized tool or machine. As it is pulled, the diameter of the fiber gradually reduces.
4. Once the desired taper shape and diameter are achieved, the fiber is cooled rapidly to set the shape and prevent the fiber from returning to its original shape.

There are several factors that must be carefully controlled during the tapering process to ensure the desired shape and properties of the tapered fiber. These include the temperature and heating rate, the pulling rate and force, and the cooling rate. The exact parameters will depend on the specific application and the materials used in the fiber.

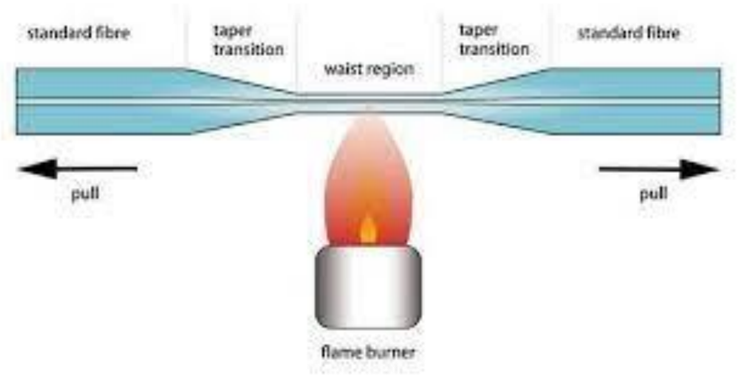
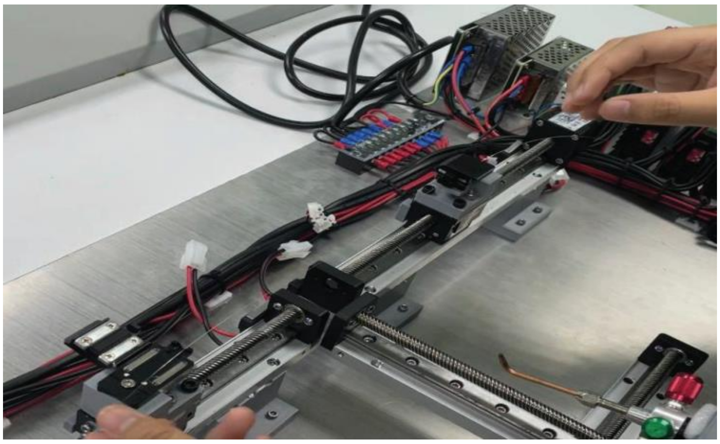
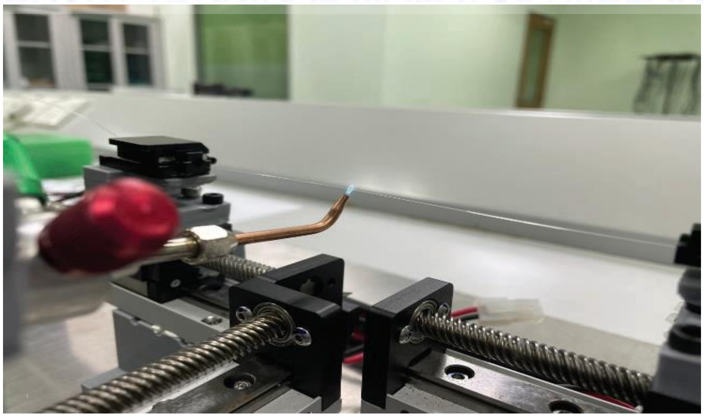
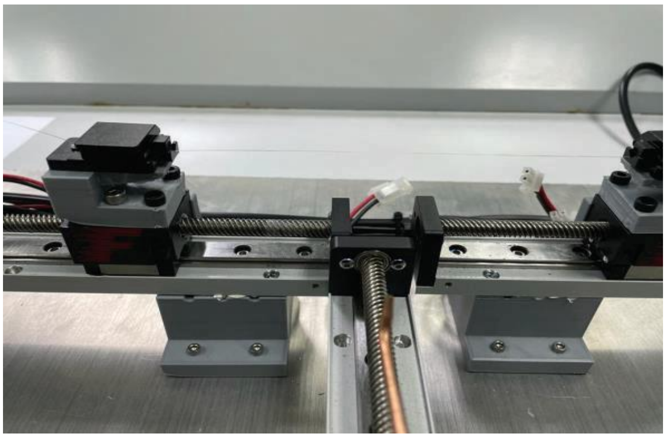


Figure 3.12 Tapering Process

Table 3.2 Step on Tapering Process

NO.	PROCEDURE
1.	 Cut and remove the second layer (cladding) at the center part using stripping tools
2.	 Remove dust by using tissues and alcohol

<table>
<tr><td>3.</td><td>
Placed the microfiber on the grip so to start the process</td></tr>
<tr><td>4.</td><td>
Adjust the flame to be small by controlling the gas and oxygen.</td></tr>
<tr><td>5.</td><td>
The torch moves and heat the center of fiber</td></tr>
</table>

6.	 Stop the process and open the holders carefully
7.	 Placed the tapered microfiber on the board

ii. Fusion splicing

The process of splicing optical fiber involves joining two fiber optic cables together. Termination or connectorization is another common method of joining fibers. A variety of methods and devices are used to install and repair damaged fibers in the field. The three common methods of fiber optic repair are mechanical splicing, field termination, and fusion splicing (Laurence N. Wesson, 2010). In the development of this microfiber sensor are used fusion splicing. Fusion splicing is a process in which fibers are aligned and heated to form a single continuous fiber with no air gaps or misalignments, resulting in effective light transmission. Misalignment of the core axis will arise if there is a little amount of dust between the fiber and the V-groove or if the diameter of the fiber varies (Marcuse, n.d.). Fusion splicing offers numerous benefits in fiber optic communication. It enables low-loss connections, minimizing signal attenuation and ensuring efficient data transmission. The splices exhibit high reliability and stability, making them suitable for demanding environments.

In comparison to mechanical splicing, fusion splicing is more expensive but has a longer lifespan. Fusion splices are also compact, allowing for seamless integration into fiber optic networks and facilitating the deployment of high-speed data connections. For SMF, Fusion splices provide the highest quality connections with the lowest loss within the range of 0.05 dB to 0.2 dB compared to mechanical splices which lose in the range of 0.05 dB to 0.2 dB. Fusion splicing is made using a specialized apparatus for aligning the fiber ends, following which the ends of the glass are "welded" together using an electric arc or some type of heat. The result is a non-reflective, transparent, and continuous connection between the fibers, resulting in low light loss.

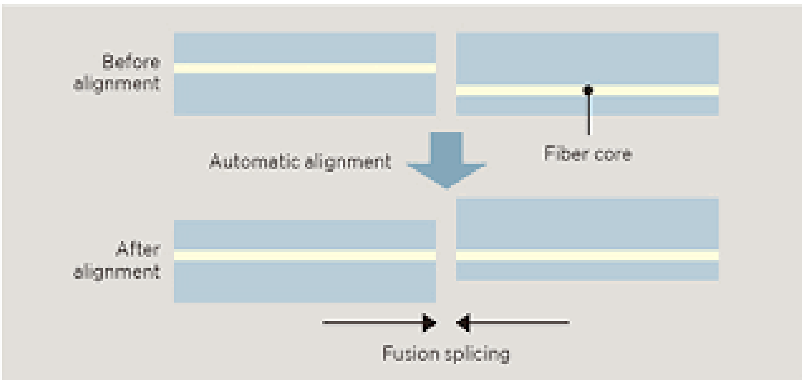


Figure 3.13 Fusion Splicing process

Table 3.3 Steps on Splicing Process

NO.	PROCEDURE
1.	 Cut and remove the second layer (cladding) using stripping tools
2.	 Remove dust by using tissues and alcohol

3.	 Cleave the fiber using hand cleaver
4.	 Insert the fibres into the fibre holders of the fusion splicer. To begin the fusion splicing, press the SET button.

5.	 Result for splicing process
6.	 Place the optical fiber on the board after the splicing process is done

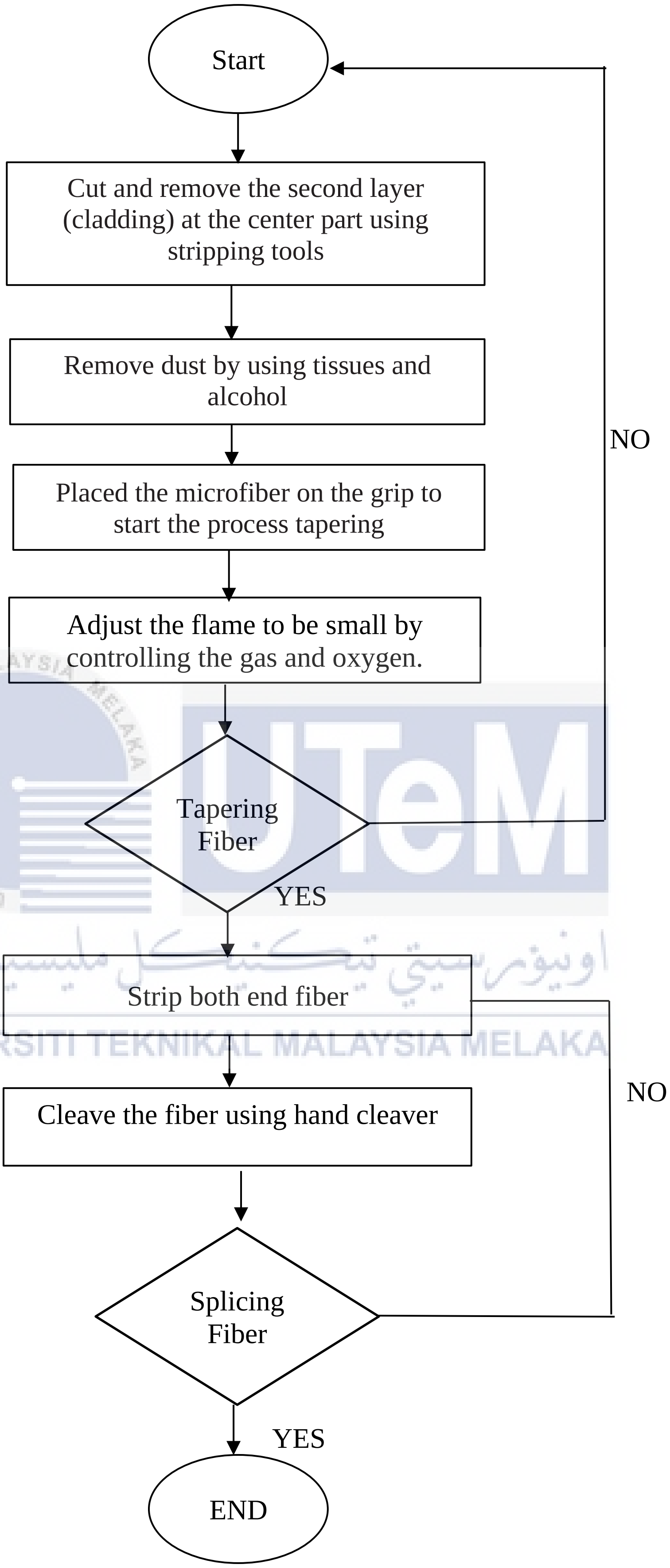
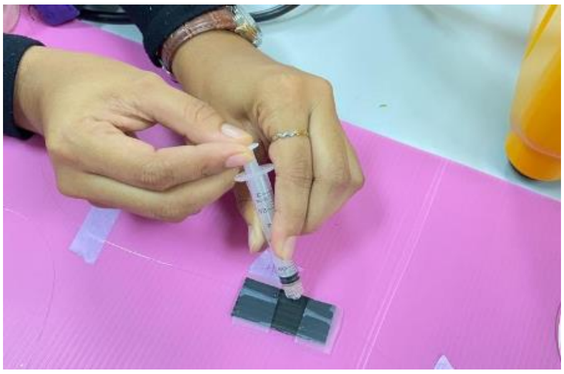
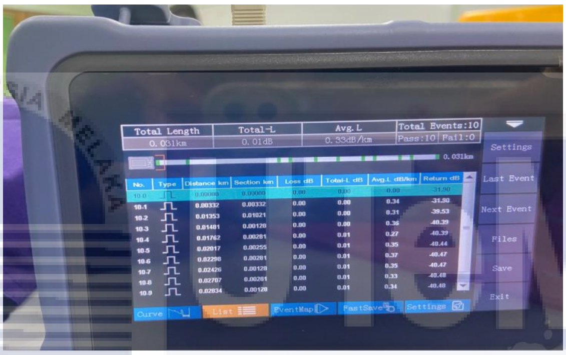


Figure 3.14 Splicing and Tapering Process

3.2.1.5 Output Power Measurement Process

Table 3.4 Steps on Output Power Measurement

No.	Procedure
1.	 Connect one end of the fiber to the OTDR.
2.	 Connect the other end of the fiber to the light source. Set the wavelength either 1550 nm or 1310 nm
3.	 Drop the glucose liquid onto the microfiber tapering part

4.	 Set the wavelength and time as desired and click the ‘Auto Test’
5.	 Record the output and repeat the step for another parameter combination

3.2.1.6 Design of Experiment (DOE) Process

The Design of Experiments method in Box-Behnken Design (BBD) includes defining objectives, determining components and their levels, and choosing a response variable. The BBD algorithm creates a design matrix with a mixture of centre and axial points, making it appropriate for three to five factors. This allows for an effective investigation of different factor combinations. The reliability of the results is improved by randomising the run order. The BBD prepares the groundwork for statistical analysis, including regression and response surface techniques, by carrying out experimental runs and gathering data. The analysis's conclusions provide light on the connections between the response variable and the variables, making it easier to identify the important factors and the best places for them to be. For the sake of replication and future reference, the entire procedure must be documented. The BBD process is an organized and effective method for understanding complex systems and optimizing processes with a limited number of experimental runs.

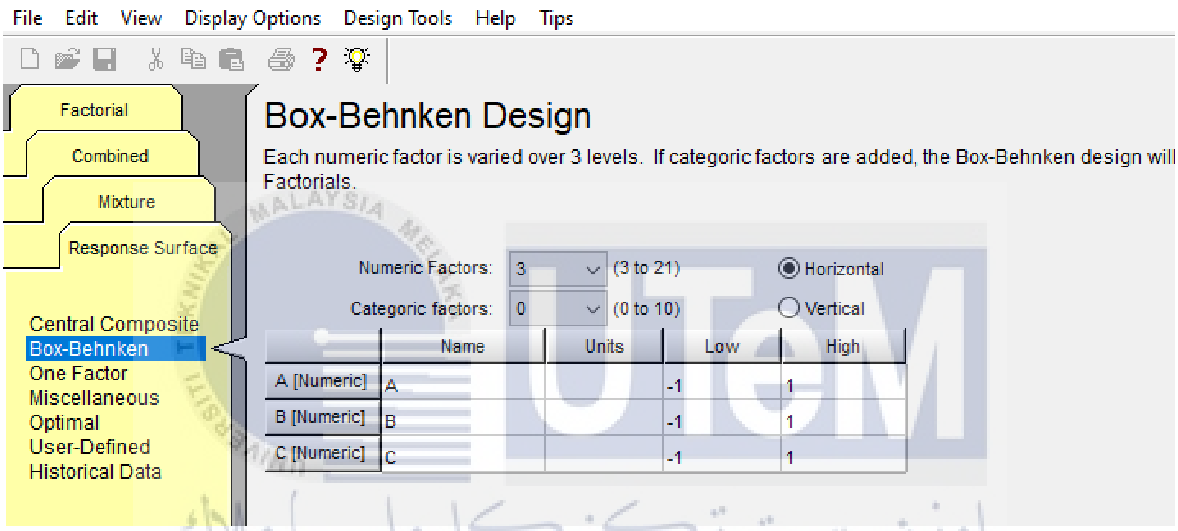


Figure 3.15 Specifying name,units and type of all factors in Box-Behnken Design

Figure 3.12 above show the Box-Behnken Design window in Design-Expert software. Design-Expert is a software program used for designing experiments. In setting up a Box-Behnken Design in software like Design-Expert, defining factors and their respective levels is a crucial step. Factors can be either categorical or numeric, representing independent variables deliberately varied in an experiment. Categorical factors, such as types of materials, are specified with distinct categories, while numeric factors, like diameter, require defining minimum and maximum levels.

Select	Std	Run	Factor 1 A:TYPE OF F...	Factor 2 B:WAVELEN... nm	Factor 3 C:DIAMETER um	Factor 4 D:CONCENT... mmol/L	Response 1 POWER(dB)
	12	1	SINGLE MODE	1310	13.00	4.8	68.04
	4	2	SINGLE MODE	1550	13.00	4.8	69.83
	6	3	MULTIMODE	1310	13.00	4.8	48.18
	1	4	MULTIMODE	1550	13.00	4.8	42.43
	15	5	SINGLE MODE	1310	9.00	4.8	53.39
	16	6	SINGLE MODE	1550	9.00	4.8	51.09
	11	7	MULTIMODE	1310	9.00	4.8	66.97
	5	8	MULTIMODE	1550	9.00	4.8	51.1
	2	9	SINGLE MODE	1310	13.00	9	37.45
	14	10	SINGLE MODE	1550	13.00	9	53.46
	3	11	MULTIMODE	1310	13.00	9	39.53
	13	12	MULTIMODE	1550	13.00	9	48.55
	7	13	SINGLE MODE	1310	9.00	9	48.48
	9	14	SINGLE MODE	1550	9.00	9	60.18
	8	15	MULTIMODE	1310	9.00	9	50.2
	10	16	MULTIMODE	1550	9.00	9	51.62

Figure 3.16 Matrix Design

The figure above show of the matrix table design Design-Expert software provides insights into a successful Box-Behnken design experiment aimed at optimizing a process. The experiment involves four factors: Type of fiber (Factor A), Wavelength (Factor B), Diameter (Factor C), and Concentration (Factor D), with the response variable being Power. The table displays predicted and actual values of the response variable for each experimental run. The "Std" column indicates the standard deviation of the response, and the "Run" column denotes the order of the conducted runs. The highlighted row presents the predicted optimal values for factors A, B, C, and D, which are anticipated to yield the highest response variable value. For instance, the predicted optimal settings include using a single-mode fiber, a wavelength of 1550 nm, a diameter of 9 um, and a concentration of 9%. This proximity suggests that the model accurately predicts optimal settings for maximizing the response variable. In essence, the image showcases the efficacy of the Box-Behnken design in identifying and validating optimal conditions for process optimization.

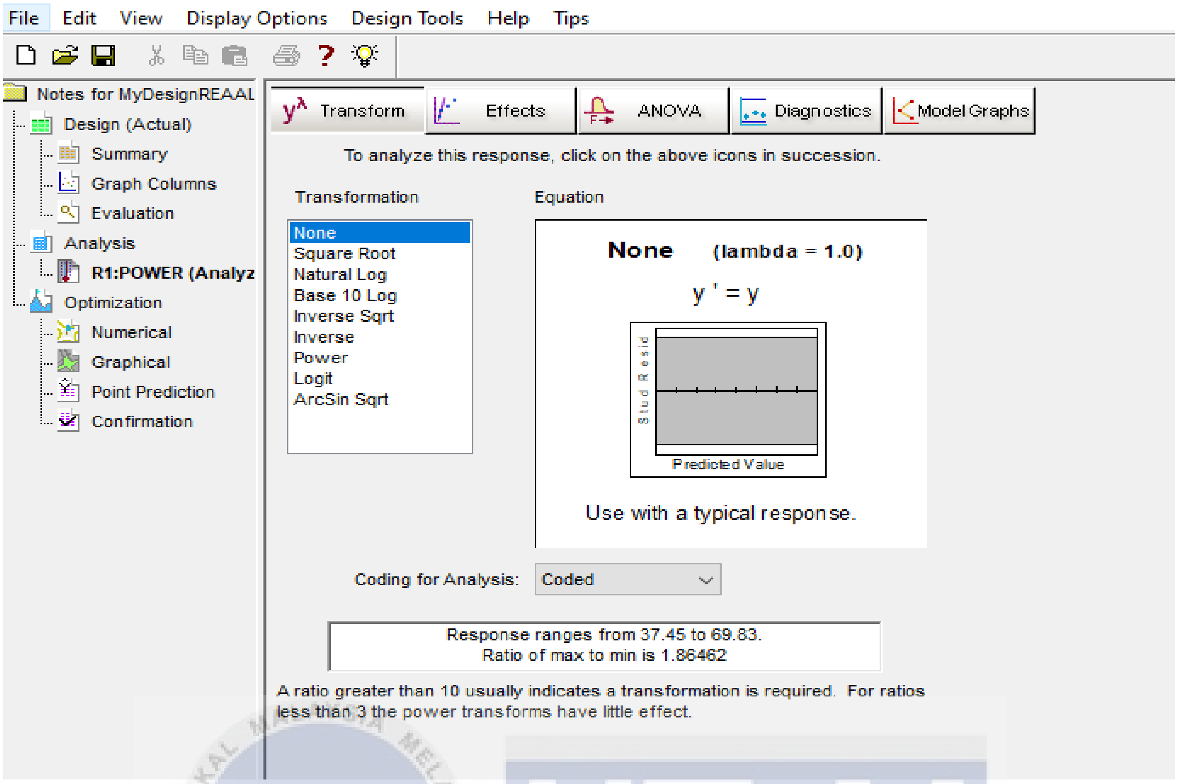


Figure 3.17 Analysis Section

Next, all the values which represents for the factors and responses are analyzed by clicking the "Analysis" section. In this section, there are five tabs that are Transform, Effects, ANOVA, Diagnostics and Model Graphs. The Transform tab is for the transformation of the data. The Effects tab provide some useful tools such as Half Normal Plot and Normal Plot that are used for determining the significant and insignificant effect. As for the ANOVA tab, it provide the analysis of variance for all the signficant effect and the mathematical model for the respone. Then, the analysis process can be continued with the Diagnostics tab which containing several pl ts for the studentizad residuals and constant error and look for the influential values (outliers). Lastly, in Model Graps tab, it provide some graphs tool such as One Factor, Interaction and Cube as tosudy how each factor reacts to the response either by their own or with the interaction with some factors.

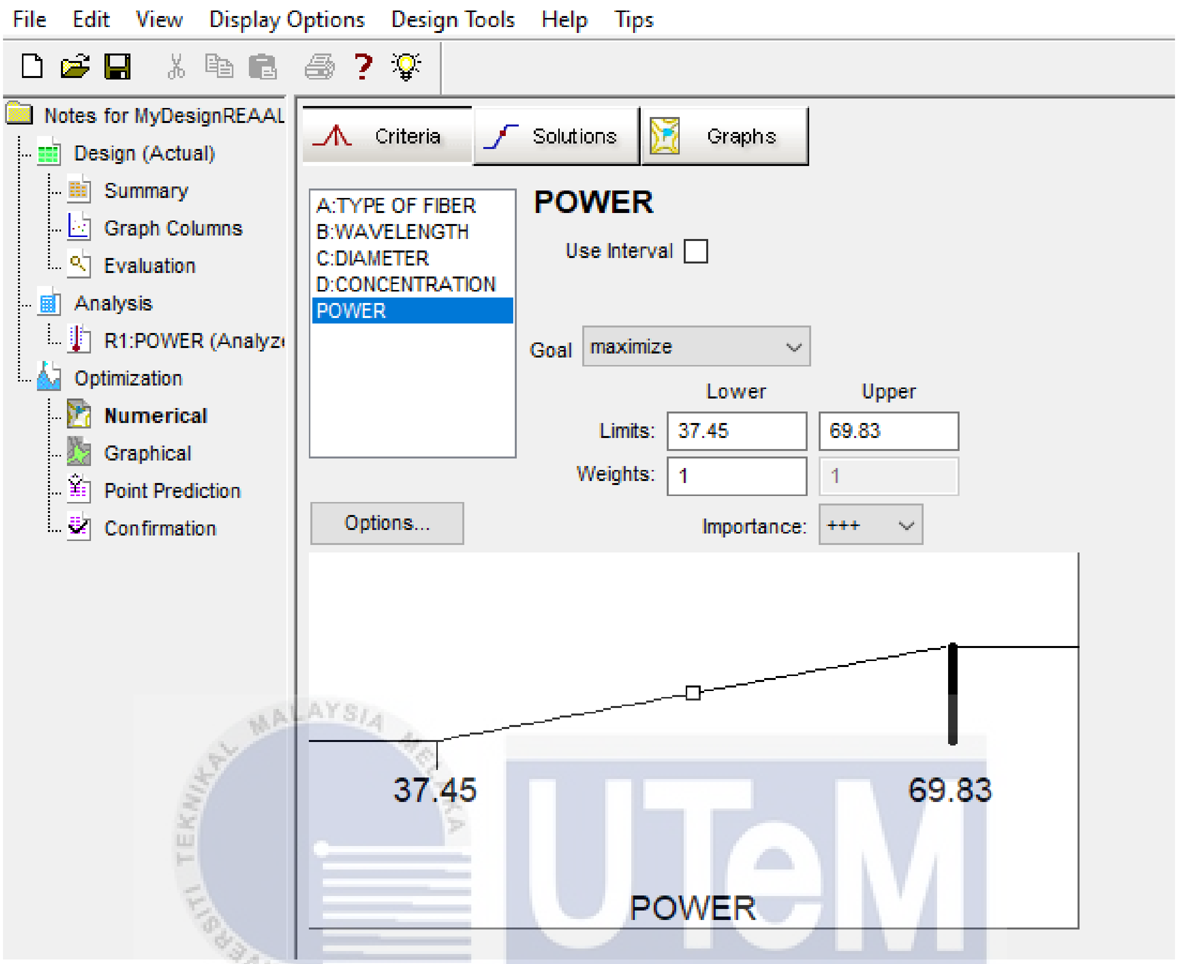


Figure 3.18 Optimization Section

As to end analysis stage and suits with the objective of this research, click on the "Numerical" at the Optimization section as to generate the optimal solutions. The criteria tab provide choices for specifying the goal for each and the response. In this research, the goal for all the response is set to be "maximize" as to obtain the ideal combination of parameters which affecting the optimization of fiber optic to achieve the maximum output power.

3.2.1.7 Type of Analysis

i. Half Normal Plot

The Half Normal Plot is a graphical tool used in DOE (Design of Experiments) to analyses the relevance of elements in a statistical model and identify potential outliers or influencing factors. Researchers frequently explore the influence of numerous variables on the response variable in an experimental design. The Half Normal Plot is very beneficial for investigating trials where the primary purpose is to effectively identify the most relevant components. The absolute values of the estimated impacts of factors are shown as a function of their corresponding factor combinations to generate a half normal plot. These combinations are frequently graded in terms of impact magnitude. Researchers can use the Half Normal Plot to visually discriminate between significant and non-significant effects. Factors with a greater plot absolute value are considered more influential. If a point falls above a certain threshold line on the half-normal curve, it indicates that the corresponding factor has a significant effect on the response variable. Conversely, scores below the threshold indicate factors with less influence. This graphical representation helps researchers prioritize factors for further study or improvement in subsequent experiments. In conclusion, the Half Normal Plot is a valuable tool in the early stages of experimental design to help researchers effectively identify key factors and guide the optimization of experimental conditions.

ii. Normal Plot

A normal plot is a graphical tool used in DOE (Design of Experiments) to assess the normality of a statistical model's residuals. The disparities between observed and expected values are known as residuals, and their normal distribution is a crucial assumption in many statistical analysis. The normal plot is especially useful for verifying this assumption. A normal plot is created by plotting ranked residuals based on the predicted rank statistics of a conventional normal distribution. If the residuals on the graph follow a straight line, the assumption of normality is acceptable. Deviations from a straight line can be a sign of deviations from the normal, such as deflection or deviations. Researchers usually use a normal plot after fitting a statistical model to experimental data. If the curve shows an approximately straight line, this gives confidence in the assumption of normality, which supports the correctness of subsequent statistical inferences. On the other hand, if the graph shows significant deviations, it can prompt researchers to investigate the source of the deviation and consider alternative modeling methods. In summary, the standard DOE plot serves as a diagnostic tool to assess the normality of the residuals, helping researchers to ensure the appropriateness of the statistical model and the reliability of subsequent analyses. Deviations from a straight line can be a sign of deviations from the normal, such as deflection or deviations. Researchers usually use a normal plot after fitting a statistical model to experimental data. If the curve shows an approximately straight line, this gives confidence in the assumption of normality, which supports the correctness of subsequent statistical inferences. On the other hand, if the graph shows significant deviations, it can prompt researchers to investigate the source of the deviation and consider alternative modeling methods. In summary, the standard DOE plot serves as a diagnostic tool to assess the normality of the residuals, helping researchers to ensure the appropriateness of the statistical model and the reliability of subsequent analyses.

iii. ANOVA Analysis

ANOVA, often known as analysis of variance, is a statistical approach used in design of experiments (DOE) to examine the significance of differences in averages across different groups or levels in experimental research. DOE employs ANOVA to study the variation of response variables caused by multiple factors and their interactions. The basic idea is to separate a response variable's total observed variation into distinct components, such as variance due to individual factor main effects and variance due to factor interactions. ANOVA analysis evaluates the variance ratios of several components. The F statistic generates groups inside groupings. A higher F statistic suggests a greater disparity in group means. The researchers then use this statistic to test whether the observed differences are statistically significant or could be due to chance. A significant F statistic indicates that at least one factor or interaction has a significant effect on the response variable. ANOVA is a powerful DOE tool to help identify influential factors in test results. It also helps to understand the relative importance of different factors and their interaction. ANOVA results play a crucial role in guiding researchers to make informed decisions about process or system optimization by focusing their efforts on the most influential factors. In general, ANOVA is the main statistical technique in the analysis phase of DOE and provides valuable information about the sources of variation in experimental data.

iv. Normal of Residual

The evaluation of residual normality is a crucial aspect of statistical analysis in the field of design of experiments (DOE). The residuals are the disparities between the observed and expected values of the response variable. A normal probability plot of residuals is a graphical tool used to determine whether these residuals follow a normal distribution. The fundamental assumption is that residuals must be regularly distributed in order for statistical inferences generated from experimental data to be valid.To create a normal probability plot of the residuals, the ordered residuals are plotted against the expected quantiles of the standard normal distribution. If the points on the graph form an approximate straight line, this indicates that the residuals follow a normal distribution. On the other hand, deviations or patterns in a chart can indicate deviations from the norm, such as trends or outliers. Analysis of the normal probability plot of the residuals is critical for DOE operators to ensure the assumption of normality and the accuracy of the statistical model. Non-normality of residuals can affect the reliability and confidence interval of hypothesis testing. Identifying and dealing with deviations from normality allows researchers to make more reliable statistical inferences and ensure the validity of conclusions drawn from experimental data. In conclusion, the normal probability plot of residuals is a valuable diagnostic tool in DOE to help researchers assess the normality of residuals and increase the confidence of statistical analyses.

v. Residual vs Predicted Plot

A residual versus predicted plot is a typical graphical tool used in statistical analysis, particularly design of experiments (DOE), to evaluate the fit of a regression or prediction model. This graphic aids in evaluating the model and performance in the DOE setting, where the goal is frequently to understand the link between the input components and the response variable. The residuals (differences between the observed and predicted values of the response variable) are represented as a function of the predicted values itself in the predicted plot. The horizontal axis represents the predicted values, while the vertical axis represents the corresponding residual values. A well-fitted model would have a random spread of scores around zero on the vertical axis, indicating that the residuals are uniformly distributed in the range of predicted values. Patterns or trends in the residual versus predicted curve can reveal important information about the model and performance. If the graph shows a systematic pattern (such as a curve, an increasing or decreasing trend), this indicates that the model may not adequately capture the underlying relationships in the data. Additionally, the plot can help identify outliers or influential observations that may disproportionately affect the model and performance. Analyzing the residuals and predicted plot analysis is necessary to confirm the assumptions of the regression model and ensure the adequacy of the model to make reliable predictions.

vi. One Factor Effect Plot

A one factor effect plot is a graphical representation of a single factor's effect on a response variable that is commonly used in design of experiments (DOE). Researchers at DOE experiment with various parameters to see how they effect a desired outcome. A one-factor effect plot is particularly useful for evaluating the effect of a single variable while controlling for other variables. The response variable's values are shown on the vertical axis, while the levels or values of the factor under investigation are shown on the horizontal axis. The average reaction at a given factor level or value is represented by each point on the graph. Researchers can see trends or patterns in how changes in the factor correspond to changes in the response variable by visually inspecting a one-factor effect plot. A plot might illustrate a linear relationship, a non-linear trend, or other notable patterns. A one-factor effect plot is useful for determining the impact of a single factor on the outcome of an experiment. This assists researchers in identifying appropriate amounts of agent to generate desired reactions, as well as guiding decisions about process optimization or more testing. The single-factor effect diagram is a useful tool for visualizing and evaluating the impacts of individual factors in DOE studies in general.

vii. Interaction Effect Plot

An interaction effects diagram is a graphical representation of the combined effect of two or more factors on a response variable that is commonly used in design of experiments (DOE). Researchers frequently explore not only the individual effects of components, but also how these elements interact with one another in experimental design. The interaction effect plot is very useful for visualizing and comprehending the interplay of variables on test outcomes. The values of the response variable are represented on the vertical axis of this graph, while the levels or values of the two interacting factors are plotted on the horizontal axis. Different lines or curves on the graph indicate the reaction with various combinations of factor values, allowing researchers to see how the components interact.

An interaction effect plot analysis can assist researchers determine whether the effect of one factor on a response variable is dependent on the amount of another component. The plot may show parallel lines suggesting no interaction, or lines that cross or diverge showing interaction. Understanding interaction effects is crucial for optimizing processes or systems since it provides insight into how a range of factors affect experiment findings. Interaction effect plots assist researchers in making informed decisions about how factors interact and in adjusting experimental conditions to optimize performance. The Interaction Effect Plot is a useful tool for visualizing and interpreting the interaction of components in DOE studies, allowing researchers to improve their capacity to optimize processes and obtain desired results.

3.3 Limitation of proposed methodology

A limitation of the proposed methodology for developing a microfiber sensor to detect glucose conditions in the pharmaceutical industry is its reliance on a specific type of microfiber material. The methodology assumes that the microfiber material will consistently produce accurate and reliable results, but it may not account for variations in the composition or quality of the material. This could limit the methodology's effectiveness in detecting glucose conditions in certain contexts, such as when using a different type of microfiber material or when the quality of the material varies. To address this limitation, further research could explore alternative microfiber materials or additional controls to ensure consistent results across different materials.

Next, the tapering process also will be the limitation of this project which is for fiber processing that assumes a uniform fiber structure and behavior throughout the length of the fiber. However, in reality, fibers may have variations in diameter, strength, and other properties that affect their behavior during processing. This can lead to uneven tapering or other issues that reduce the quality or consistency of the final product. To address this limitation, further research could explore alternative tapering approaches that account for variations in fiber properties, such as using different processing parameters at different points along the fiber to achieve a more uniform taper. Additionally, incorporating in-line monitoring or feedback systems could help to detect and correct any inconsistencies or deviations during the tapering process.

3.4 Summary

This chapter presents the proposed methodology for the development of a microfiber sensor for detecting glucose conditions. The proposed methodology provides a systematic strategy to designing a microfibre sensor for monitoring glucose condition. It entails employing Design of Experiments (DOE) and Box-Behnken Design (BBD) to optimise important factors such as wavelength, microfibre diameter, and glucose content. The experimental setup involves steps such as microfiber preparation, coating with a glucose-specific enzyme, and validation with glucose samples. Tapering and fusion splicing are well-documented fabrication procedures. The methodology comprises multiple types of studies, which provide insights into the relevance of components, residual normalcy, and interaction effects. However, there are several limitations, such as dependency on a specific microfibre material and assumptions about homogenous fibre architectures. Exploring different materials and tapering methodologies to address these constraints could improve the methodology's durability in glucose monitoring applications in the future.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter focuses on presenting the results and analysis derived from the development of microfiber sensors using the Design Expert software and the Box-Behnken Design (BBD) optimization parameters approach. The purpose of this study was to investigate and enhance the capabilities of microfiber sensors in detecting glucose conditions.

4.2 Experimental Setup

Figure 4.1 provides specifics on the experimental setup used for this study and illustrates how an optical fiber sensor for glucose condition sensor measures power. As seen in Figure 4.1, this experiment involves introducing the glucose liquid to be evaluated to a fiber optic sensor. To determine the concentration of the tested glucose, the fiber optic cable directs light from a chosen light source through an excitation light. Subsequently , the obtained data is transferred to the table for further processing. Design Expert software is then utilized to analyses the results and perform optimization, as shown in figure 4.2. This experiment facilitates a comprehensive assessment of the test results, providing crucial detail about the detecting glucose condition.

Figure 4.1 Schematic of Optical Fiber Sensor for Glucose Concentration

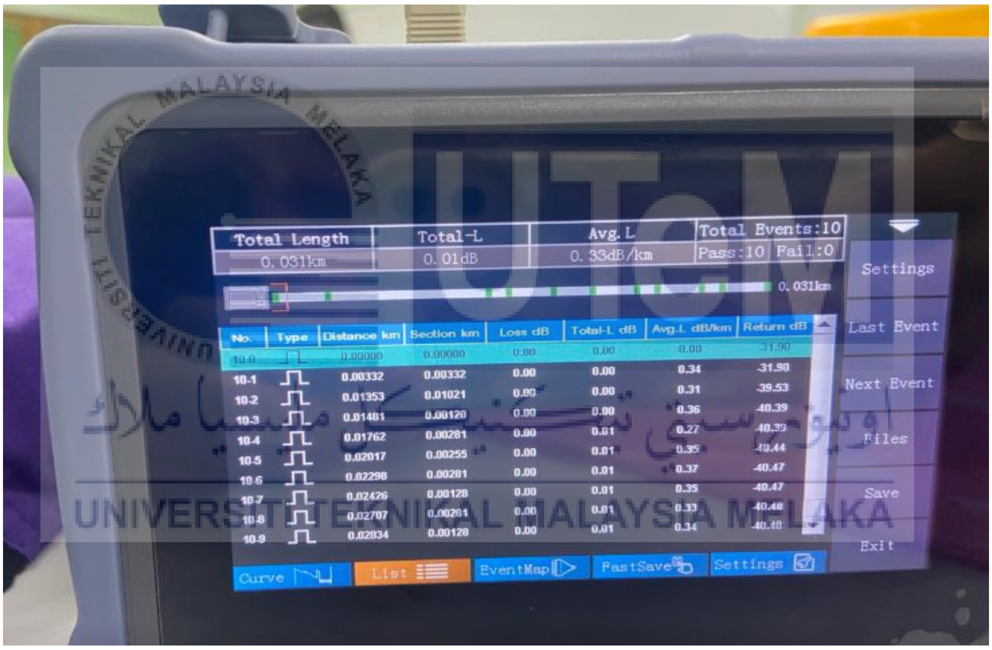


Figure 4.2 The Output Power display on OTDR

4.3 Results and Analysis

The experiment data and result have been collected for two levels of glucose concentration. A total of 16 data were collected , with each level having 8 data. The output power corresponding to the concentration of glucose was analyzed for the 8 combination of its parameters which are the type of fiber, wavelength, diameter of fiber and concentration.

4.3.1 Experiment Result

Table 4.1 Experiment Result of Output Power

NO	TYPE	WAVELENGTH	DIAMETER	GLUCOSE LEVEL	OUTPUT POWER(dB)
1.	Single Mode	1310nm	13µm	4.8mmol/L	68.04
2.	Single Mode	1550nm	13µm	4.8mmol/L	69.83
3.	Multi-Mode	1310nm	13µm	4.8mmol/L	48.18
4.	Multi-Mode	1550nm	13µm	4.8mmol/L	42.43
5.	Single Mode	1310nm	9µm	4.8mmol/L	53.39
6.	Single Mode	1550nm	9µm	4.8mmol/L	51.09
7.	Multi-Mode	1310nm	9µm	4.8mmol/L	66.97
8.	Multi-Mode	1550nm	9µm	4.8mmol/L	51.1
9.	Single Mode	1310nm	13µm	9 mmol/L	37.45
10.	Single Mode	1550nm	13µm	9 mmol/L	53.46
11.	Multi-Mode	1310nm	13µm	9 mmol/L	39.53
12.	Multi-Mode	1550nm	13µm	9 mmol/L	48.55
13.	Single Mode	1310nm	9µm	9 mmol/L	48.48
14.	Single Mode	1550nm	9µm	9 mmol/L	60.18
15.	Multi-Mode	1310nm	9µm	9 mmol/L	50.2
16.	Multi-Mode	1550nm	9µm	9 mmol/L	51.62

Table 4.1 shows the experiment result of glucose concentration. The output power was observed by using a light source and Optical Time Domain Reflectometer (OTDR). The OTDR will present the reading of output power.

4.3.2 Result Analysis

The results from Table 4.1 are inserted into the Design Expert Software. using the software, the studied parameters studied are evaluated for significance and interactions, and the optimal combination of parameters is identified for glucose concentration. Based on the analysis, a half normal plot is generated to identify the significant parameters and interactions influencing the output power. These significant parameters are then further analyzed and summarized in an Analysis of Variance (ANOVA) table.

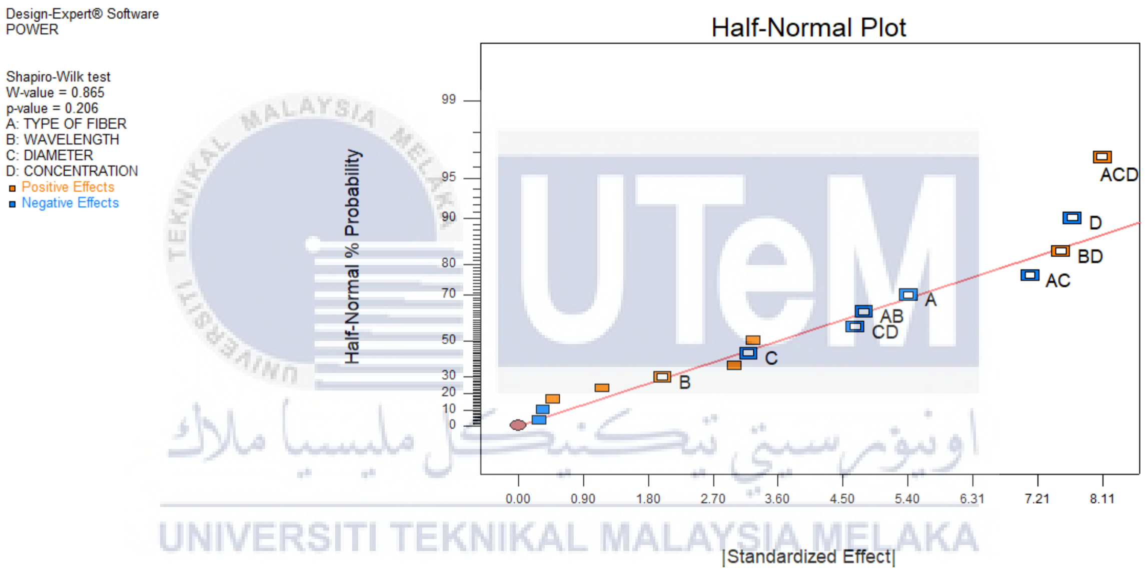


Figure 4.3 Half-Normal Plot for first level glucose concentration

Figure 4.3 shows a half-normal plot of internally studentized residuals, used to assess the normality of errors within a linear regression model. The x-axis displays the standardized effect, representing how much each residual deviates from the fitted line in standard deviation units,Meanwhile, the y-axis illustrates the half-normal probability. A red line on the graph represents the expected pattern for normally distributed errors, with points ideally aligning with this line if the errors conform to a normal distribution. Blue lines denote the

95% confidence limits for the normal distribution, and points outside these lines suggest potential deviations from normality.

In this instance, the points cluster closely around the red line, indicating that the errors are reasonably normally distributed. This adherence to normality is crucial for linear regression models, enabling the use of statistical tests grounded in the normal distribution. The graph also features labeled points A, B, C, and D, potentially corresponding to distinct groups of observations within the dataset. The left side of the y-axis displays half-normal probability percentages, while the right side of the x-axis exhibits standardized effects. Overall, the graph visually confirms that the errors in the linear regression model adhere to normal distribution assumptions, validating the application of pertinent statistical tests.

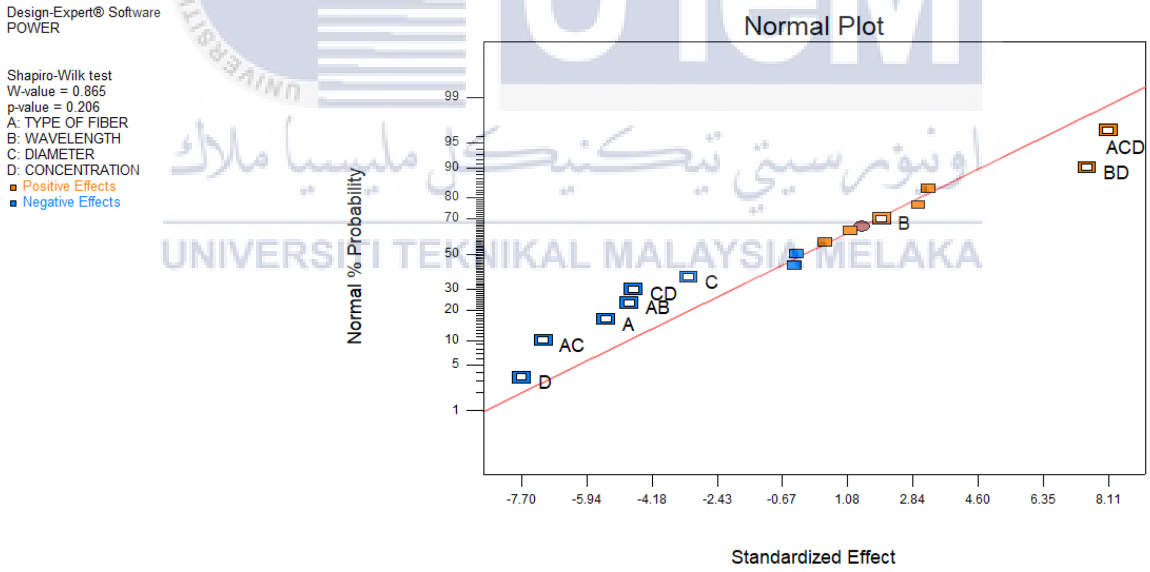


Figure 4.4 The Normal Plot Graph

The graph above provides a comprehensive visualization of the normality assessment for the errors in a linear regression model. On the X-axis, we observe the standardized residuals, quantifying how much each data point deviates from the fitted regression line in standard deviation units. The Y-axis, depicts the expected cumulative probability of these standardized residuals, assuming a normal distribution of errors. The red line, representing the theoretical cumulative probability for a normal distribution, serves as a benchmark. When the actual data points closely align with this line, it indicates that the errors in the model adhere to a normal distribution.

Additionally, the blue lines delineate the 95% confidence interval for the normal distribution. The majority of data points falling within these lines instills confidence in the normality assumption. In the specific case, the data points exhibit a general alignment with the red line, and most fall within the confines of the blue confidence interval. This convergence suggests that the errors in the model are likely normally distributed. Such adherence to normality is pivotal for linear regression models, enabling the application of statistical tests that rely on the normality of errors. Overall, the graphical representation provides a reassuring indication of the appropriateness of the normality assumption in the context of the linear regression model.

Table 4.2 ANOVA of Output Power Glucose Concentration

Analysis of variance table [Partial sum of squares - Type III]

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1282.66	9	142.52	9.97	0.0056	significant
A-TYPE OF I	*117.40*	*1*	*117.40*	*8.21*	*0.0286*	
B-WAVELEN	*16.04*	*1*	*16.04*	*1.12*	*0.3303*	
C-DIAMETEF	*40.83*	*1*	*40.83*	*2.86*	*0.1420*	
D-CONCENT	*236.85*	*1*	*236.85*	*16.56*	*0.0066*	
AB	*92.06*	*1*	*92.06*	*6.44*	*0.0442*	
AC	*201.92*	*1*	*201.92*	*14.12*	*0.0094*	
BD	*227.10*	*1*	*227.10*	*15.88*	*0.0072*	
CD	*87.52*	*1*	*87.52*	*6.12*	*0.0482*	
ACD	*262.93*	*1*	*262.93*	*18.39*	*0.0052*	
Residual	85.79	6	14.30			
Cor Total	1368.45	15				

Std. Dev.	3.78	R-Squared	0.9373
Mean	52.53	Adj R-Squared	0.8433
C.V. %	7.20	Pred R-Square	0.5542
PRESS	610.07	Adeq Precisior	9.371

The table 4.2 presents the Analysis of Variance (ANOVA) table, utilizing Type III sum of squares. This method is specifically designed to assess the impact of multiple factors on a continuous dependent variable, considering hierarchical relationships between these factors. The breakdown of the table components offers valuable insights into the significance and contribution of each factor or interaction.

In the "Source" column, factors A, B, C, and D are listed, alongside two-way interactions (AB, AC, AD, BC, BD, and CD) and a three-way interaction (ACD). The "Sum of Squares (SS)" column indicates the variability in the dependent variable attributed to each factor or interaction, with higher values signifying a more substantial influence. Degrees of freedom (df) reveal the number of independent comparisons that can be made for each factor or interaction. Mean Square (MS), obtained by dividing SS by df, facilitates comparisons across factors with differing degrees of freedom. The "F Value" column displays the F statistic, where higher values imply a stronger effect of the factor or interaction on the dependent variable. The p-value denotes the probability of observing the F value by chance, with lower values indicating statistical significance. Upon analysis of the specific values in the table, it becomes evident that all model terms (A, B, C, D, AB, AC, AD, BC, BD, CD, and ACD) explain a significant portion of the variance in the dependent variable, supported by their considerable sum of squares values. Additionally, the F values for all model terms are statistically significant (p-values < 0.05), emphasizing the meaningful impact of each factor and interaction.

Table 4.3 Output Power Equation

POWER =+52.53-2.71 * A+1.00 * B-1.60 * C-3.85* D-2.40 * A * B-3.55 *A * C+3.77* B * D-2.34 * C * D+4.05* A * C * D

The provided equation represents a power equation that captures the relationship between the transferred power (POWER) and several influencing variables. denoted as A, B, C, and D. Each of thee represents physical quantities affecting power transfer. The equation also includes interaction terms (A * B, A * C, B * D, C * D, and A * C * D) signifying combined effects. The coefficients accompanying each variable indicate both the strength and direction of their influence on power transfer. Positive coefficients imply a direct relationship, while negative coefficients suggest an inverse correlation.

For instance, a positive coefficient for A (52.53) suggests that as A increases, the transferred power also increases. Conversely, a negative coefficient for B (-2.71) implies that an increase in B corresponds to a decrease in power transfer. The interaction terms introduce complexity by illustrating how the influence of one variable can be contingent on the values of others. For example, a negative coefficient for A * B (-2.40) implies that the combined effect of A and B on power transfer is negative, indicating a potential decrease in power transfer even with an increase in A if B is sufficiently high. In essence, this equation serves as a mathematical model delineating the intricate dependencies between various physical quantities and their interactions in the context of power transfer. The specific interpretation of the equation hinges on the contextual relevance of the variables involved.

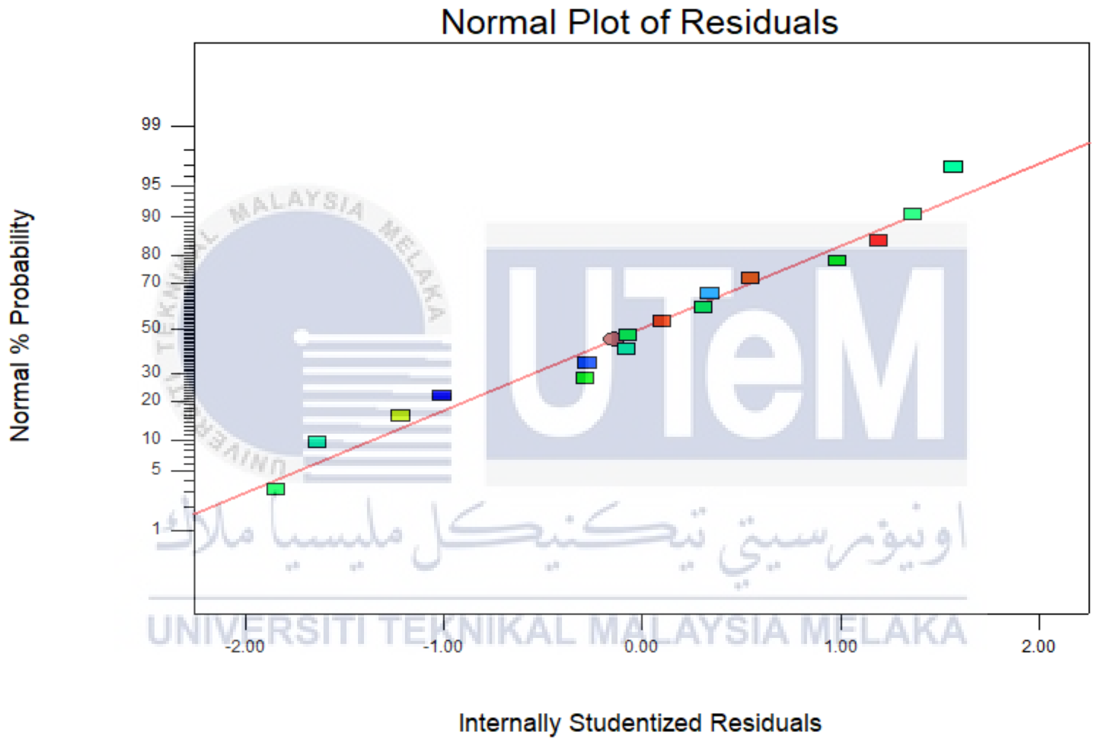


Figure 4.5 The Normal Plot of Residuals

Figure 4.5 shows, the normal plot of residuals is a graphical diagnostic tool used to assess whether the errors in a statistical model are normally distributed. In other words, it helps to check if the residuals (the difference between the predicted and actual values) follow a normal distribution. The normal plot is interpreted by examing how closely the points follow a straight line. If the points fall roughly along a straight line, it is an indicates that the residuals are normally distributed. Deviation from the straight line suggests non-normal distribution of residuals.

The graph above shows the points do not fall exactly on a straight line, but they are fairly close. This suggests that the errors are not perfectly normal, but they are not too far from normal either. This is often good enough for many statistical analyses.The red line in the plot is the line that would be expected if the errors were perfectly normal. The blue points are the actual standardized residuals. The text at the top of the plot says "Internally Studentized Residuals" and "Normal % Probability". These are two different ways of calculating the standardized residuals, and they can sometimes give slightly different results.

The numbers at the right of the plot show the values of the predictor variable for each data point. The bottom of the plot shows the scale of the standardized residuals. Overall, the normal probability plot in the graph show the errors in the statistical model are not perfectly normal, but they are not too far from normal either. This is often good enough for many statistical analyses.

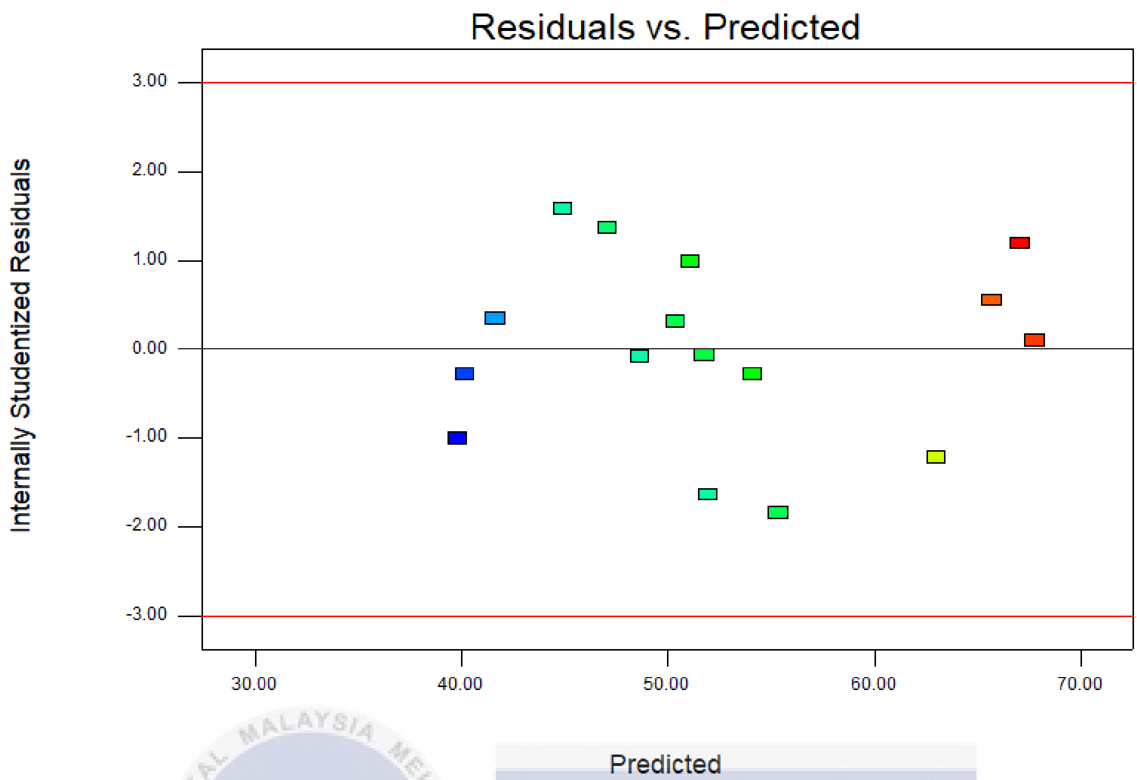


Figure 4.6 The Residuals vs. Predicted ResponseValue Graph

The plot displays the relationship between predicted and observed values, with the x-axis representing predicted values and the y-axis indicating residuals. Ideally, a random scatter around the zero line suggests a well-captured relationship between variables. However, the plot reveals non-random patterns, specifically increasing residuals as predicted values rise. This pattern is termed heteroscedasticity, indicating varying residual variance across predicted values. Heteroscedasticity poses challenges for accurate statistical analysis, potentially stemming from a non-linear relationship between variables or the presence of outliers not adequately accounted for by the model. Addressing these issues is crucial for drawing valid conclusion from the data .

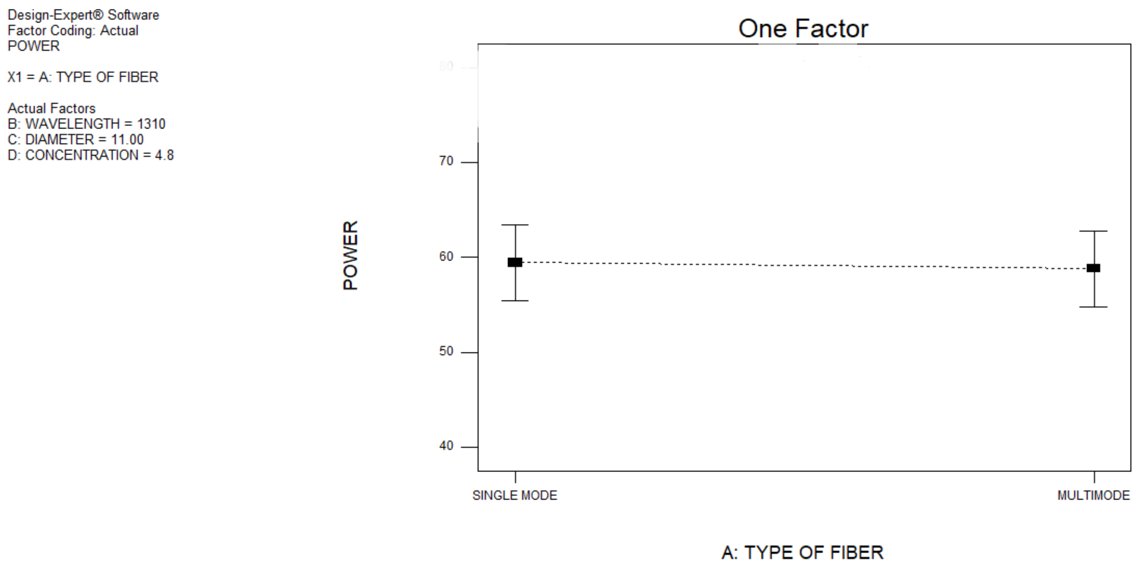


Figure 4.7 One Factor Effect Plot for (Type of fiber)

The graph title of "One Factor". The graph shows a relationship between power and fiber type. The x-axis is labeled "A TYPE OF FIBER" and is listed as Single Mode and Multimode. The y-axis is labeled "POWER" but has no units. The graph illustrates that the power output of the fiber optic cable increases with fiber concentration up to a certain point, beyond which it starts to decrease. This decrease is attributed to higher fiber concentrations absorbing transmitted light. Notably, the single-mode cable consistently exhibits higher power output than the multimode cable across all concentrations. This superiority stems from the single-mode cable's ability to transmit only one mode of light, resulting in less loss due to scattering compared to the multimode cable, which can transmit multiple modes, leading to greater scattering-induced light loss.

There are a few possible explanations for this relationship. One possibility is that Single Mode fibers have a smaller core diameter than Multimode fibers. The core is the central part of the fiber where light travels. Light travels through the core by bouncing off the sides of the core. In a Single Mode fiber, the smaller core diameter forces the light to travel in a single path. This reduces the amount of scattering that occurs, which can attenuate the signal. As a result, more power is transmitted through the fiber.

Another possibility is that the refractive index of the core and cladding is different for Single Mode and Multimode fibers. The refractive index is a measure of how much light bends when it passes through a material. In a Single Mode fiber, the core has a higher refractive index than the cladding. This difference in refractive index helps to confine the light to the core. In a Multimode fiber, the core and cladding have a smaller difference in refractive index. This allows light to travel in multiple paths through the core. The different paths that the light takes can cause the signal to be spread out in time, which can lead to intersymbol interference. Intersymbol interference is a type of distortion that can occur when the signal from one symbol overlaps with the signal from another symbol. It can make it difficult to recover the original data from the signal.The specific relationship between power and fiber type will depend on the specific properties of the fibers, such as the core diameter, the refractive index of the core and cladding, and the wavelength of the light being transmitted.

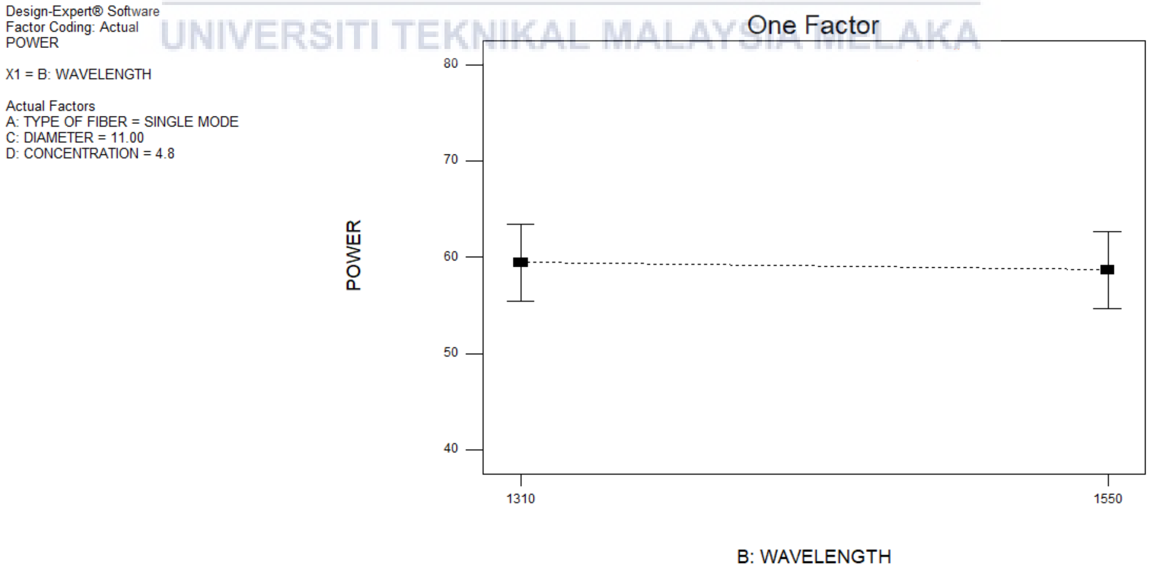


Figure 4.8 One Factor Effect Plot for (Wavelength)

The graph above to depict the outcomes of an experiment examining the impact of various factors on the power output of a single-mode optical fiber. The investigated factors include the wavelength of the light passing through the fiber, the diameter of the fiber core, and the concentration of a dopant within the fiber core.The graph reveals that the power output of the fiber is maximized around a wavelength of approximately 1310 nanometers, and it diminishes as the wavelength deviates from this peak. This decline in power output is attributed to the fiber's design, which is optimized for efficiency at this specific wavelength. Additionally, the graph illustrates that the power output decreases as the diameter of the fiber core decreases and as the concentration of the dopant in the core increases.

The specific numerical values for power output, wavelength, diameter, and dopant concentration depend on the characteristics of the particular fiber under study, the overarching trends highlighted in the graph are representative of typical behaviors observed in single-mode optical fibers.

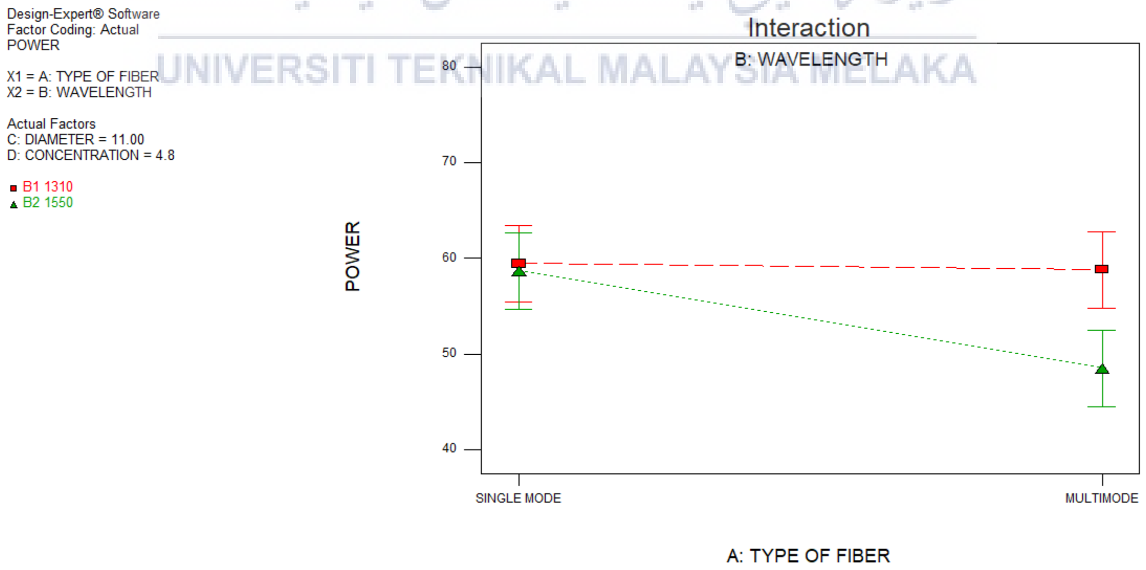


Figure 4.9 Interaction Effect Plot for (Wavelength and Type of Fiber)

The figure 4.9 above represent of an experiment investigating the interaction between different factors, specifically the type of fiber and the wavelength of light. Utilizing Design-Expert software with factor coding based on actual values, the graph plots power on the y-axis against wavelength on the x-axis. There are two lines on the graph labeled "B1 1310" and "B2 1550," likely indicating the power output of two distinct types of fibers at different wavelengths, with "1310" and "1550" representing the wavelengths in nanometers.

The presence of the term "Interaction" in the text at the top of the graph suggests that the experiment explores how these factors interact with each other and influence the power output. The use of actual factor coding implies that real values were employed in the experimental design.The red line, denoted as "B1 1310," likely represents the power output of a specific fiber type at a wavelength of 1310 nanometers. Simultaneously, the green line, labeled "B2 1550," seems to depict the power output of another fiber type at a wavelength of 1550 nanometers. The graph further reveals that both fiber types exhibit higher power outputs at shorter wavelengths, attributable to the increased energy of shorter light wavelengths. Ultimately, the findings emphasize that, across all wavelengths, single-mode fiber consistently outperforms multimode fiber in power output due to its smaller core and the more direct path the light takes through it.

Additionally, the comparison between the two lines indicates that the "B1" fiber generally outperforms the "B2" fiber in terms of power output, particularly at a wavelength of 1310 nanometers. This suggests that, for transmitting light at this specific wavelength, the "B1" fiber is a preferable choice. The graph thus provides valuable insights into the interaction between fiber type and wavelength in influencing power output, aiding in making informed decisions about fiber selection for optimal performance in specific conditions.

4.4 Optimization Result

Table 4.4 below shows the optimization criteria setting for the concentration of glucose for the responses according to the variables studied in the experiment. From the setting, the analysis in Design Expert listed 100 optimization solutions with the output power obtained as can be seen in Table 4.5. This experiment is intended for optimization research, which it is attempted to find the maximum setting of parameters that let the sensor to measure which causing the sensor can identify the factors or response where it is most efficient to identify and determine the level of glucose in human blood. The data collected can serve the purpose of the experiment. The result obtained by response optimization in Design Expert showed as below:

Table 4.4 Optimization Criteria Setting

Constraints

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A:TYPE OF FIE	is in range	SINGLE MODE	MULTIMODE	1	1	3
B:WAVELENG	is in range	1310	1550	1	1	3
C:DIAMETER	is in range	9	13	1	1	3
D:CONCENTRA	is in range	4.8	9	1	1	3
POWER	maximize	37.45	69.83	1	1	3

Table 4.4 provides a comprehensive overview of the limitations associated with a fiber optic connection, detailing information for each limitation, including its name, lens, lower and upper limits, lower and upper weight, and overall weight. The table employs a systematic approach to prioritize constraints based on their importance, aiding in decision-making during fiber optic connections. Each row in the table corresponds to specific parameters such as fiber type, diameter, wavelength, and power. For instance, a type constraint specifies that a fiber must be either SingleMode or MultiMode. The inclusion of weights for both lower and upper limits serves to calculate the overall importance of each constraint. If the weights are equal, the limit is considered equally important.

However, differing weights indicate varying importance between lower and upper bounds. The importance value assigned to each limitation helps guide the decision-making process. Constraints with higher importance values take priority, influencing the selection of fiber that aligns with those specific limits. This approach allows for a systematic evaluation and prioritization of constraints associated with fiber optic connections, ensuring that decisions align with the most critical limitations, even if other constraints are not fully satisfied.

Table 4.5 Optimization Solution (8 over 100 solutions displayed)

Solutions for 8 combinations of categoric factor levels

Number	TYPE OF FIBER	WAVELENGTH	DIAMETER	CONCENTRATION	POWER	Desirability	
1	SINGLE MODE	1310	13.00	4.8	67.8025	0.937	Selected
2	SINGLE MODE	1550	13.00	4.8	67.0675	0.915	
3	MULTIMODE	1310	9.00	4.8	65.7	0.872	
4	SINGLE MODE	1550	9.00	9	62.9975	0.789	
5	MULTIMODE	1550	9.00	4.8	55.37	0.553	
6	MULTIMODE	1550	9.00	9	51.78	0.443	
7	SINGLE MODE	1310	9.00	9	48.6625	0.346	
8	MULTIMODE	1310	9.00	9	47.04	0.296	

8 Solutions found

The table 4.5 shows eight solutions for a combination of categorical factor levels. The levels are fiber type, wavelength, diameter, concentration, and power density. The desirability is a score that indicates how good each solution is. The higher the desirability score, the better the solution.

The table shows that solution number 1, a single-mode fiber with a wavelength of 1310 nm, a diameter of 13.00 µm, a concentration of 4.8 mmol/L, and a power density of 67.8025 mW/µm², has the highest desirability score (0.937) and is marked as "Selected". This suggests that it is the optimal solution for the given criteria.

The other solutions have lower desirability scores for various reasons. For example, solution number 2 has a slightly lower score (0.915) because it has a longer wavelength (1550 nm). Solutions 3 to 8 are multimode fibers, which generally have lower desirability scores than single-mode fibers due to their higher transmission losses and modal dispersion. Additionally, solutions with smaller diameters and higher concentrations tend to have higher desirability scores.Overall, the table provides a comparison of different optical fiber solutions based on their characteristics and a desirability score.

4.5 Discussion

The experiment focused on developing microfiber sensors to detect glucose conditions, employing Design Expert software and Box-Behnken Design (BBD) optimization. The experimental setup involved exposing a fiber optic sensor to glucose liquid, and the obtained data were processed using Design Expert software for analysis and optimization. The results presented in Table 4.1 illustrated the experiment's outcomes, detailing output power under different combinations of parameters such as fiber type, wavelength, diameter, and glucose level. Subsequent analysis, as depicted in Figures 4.3 and 4.4, confirmed the normal distribution of errors, a crucial assumption for linear regression models.

The ANOVA table (Table 4.2) provided insights into the significant factors influencing output power, with wavelength and its interactions showing substantial impacts. The generated power equation (Table 4.3) offered a mathematical model describing the relationship between various variables and their interactions in power transfer. The normal plot of residuals (Figure 4.5) and the residuals vs. predicted response value graph (Figure 4.6) indicated reasonably normal distribution and revealed patterns of increasing residuals with rising predicted values, hinting at potential heteroscedasticity. The one-factor effect plots (Figures 4.7 and 4.8) demonstrated the influence of fiber type and wavelength on power output. Notably, the superiority of single-mode fiber over multimode fiber in power output was attributed to its smaller core diameter and more direct light path. The interaction effect plot (Figure 4.9) explored how fiber type and wavelength interacted to influence power output, with single-mode fiber consistently outperforming multimode fiber.

The optimization results (Table 4.4 and Table 4.5) provided criteria settings for glucose concentration and presented multiple optimization solutions for maximizing power output. The experiment aimed to identify optimal parameters for efficient glucose detection, enhancing the sensor's ability to measure and determine glucose levels in human blood. In summary, the study successfully utilized Design Expert software and BBD optimization to develop and analyze microfiber sensors for glucose detection. The findings contribute valuable insights into the complex interactions between various parameters, aiding in the optimization of fiber optic sensors for practical applications in glucose monitoring.

4.6 Summary

This chapter presented the results obtained from this experiment and provides a detailed analysis and interpretation of these findings. It highlights the development of microfiber sensors for detecting glucose conditions in the pharmaceutical industry, utilizing Design Expert Software and the Box-Behnken Design (BBD) optimization parameter approach. Significant results have been achieved through this research.

The researchers employed a software tool called Design Expert to systematically design and analyze experiments, enhancing the understanding of the relationships between variables and responses. The BBD approach was utilized to optimize the sensor system, aiming to improve the sensitivity, accuracy, and reliability of the microfiber sensors specifically designed for glucose detection. By identifying and optimizing key parameters of the sensor technology, the study resulted in improved product quality and enhanced sensor technology for glucose detection.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, this research focused on the development of a microfiber sensor for measuring glucose levels, leveraging the advantages of microfiber optical sensors, including high sensitivity, small size, flexibility, and non-invasiveness. The significance of wearable optical microfiber sensors was emphasized, showcasing their potential for glucose monitoring. The sensor's performance was optimized by considering various input parameters such as wavelength, microfiber diameter, glucose concentration, and microfiber type. To systematically optimize these parameters and enhance sensitivity, the Design of Experiments methodology was employed. The main goal was to develop a microfiber sensor capable of precisely and reliably detecting glucose levels in pharmaceutical operations, taking into account the industry's unique needs and constraints.

The findings presented in this chapter demonstrated the research's success in achieving considerable advancements in microfiber sensor technology for glucose detection. The application of Design Expert Software and the Box-Behnken Design optimization approach played a crucial role in systematically planning and analyzing trials, resulting in a deeper understanding of the correlations between variables and responses.The findings presented the solution which are a single-mode fiber with a wavelength of 1310 nm, a diameter of 13.00 µm, a concentration of 4.8 mmol/L are the best parameter and it is the optimal solution for the given criteria.

Overall, the study showed the effective development and optimization of microfiber sensors in the pharmaceutical industry for detecting glucose situations. The research contributed to improved product quality and sensor technology by identifying and optimizing important factors, potentially leading to more efficient and accurate glucose. The findings highlight the necessity of novel approaches to sensor design for specific industrial applications, paving the way for advances in the field of glucose detection in pharmaceutical settings.

5.2 Potential for Commercialization

The commercial potential of a microfiber optical sensor developed for glucose detection in the pharmaceutical industry is significant. Its unique features such as high accuracy and reliability make it a promising solution in the rapidly growing market for diabetes monitoring and management. The sensor's ability to provide continuous and real-time glucose monitoring, especially when integrated into mobile devices, aligns well with the increasing demand for personalized health solutions.

The focus on optimizing the sensor for the pharmaceutical industry underlines its importance in an industry where accurate glucose monitoring is paramount. This creates opportunities for collaboration and partnership with pharmaceutical companies seeking to streamline processes and improve patient outcomes. An innovative approach to sensor design , including optimization techniques like Design of Experiments (DOE), adds a layer of complexity that can attract interest from investors, healthcare providers and technology companies seeking cutting-edge solutions.

Additionally, the emphasis on patient empowerment aligns with the broader trendtoward patient-centered healthcare. A commercially successful microfiber optical sensor can significantly improve patient outcomes and satisfaction. Given the global prevalence of diabetes and the growing market demand for advanced glucose monitoring technologies, the commercialization of the sensor is timely. To maximize business potential, collaboration with industry stakeholders, thorough market research andstrategic marketing activities are crucial. Compliance with medical device regulations is essential to achieving market acceptance and building trust between healthcare professionals and end users.

In summary , the innovative microfiber optical sensor is poised to make a major impact on the diabetes monitoring market by providing a reliable and advanced solution for glucose monitoring.

5.3 Future Works

For future improvements, glucose condition detection results could be enhanced as follows:

a. Improved Sensitivity and Specificity: Future research could focus on enhancing the sensor's sensitivity and specificity by experimenting with advanced materials or coatings. Investigate the use of nanomaterials or biomimetic surfaces to improve the sensor's ability to selectively and accurately detect glucose concentrate on improving the sensor’s

b. Long-Term Stability and Durability: Addressing the microfibre sensor's long-term stability and durability is critical for practical applications. Future research should concentrate on improving the sensor's robustness over extended periods, ensuring consistent performance in various situations, and enhancing its operating lifespan.

c. Integration with IoT and Smart Devices: Explore opportunities for integrating the microfiber sensor with Internet of Things (IoT) platforms and smart devices. This would enable real-time data transmission, providing individuals with diabetes and healthcare professionals immediate access to glucose level information for timely interventions and adjustments.

d. Multi-Parameter Monitoring: Extend the capabilities of the microfiber sensor to detect multiple parameters relevant to diabetes management. Investigate the integration of additional sensors or functionalities to provide a comprehensive picture of the individual's health, such as monitoring other biomarkers or physiological parameters alongside glucose levels

REFERENCE

[1] Aisyah M. Aris, H. A. R. and S. W. H. (2017). Microfiber Bragg Grating with Zinc Oxide Nanorod Arrays for Temperature Sensing. *Microfiber Bragg Grating with Zinc Oxide Nanorod Arrays for Temperature Sensing*.

[2] Amor-Gutiérrez, O., Costa-Rama, E., & Fernández-Abedul, M. T. (2022). Paper-Based Enzymatic Electrochemical Sensors for Glucose Determination. In *Sensors* (Vol. 22, Issue 16). MDPI. https://doi.org/10.3390/s22166232

[3] Arif, D., Hussain, Z., Sohail, M., Liaqat, M. A., Khan, M. A., & Noor, T. (2020). A Non-enzymatic Electrochemical Sensor for Glucose Detection Based on Ag@TiO2@ Metal-Organic Framework (ZIF-67) Nanocomposite. *Frontiers in Chemistry*, *8*. https://doi.org/10.3389/fchem.2020.573510

[4] Brambilla, G. (2010). Optical fibre nanowires and microwires: A review. In *Journal of Optics A: Pure and Applied Optics* (Vol. 12, Issue 4). https://doi.org/10.1088/2040-8978/12/4/043001

[5] Colmegna, P. H., Sanchez-Pena, R. S., Gondhalekar, R., Dassau, E., & Doyle, F. J. (2016). Switched LPV Glucose Control in Type 1 Diabetes. *IEEE Transactions on Biomedical Engineering*, *63*(6), 1192–1200. https://doi.org/10.1109/TBME.2015.2487043

[6] Datatronix. (n.d.). *Singlemode vs Multimode Optical Fibre*. www.datatronix.com

[7] Durakovic, B. (2017). Design of experiments application, concepts, examples: State of the art. *Periodicals of Engineering and Natural Sciences*, *5*(3), 421–439. https://doi.org/10.21533/pen.v5i3.145

[8] Güemes, M., Rahman, S. A., & Hussain, K. (n.d.). *What is a normal blood glucose?*

[9] Irawati, N., Rahman, H. A., Yasin, M., Al-Askari, S., Hamida, B. A., Ahmad, H., & Harun, S. W. (2017). Relative Humidity Sensing Using a PMMA Doped Agarose Gel

Microfiber. *Journal of Lightwave Technology*, *35*(18), 3940–3944. https://doi.org/10.1109/JLT.2017.2698044

[10]Jali, M. H., Rahim, H. R. A., Md Johari, M. A., Baharom, M. F., Ahmad, A., Yusof, H. H. M., & Harun, S. W. (2021). Optical Microfiber Sensor: A Review. *Journal of Physics: Conference Series*, *2075*(1). https://doi.org/10.1088/1742-6596/2075/1/012021

[11]Kien, . F L, Liang, J. Q., Hakuta, K., & Balykin, J. I. (1999). Field intensity distributions and polarization orientations in a vacuum-clad subwavelength-diameter optical fiber. In *Opt. Commun* (Vol. 16). http://www.opticsexpress.org/abstract.cfm?URI=OPEX-13-6-2135

[12]Klonoff, D. C. (2012). Downloaded from 1243 Overview of Fluorescence Glucose Sensing: A Technology with a Bright Future Klonoff www.journalofdst.org. In *Journal of Diabetes Science and Technology* (Vol. 5147, Issue 6). www.journalofdst.org

[13]Komal Lawand, Mahesh Parihar, & Shital N.Patil. (n.d.). *Design and Development of Infrared LED Based Non Invasive Blood Glucometer*.

[14]Kumar, P., Bhimrao, Y. B., Srivastava, R., Chaurasiya, N., & Yadav, P. K. (2018). *Optical Fiber Sensor: Review and Applications Investigation of Synthesis, Characterization and Properties of Nanosized Nickel Doped Tin Oxide and its Application View project Nanomaterial and sensor View project Optical Fiber Sensor: Review and Applications* (Vol. 6, Issue 1). www.ijcrt.org

[15]Laurence N. Wesson. (2010). *FIELD REPAIR OPTIONS FOR FIBER OPTIC CABLE; FUSION SPLICING, MECHANICAL SPLICING, AND FIELD TERMINATION* (Inc. B. A. P. Laurence N. Wesson Aurora Optics, Ed.).

[16]Li, Y., Ma, H., Gan, L., Liu, Q., Yan, Z., Liu, D., & Sun, Q. (2018). Immobilized optical fiber microprobe for selective and high sensitive glucose detection. *Sensors and Actuators, B: Chemical*, *255*, 3004–3010. https://doi.org/10.1016/j.snb.2017.09.123

[17]Lou, J., Wang, Y., & Tong, L. (2014). Microfiber optical sensors: A review. In *Sensors (Switzerland)* (Vol. 14, Issue 4, pp. 5823–5844). Molecular Diversity Preservation International. https://doi.org/10.3390/s140405823

[18]Marcuse, D. (n.d.). Loss Analysis of Single-Mode Fiber Splices. In *THE BELL SYSTEM TECHNICAL JOURNAL* (Vol. 56, Issue 5).

[19]Marzuki, A., Pratiwi, A. C., & Suryanti, V. (2018). Evanescent Wave Absorption Based Fiber Sensor for Measuring Glucose Solution Concentration. *IOP Conference Series: Materials Science and Engineering*, *333*(1). https://doi.org/10.1088/1757-899X/333/1/012016

[20]Mohamad Ali, U. U., Jusoh, Z., Md Johari, M. A., Abdul Rahman, H., Adnan Zain, H., Zulkipli, N. F., & Wadi Harun, S. (2022). Effect of Microfiber Diameters on Micro-sphere Resonator Based Humidity Sensor. *Journal of Electrical & Electronic Systems Research*, *20*(APR2022), 66–69. https://doi.org/10.24191/jeesr.v20i1.009

[21]Multar, E., Daud, S., Rohizad, S. N. A., & Tan Halid, N. S. (2020). Functionalized Fiber Optics for Glucose Detection. *Journal of Physics: Conference Series*, *1484*(1). https://doi.org/10.1088/1742-6596/1484/1/012010

[22]Nandhakumar, P., & Kumar, A. (2021). Backbone Optical Fiber Analysis at 1310 nm and 1550 nm. *Journal of Optical Communications*, *42*(1), 79–84. https://doi.org/10.1515/joc-2018-0042

[23]Ong, Y. S., Kam, W., Harun, S. W., Zakaria, R., & Mohammed, W. S. (2015). Low-Cost Transducer Based On Surface Scattering Using Side-Polished D-Shaped Optical Fibers. *IEEE Photonics Journal*, *7*(5). https://doi.org/10.1109/JPHOT.2015.2481606

[24]Pendão, C., & Silva, I. (2022). Optical Fiber Sensors and Sensing Networks: Overview of the Main Principles and Applications. In *Sensors* (Vol. 22, Issue 19). MDPI. https://doi.org/10.3390/s22197554

[25]Ranga, S., Jaimini, M., Sharma, S. K., Chauhan, B. S., & Kumar, A. (n.d.). *INTERNATIONAL JOURNAL OF PHARMACEUTICAL AND CHEMICAL SCIENCES A Review on Design OF Experiments (DOE)*. www.ijpcsonline.com

[26]Rekha, M., Singh, M., & Raj, B. (n.d.). *SINGLE MODE FIBER STANDARDS: A REVIEW*.

[27]Rghioui, A., Lloret, J., Harane, M., & Oumnad, A. (2020). A smart glucose monitoring system for diabetic patient. *Electronics (Switzerland)*, *9*(4). https://doi.org/10.3390/electronics9040678

[28]Shendurse, A., Khedkar, C. D., & Shendurse, A. (2016). *Planning for a mega clinical trial on synbiotic-assisted (probiotic+prebiotic) interventions for sustainable irradication of malnutrition from Maharashtra. View project Effect of mushrooming of softwares aimed at quick writing of scientific publications on the sustainance of scientific vigour in the budding scientists View project Glucose: Properties and Analysis*. *3*, 239–247. https://doi.org/10.13140/RG.2.1.3460.0725

[29]S.Panzer. (2021, March 30). *Optical Fibre Cable: Working, Applications & More*.

[30]Tang, J., Zhou, J., Guan, J., Long, S., Yu, J., Guan, H., Lu, H., Luo, Y., Zhang, J., & Chen, Z. (2017). Fabrication of Side-Polished Single Mode-Multimode-Single Mode Fiber and Its Characteristics of Refractive Index Sensing. *IEEE Journal of Selected Topics in Quantum Electronics*, *23*(2), 238–245. https://doi.org/10.1109/JSTQE.2016.2615941

[31]Tong, L., Gattass, R. R., Ashcom, J. B., He, S., Lou, J., Shen, M., Maxwell, I., & Mazur, E. (2003). Subwavelength-diameter silica wires for low-loss optical wave guiding. *Nature*, *426*(6968), 816–819. https://doi.org/10.1038/nature02193

[32]Ujah, E., Lai, M., & Slaughter, G. (2023). Ultrasensitive tapered optical fiber refractive index glucose sensor. *Scientific Reports*, *13*(1), 4495. https://doi.org/10.1038/s41598-023-31127-4

[33]Venkata, P., Kumari, K., Yarraguntla, S. R., Sharmila, M., & Gulibindala, E. (n.d.). Application of Box-Behnken Design for Formulation Parameters of Eslicarbazepine Tablets. In *Indian Journal of Pharmaceutical Sciences* (Vol. 575). www.ijpsonline.com

[34]Warken, F., Vetsch, E., Meschede, D., Sokolowski, M., & Rauschenbeutel, A. (2007). *Ultra-sensitive surface absorption spectroscopy using sub-wavelength diameter optical fibers*.

[35]world health organization, & Leanne Riley. (n.d.). *Mean fasting blood glucose*.

[36]Wu, X., & Tong, L. (2013). Optical microfibers and nanofibers. *Nanophotonics*, *2*(5–6), 407–428. https://doi.org/10.1515/nanoph-2013-0033

[37]Yadav, J., Rani, A., Singh, V., & Mohan Murari, B. (n.d.). *Near-infrared LED based Non-invasive Blood Glucose Sensor*.

[38]Zibaii, M. I., Latifi, H., Karami, H., Gholami, M., Hosseini, S. M., & Ghezelayagh, M. H. (2010). Non-adiabatic tapered optical fiber sensor for measuring the interaction between α-amino acids in aqueous carbohydrate solution. *Measurement Science and Technology*, *21*(10). https://doi.org/10.1088/0957-0233/21/10/105801

APPENDICES

Appendix A GANTT CHART PSM 1

PROJECT ACTIVITY	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Preparation and Comfirming Project Title	/														
Research Related on Project	/	/	/	/											
Log Book Writing	/	/	/	/	/		/	/	/	/	/	/	/	/	/
Chapter 1 Report Writing			/	/											
Chapter 2 Report Writing			/	/	/										
Chapter 3 Report Writing				/	/										
Project Experiment															
Implementation Project															
Work Progress							/					/			
Report Progress							/								
Draft Report Submission												/			
Slides Preparation												/	/		
Presentation with Supervisor															
Submit Report														/	
BDP Presentation														/	
Submission Final Report															

Appendix B GANTT CHART PSM 2

PROJECT ACTIVITY	WEEK														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Discussion with Supervisor	/	/	/	/	/		/	/	/	/	/	/	/		
Literature Review	/	/	/	/	/										
Research on Project Information	/	/	/	/	/		/	/	/						
Study for Project Progress					/		/	/	/	/	/				
Study for Raw Material			/	/	/										
Simulation in Design Expert									/	/	/	/			
Study for Simulation Result										/	/	/			
Development and lab review			/	/	/		/								
Hardware Designing							/	/				/			
Hardware Contruction				/	/		/								
Hardware Testing								/	/	/					
Final hardware simulation and testing										/	/				
Bachelor degree project writing PSM2							/	/	/	/					
Final report writing												/	/		
BDP Presentation														/	
Submission Final Report															/

Appendix C OPTICAL FIBER SPECIFICATIOS

TIA/EIA-568A Optical Fiber Specifications

Optical Fiber Type		Multimode	Single Mode
Dimensions		62.5/125μm	8.3/125μm
Bandwidth	-Low speed (850nm)	160MHz•km	NA
	-High speed (1300nm)	500MHz•km	>1GHz
Attenuation	-Low speed	3.5 dB/km	NA
	-High speed	1.0 dB/km	>0.5 dB/km
Backbone Cable Length		2000m	3000m
Horizontal Cable Length		100m	Not Recommended
Applications		E-net, TR, FDDI 155 Mbps ATM Baseband Video Security Systems	Channel Extension FDDI, ATM (1.2 Gbps) Fibre Channel Broadband Video
Connector Type:	T568-SC	Beige Shroud	Blue Shroud

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