WATER QUALITY PERFORMANCE ANALYSIS USING FIBER OPTIC SENSOR BASED ON LATERAL OFFSET DISPLACEMENT FOR AGRICULTURAL APPLICATION.

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This report is submitted in partial fulfilment of the requirements for the degree of Bachelor of Electronic Engineering with Honours

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DECLARATION

I declare that this report entitled "Water Quality Performance Analysis Using Fiber Optic Sensor Based on Lateral Offset Displacement Sensor for Agricultural Application" is the result of my own work except for quotes as cited in the references.

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Date : 25 June 2021

APPROVAL

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of Bachelor of Electronic Engineering with Honours.

Signature :

Supervisor Name : Dr. Hazura Binti Haroon ……………………………………

Date : 25 June 2021 ……………………………………

DEDICATION

I dedicate this thesis wholeheartedly to my supervisor, Dr. Hazura Binti Haroon, for the guidance and encouragement in completing this project, my beloved family and friends who have supported me throughout the whole process of my journey in completing this project.

ABSTRACT

Agricultural activities have played the most significant role in economic's growth which one of the activities is the hydroponic crop system. In this paper, a compact and sensitive fiber optic sensor based on a lateral offset displacement sensor is formed and demonstrated in measuring the water quality of the hydroponic crop system. The fiber is designed in SM-SM and MM-MM fiber mode configuration with a lateral offset structure. The fiber's core has been spliced in various offset distances, which act as a sensing region of the fiber sensor towards the pH and temperature. Upon completion, the sensitivity obtained for SM-SM based on lateral offset is -0.5744 dBm/pH and the -0.1432 dBm/°C that obtained for pH and temperature measurement where the offset distance is 18.72µm, meanwhile for the MM-MM based on lateral offset, the sensitivity is -0.8322 dBm/pH and -0.1645 dBm/°C for the pH and temperature measurement, where the offset distance is 7.83µm. The fiber sensor has successfully developed and used the sensor to measure the pH and temperature of the water quality.

ABSTRAK

Kegiatan pertanian telah memainkan peranan yang paling penting dalam pertumbuhan ekonomi yang dimana salah satunya adalah sistem tanaman hidroponik. Dalam kertas ini, sensor fiber optic yang padat dan sensitif berdasarkan 'lateral offset displacement' telah diciptakan dan didemonstrasi dalam mengukur kualiti air pada sistem tanaman hidroponik.. Fiber ini telah direka bentuk mod konfigurasi fiber SM-SM dan MM-MM berdasarkan struktur 'lateral offset'. Teras fiber ini telah disambungkan dalam pelbagai jarak 'offset', dimana akan dijadikan sebagai kawasan ukuran untuk sensor fiber terhadap kualiti air seperti, pH dan juga suhu. Setelah selesai, sensitiviti yang telah diperoleh bagi SM-SM berdasarkan 'lateral offset' adalah -0.5744 dBm/pH dan 0.1432 dBm/°C dimana telah diperoleh dalam pengukuran larutan untuk pH dan suhu dimana jarak 'offset' adalah bersamaan dengan 18.72 µm manakala, bagi MM-MM berdasarakan 'lateral offset', sensitiviti yang diperoleh adalah -0.8322 dBm/pH dan -0.1645 dBm/°C dalam pengkuran larutan untuk pH dan suhu dimana jarak 'offset' adalah pada 7.83 µm. Sensor fiber ini telah berjaya dicipta dan digunakan bagi mengukur pH dan suhu bagi kualiti air.

ACKNOWLEDGEMENTS

First and foremost, praises and thanks to Allah S.W.T, the Almighty, for showers His blessings throughout my journey in completing my Final Year Project, entitled *"Water Quality Performance Analysis Using Fiber Optic Sensor Based On Lateral Offset Displacement For Agricultural Application"*, successfully. Not to forget, a special appreciation to my supervisor, Dr. Hazura Binti Haroon, for her encouragement and valuable guidance in helping me in completing this project. I am beyond thankful to her for all the knowledge she has shared and helped me whenever I needed help. She has fully guided me as clearly as possible, and it is such an honour to study under her guidance. Not just that, to my beloved family, I would like to express my deep and sincere gratitude for their continued support, financially and morally, throughout the whole project. I extremely grateful for their loves, cares and sacrifices for me to finish my study without facing any hardships is much appreciated. Their encouragement whenever times get rough while completing this project is such a relief and comfort to me. Not just that, special thanks to my friends and seniors of Master and PhD students that have been very helpful and gave me guidance throughout my project. My whole journey in completing this project has been so meaningful and knowledgeable.

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LIST OF SYMBOLS AND ABBREVIATIONS

OPM	:	Optical Power Meter
OLS	:	Optical Light Source
FOS	:	Fiber Optic Sensor
SMF	:	Single Mode Optical Fiber
MMF	:	Multimode Optical Fiber
POF	:	Polymer Optical Fiber
PMMA	:	Polymethyl Methacrylate Polymer
LED	:	Light Emitting Diode
FBG	:	Fiber Bragg Grating
OFS	:	Optical Fiber Sensor
P	:	Phosphorus
N	:	Nitrogen
K	:	Potassium
Fe	:	Iron
SM-SM	:	Single Mode to Single Mode
MM-MM	:	Multimode to Multimode
OSA	:	Optical Spectrum Analyzer

CHAPTER 1

INTRODUCTION

This chapter consists of an introduction of the project, problem statement, objectives of the project, significance of this project and project outline. Each of these sections will be briefly explained in this Introduction part.

1.1 Introduction

Nowadays, agricultural productivity has become an increasingly important source as it can increase the world population to grow. Aside from providing more food, agricultural productivity has proven it helps alleviate poverty in the poor and increase competitiveness growth in producing agricultural products. One of the leading agricultural activities is crop productivity, which has become one of the main factors in satisfying the growth worldwide since the demand for food, feed, and fuel increases rapidly. Crop productivity can be soil mineral-based or water mineral-based, and crop nutrients play an important role in growing plants. As for this project, the hydroponic crop system is the major aspect of using a water mineral based on growing plants. Thus, the nutrients and water quality of this hydroponic system is the major part of this project.

The main purpose of this project is to design and develop a device, which can measure the water quality of the hydroponic system by using Fiber Optic sensor using the Lateral Offset Displacement method. By using Fiber Optic Sensor (FOS), this device is created to dip inside the water of the crop system and measure the water quality, such as temperature and pH of the water. With Fiber Optic sensor technology, the result of the water quality is transmitted from the Optical Light Source (transmitter) to the Optical Power Meter (receiver). With the flexibility and low cost of Fiber Optic based on Lateral Offset Displacement, it can measure the water quality of the hydroponic crop system so that the optimized pH value and temperature used for the crop will be analyzed.

1.2 Problem Statement

In recent years, agricultural growth has been remarkably accelerated in Malaysia, especially in rural area. Then, the current study shows that agricultural activity can meet the global needs as crop productivity is one of the leading agricultural activities worldwide. Products produced from the crop production process such as oil, feed grain, food and fiber has proved that there rapidly growing demand for those products in helping the global growth to continue. However, world crop production has slowed due to some major factors that are crop nutrient-related problems. Lacking crop nutrient will affect the growth of the plants. The same goes for this hydroponic crop system, the water quality itself is the major part of growing plants because the water is the main carrier in giving nutrients for the plants. Bad water quality will lead to a dramatic decrease in crop performance because it can decrease crop nutrients and reduced the opportunity for plant production. With the traditional way to measure the pH value and temperature, it will be hard, and the value will always be inaccurate to measure the water quality. Thus, the improvement of crop production in improving the crop nutrient quality will be difficult. Not just that, other than in hydroponic terms, the technique of splicing the fiber is the main problem too. This is because the normal taper has less sensitivity compared to the lateral offset splicing method.

Hence, the purpose of this project is to develop and design a low-cost measuring device using a single mode fiber optic sensor that use to measure pH level and temperature of the water in a hydroponic crop system based on the lateral offset splicing method. By developing this project, this device able to detect the pH value and temperature of the water used in the crops with a different design of fiber optic probes. The performance of the fiber sensor with different offset distances is studied in detail with variations of water quality sample. By that, the pH value and temperature in the water will be analyzed to find the optimized value to be used in the water of the hydroponic crop.

1.3 Objectives

i. To design and develop a device to measure the water quality of a hydroponic system using single mode and multimode fiber optic sensor application based on lateral offset displacement.

ii. To analyze the sensing response of the sensor towards the pH and the temperature.

1.4 Scope of Work

Fiber Optic sensor is used in this project as a sensing device and use to measure the water quality (pH level and temperature) of the water used in the hydroponic crop system. There will be different types of water quality (variety in temperature and pH value) that will be tested for the plants. Then, the Fiber Optic sensor that acts as a measuring device also will be created in a variety of design for the probes to analyze the effect of the outcome with the use of different measurement and dimension in developing the sensing area of the fiber optic sensor to study the relationship between refractive index and power loss.

As for this project, a digital refractometer is used to measure the refractive index of the hydroponic water sample for its pH value and temperature of the water used in the hydroponic crop system. Other than that, Optical Power Meter (OPM) and Optical Light Source (OLS) is used to observe the sensor response. The working wavelength of this Fiber Optic sensor is using 1550 nm for single mode optical fiber (SMF) and 850 nm for multimode optical fiber (MMF). This analysis focuses on the fiber sensor's performance response for the water quality of the hydroponic crop system only.

Finally, the optical output reading obtained from the Optical Power Meter (OPM) will be recorded and analyzed. Then, the results of the power loss obtained from the OPM will be taken into a graph in analyzing the fiber sensitivity.

1.5 Report Structure

This project report is divided into five main chapters. The first chapter of this report introduces this project, consisting of the introduction, problem statement, objectives, scope of work, and report structure of this project. Next, the second chapter is involved with the background research of Fiber Optic Sensor technology application. With the use of background research and literature review done by other research, all of the information gained for this project will be explained thoroughly related to the fiber optic sensor. The information and articles obtained from the official website are used to understand the concept of this system. Then, for the third chapter, the methodology of the project is explained, which the content are the technical parts and procedure in developing this device, such as components and equipment used to create this device. Then, the fourth chapter is the result and discussion gained from this project. This chapter will discuss the expected outcome of this project, whether it is successful or not. Other than that, project management, financial consideration, environment and sustainability, health and safety are also explained in this chapter. Last but not least, the recommendations for future works and conclusion are listed in the fifth chapter.

CHAPTER 2

BACKGROUND STUDY

This chapter briefly explains the related research of this project. The theory of the fiber optic technology with its type of fiber optic, fiber optic sensor application, and lateral offset displacement sensor is explained. The study of journals are also discussed in this chapter.

2.1 Introduction of Fiber Optics Technology

Fiber optic technology has become increasingly beneficial throughout the last few decades due to its wide range of telecommunication, which has been seen as a major driver behind the information technology revolution. Fiber optics is a flexible, transparent fiber made by drawing glass (silica) or plastic to a diameter slightly thicker than that of a human hair. The basic medium of fiber optics is a hair-thin fiber that is sometimes made of plastic but most often of glass [1]. Fiber optics are most used often to transmit light between the two ends of the fiber. The lights travel that passes inside the fiber optic is using a process of total internal reflection. Through a process known as total internal reflection, light rays beamed into the fiber can propagate within the core for great distances with remarkably little attenuation or reduction in intensity [1]. This is the principle that fiber cables are built upon, referring to the fiber optic consisting of a core of transparent glass, surrounded by an outer layer (cladding) that is slightly less transparent glass that reflects the light back into the core.

Figure 2.1: The Hair-Thin Fibers Used in Fiber Optics [1].

For the last few years, this technology has been used in many applications in industries. This technology has become the backbone of military networking, medical imaging, laser practices, and private and public networking for cable and the internet. Other than that, fiber optics in communication is not a 'new' technology, but this technology keeps growing and growing. Fiber optics are arranged in bundles called fiber optic cable that transmit light signal over long distances, making them the chosen one among other technologies because of its high-speed system designer, wavelength, bandwidth, bigger size capacity, and more. Fiber optic is especially advantageous for its wide-ranging application because infrared light propagates through the fiber with much lower attenuation than electricity in electrical cables. Optical telecommunication is usually conducted with infrared light in the wavelength ranges of 0.8–0.9 μm or 1.3–1.6 μm wavelengths that are efficiently generated by light-emitting diodes or semiconductor laser and that suffer the least attenuation in glass fibers [1]. Other than communication, due to its elasticity and flexibility, fiber optic technology has been used in sensing applications such as security systems, measuring strain, pressure. In addition, this technology has expanded themselves in power transmission that use photovoltaic cell to convert light into electricity. Fiber Optic technology has proven used in many applications, so it has been seen as recent advanced technology.

2.1.1 Fiber Optic Structure

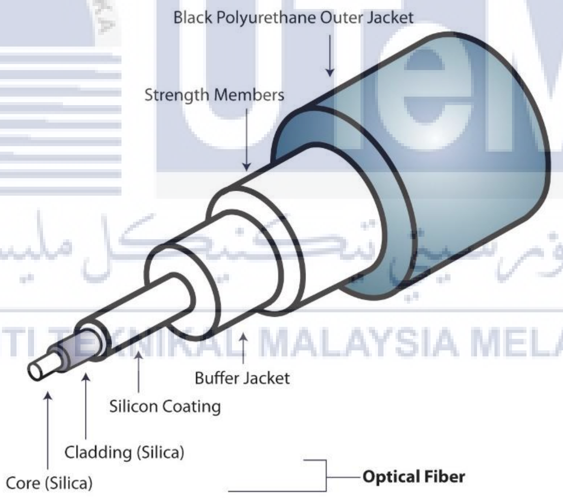


Figure 2.2: The Main Fiber Optic Structure [2].

Fiber optics are usually made of either glass or plastic. Fiber optics are consisting of three main parts, which is the core, cladding, and outer coating. The core is extremely thin, flexible [22] and has a cylindrical shape. As for the core, it is a cylindrical rod of dielectric material positioned at the innermost layer of the fiber. The core is generally made of glass that generates no electricity due to its dielectric material. The core is where the light passes through. The structure of the core influences the transmission of light. Thus, the data that is being transferred will have its transmission parameter or properties based on the structure of this segment of the fiber optic [23].

Then, the second layer protects the core. It is enclosed by a cylindrical layer of material that includes a lower refractive index which is cladding [20]. When the light travels from a medium with a high refractive index goes to a medium with a lower refractive index, and it will move away from the normal at the crossover. Cladding is made up of dielectric material and works to minimize the loss of light from the core into the encompassing air and minimize the scattering loss at the surface of the core [21]. This layer protects the fiber from absorbing any contaminants on the surface and supplies the fiber's mechanical strength.

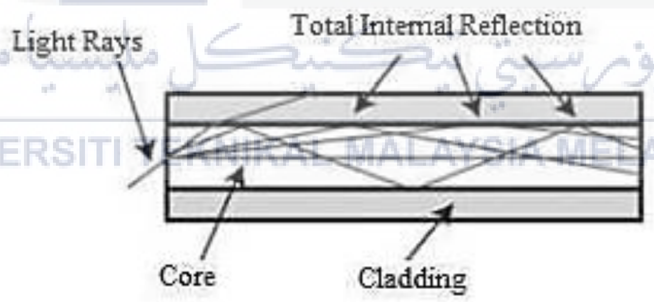


Figure 2.3: The Refractive Index of Core And Cladding [2].

Next, the coating layer or jacket surrounding the cladding [24]. The coating is generally a layer of material that use to protect the fiber from any physical damage. The coating or a buffer made of plastic is elastic in nature and can prevent abrasions. The coating or buffer can prevent the fiber optic from scattering losses caused by microbends, usually when the fiber optic is placed on a rough and distorted surface.

Thus, both jacket and buffer protect the optical fiber from environmental and physical damage [21].

2.2 Types of Optical Fiber

Copper cables use a pulse of electricity to transmit signals across a copy wire. Meanwhile, fiber optic cables use a pulse of light in transmitting signal. Fiber optic cables are used because they have several advantages over copper lines, including increased bandwidth and transmit speeds. This is why fiber optic is commonly used in long-distance communication and in high-performance data networking. There are three common types of fiber optic, which is Single Mode Optical Fiber (SMF), Multimode Optical Fiber (MMF), and Polymer Optical Fiber (POF).

2.2.1 Single Mode Optical Fiber (SMF)

Single mode fiber (SMF) cables are designed to transmit a single mode or ray of light down into the fiber in one direction. Single mode is a single strand of glass fiber with a diameter of 8.5 to 10 microns that has single mode of transmission. Single mode optical fiber will propagate at 1310 or 1550 nm due to its single mode of transmission. Single mode optical fiber (SMF) has a faster transmission rate and a nearly 50 times longer distance than multimode optical fiber (MMF). Inside the optical fiber, there is three fundamental part which consists of core, cladding and coating. Single mode optical fiber (SMF) usually 9/125 in construction, which means the diameter ratio of the core to the cladding is 9 microns to 125 microns. The reason why single mode optical fiber (SMF) has a faster transmission because of its small core-sized, coupled with a single light wave that can eliminate any distortion caused by overlapping light pulses. As a result, it offers minimal signal attenuation and the fastest signal transmission, which allows the signal to travel a long distance. Conversely, single mode's minuscule core limits dispersion, so higher bandwidth signals can be sent over a longer distance [3]. Thus, single mode commonly used inside the building that runs by telcos, CATV companies, universities, etc., due to its long-distance and higher bandwidth.

Figure 2.4: Single Mode Optical Fiber (SMF) [3]

2.2.2 Multimode Optical Fiber (MMF)

Compared to single mode optical fiber (SMF), multimode optical fiber (MMF) is a type of optical fiber used in short-distance communication. A large diametrical core in a multimode fiber optic (MMF) cable allows multiple light modes to propagate at 1300 nm and 850 nm inside the fiber. Similar to single mode optical fiber (SMF), there are three fundamental parts for the fiber: core, cladding, and coating. Multimode optical fiber (MMF) is commonly 50/125, and 62.5/125 in construction, which means the multimode optical fiber (MMF) diameter ratio of the core to the cladding is 50 microns to 125 microns and 62.5 microns to 125 microns. Since multimode optical fiber (MMF) allows multiple lights to travel inside the fiber, the number of light reflections formed as light travels through the core increases and creates more data to travel through simultaneously. As a result, high dispersion and attenuation rate occur, which will degrade the quality of the signal over long distances. This characteristic, enabled by multimode's larger core, actually creates some limitations [3]. This is the reason why multimode optical fiber (MMF) can only be applied in short distances, such as data and video/audio applications in LANs.

Figure 2.5: Multimode Optical Fiber (MMF) [3]

2.2.3 Polymer Optical Fiber (POF)

Polymer Optical Fiber (POF), both core and cladding of polymer optical fiber (POF), is a polymer. Polymer optical fiber (POF) transmits light through the core of the fiber in the same way that glass optical fiber does, such as single mode optical fiber (SMF) and multimode optical fiber (MMF). Polymer Optical Fiber (POF) is transparent to visible light and looks like a nylon rope. While plastic optical fibers (POF) cannot compare to glass fibers in terms of propagation losses or data transmission capacity, they are mechanically more robust and allow for cheaper fiber-optic systems in particular applications. Not just that, its main advantage over glass optical fiber, if all other factors are equivalent, is its robustness under bending and stretching. The core of polymer optical fiber (POF) is usually made of Polymethyl Methacrylate Polymer (PMMA), and the cladding material is a fluorinated polymer. The PMMA is usually a large core (96% of the cross-section in a fiber 1mm in diameter) and has a high numerical aperture, which supports many guided modes. PMMA fibers are frequently used for low-speed, short-distance (up to 100 meters) applications because of their attenuation and distortion properties, such as digital home appliances, home networks etc.

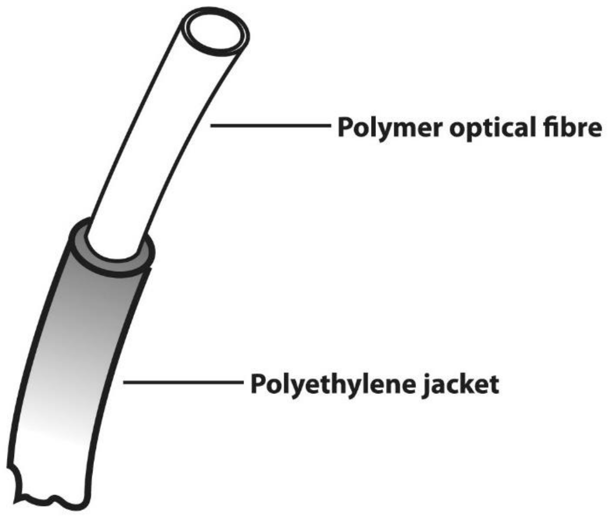


Figure 2.6: Polymer Optical Fiber (POF) [4]

2.3 Fiber Optic Sensors

Historically a number of different approaches have been used in the classification and categorization of fiber optic sensors. It consists of an optical source (Laser, LED, Laser diode etc.), optical fiber, sensing or modulator element (which transduces the measurand to an optical signal), an optical detector and processing electronics (oscilloscope, optical spectrum analyzer etc.) [5]. The structure of the optical fiber consists of core, cladding which resulting in a different refractive index. A commonly famous sensor in fiber optic is an intrinsic sensor and an extrinsic sensor. A fiber optic sensor is a sensor that used the optical fiber as a sensing element (**intrinsic sensor**) or as a means of relaying on the signals from a remote sensor to the electronics that can process the signal (**extrinsic sensor**). In general, the fiber optic sensor has an optical fiber inside its structure connected to a light source, which allows them to act as a 'detection' in a tight space or where a small profile is beneficial. As for the intrinsic sensor, it utilizes a change that takes place within the fiber itself [6] while in contrast to the extrinsic sensor in which the change is outside the fiber and the fiber itself remains unchanged [7]. This means the intrinsic sensor changes the light in its fiber while the extrinsic sensor let the light leaves the fiber, and the light is blocked or reflected before going back into the fiber. The intrinsic sensor is commonly used for a bulk application that relevant to a composite material that needs the fiber itself to perform the sensing function, but for the extrinsic sensor, the fiber is usually used as a communication path between the source and the external sensing head [8].

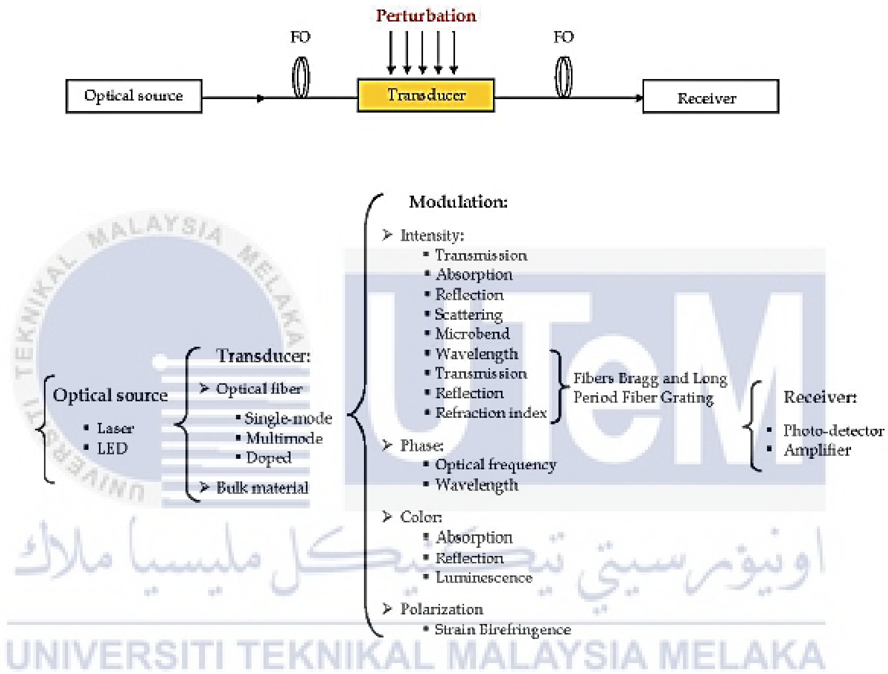


Figure 2.7: Basic Component of Optical Fiber Sensor [9].

Table 2.1: Sensor Classification Under Three Categories [2].

Category	Types
Sensing Location	Point Sensor
	Distributed Sensor
	Quasi-Distributed Sensor
Operating Principle	Intensity Sensor
	Phase Sensor
	Polarisation Sensor
Application	Physical Sensors
	Chemical Sensors
	Bio-Medical Sensors

In intrinsic sensor, they are very useful in providing distributed sensing over very large distances and optical fibers are usually used as a sensor to measure temperature, pressure, strain, and any other quantities, which can be done by modifying the fiber so that the quantities measured modulates the intensity, polarisation, phase, wavelength or transmit time of light in the fiber. According to the operating principle of the modulation and demodulation process, these parameters may be subject to change due to its external perturbations [2]. Meanwhile, for the extrinsic sensors, an optical fiber cable (usually the multimode one) is used to transmit modulated light from either a non-fiber optical sensor or an electronic sensor connected to an optical transmitter. The major benefit of the extrinsic sensor is that it is a low-cost device and can reach places that are inaccessible, for example, the measurement of internal temperature of electrical transformers, where the extreme electromagnetic fields present make other measurement techniques impossible. Other than its low cost, the extrinsic sensor also provides excellent protection of measurement signals against any noise corruption, which makes them commonly used in measuring rotation, acceleration, velocity and many more.

Fiber optic sensors can be categorized based on the detection techniques such as intensity (amplitude), phase, frequency, or polarisation. Another classification of optical fiber depending on how they work, and this type of sensors are classified as extrinsic or intrinsic sensor [10].

2.3.1 Fiber Optic Sensor Application

Fiber optic cables are tubes of glass that find a host of uses in a variety of fields. Fiber optic sensing technology has been around for many years, and over the last decade, research has been implemented in an ever-increasing number of environments

& applications. Fiber optics usually integrated into the network where they facilitate telecommunication applications. But since then, these new sensing technologies have formed an entirely new generation of sensors offering many important measurement opportunities and great potential for diverse applications [11].

The advantages of optical fibers as medical sensors are recognized worldwide nowadays [12]. As we all know, optical fiber transmits “data” by light to a receiving end, where the light signal is decoded as data. Optical fiber sensors are well known for a wide range of applications in optics and photonics [13]. Due to its small size and flexibility, this fiber optic sensor has allowed the insertion into body cavities makes them inherently electrical safe. Fiber optic sensor technologies have been integrated with physical measurands such as temperature, pressure, and strain, such as heart rate and respiratory and blood flow measurements. The most famous application in medical that using fiber optic sensor is monitoring the physical health of structures in real-time [5]. For example, the response of Fiber Bragg Grating (FBG) to strain can be used to measure the periodic mechanical movement of the chest wall caused by breathing or cardiac contractions and hence monitor respiration and heart rate [14]. Other than that, biochemical measurands can also be used in the application of fiber optic sensor, which is to measure chemical compounds, a gaseous compound from a human body, or detection in liquid phase such as pH value from human samples, which provides valuable information about diseases [15].

Other than medical, fiber optic sensor also has been widely used in many industries. The sensing applications in fiber optic have solved in the industrial factory environment by exploiting the dielectric properties of the fiber in combatting the hazardous environment and noisy areas of the electrical industry. The ability of fiber optic sensors has been enhanced to substitute traditional sensors for acoustics, vibration, electric and magnetic field measurement, acceleration, rotation, temperature, pressure, linear and angular position, strain, humidity, viscosity, chemical measurements and a host of other sensor applications [16]. For example, optical fiber sensors (OFS) have previously demonstrated their capabilities in performing real-time and continuous monitoring of pipe strength leak detection [17].

Furthermore, fiber optic sensor-enabled a long-distance transfer of information for communications and also for sensing environmental parameters [18]. Fiber optic sensors have been the ideal tool employed in monitoring the environment. In this case, for example, fiber optic sensor has been developed to detect heavy metals due to the hazardous effects of these ions on the health of human beings and ecosystems [19]. Fiber optic technology allows the possibility of the development of a wide range of physical sensors for a variety of physical parameters. Conversely, fiber optic sensors retain many advantages compared with the aforementioned sensors, such as fast speed, electrical passivity, and immunity to electromagnetic interferences, and provide a possibility for measurement of displacement [20]. The fiber sensor performance based on lateral offset structure offers high sensitivity, compact, robustness and cost-effective fiber sensor that desirable in many sensing applications such as food and agricultural industries.

2.4 Splicing Method of Fiber Optic Sensor: Lateral Offset Splicing

In fiber optic splicing, there are two splicing methods, fusion splicing and mechanical splicing. In general, the splicing method is a technique that brings and hold two fibers together to allow the optical signal to pass through the joint of the fibers. For fusion splicing, combining the two or more optical fibers is by melting them together through heat. This technique uses a fusion splicer machine by aligning the fibers and melting them using an electric arc. Meanwhile, mechanical splicing combines the two fibers. It holds them together by using an alignment device that offers a non-permanent joint of the fibers to allow the light to pass through the fibers into another. A few types of mechanical splicing are rotary splices, v-groove splices, snug tube splices, and many more.

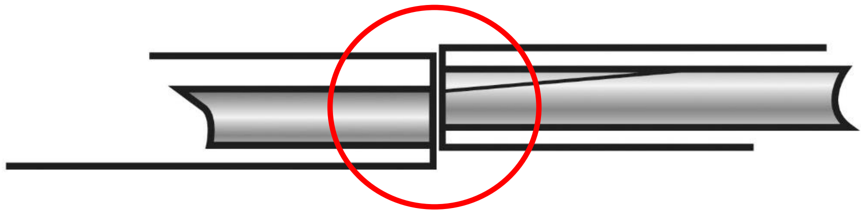


Figure 2.8: Lateral Offset/Lateral Misalignment [21].

The principal source of loss in both connectors and splices is fiber-to-fiber end face misalignment [21]. The fusion splicing method is used to combine the fiber in the lateral misalignment structure. In this project, a fusion-splicing method is used in developing and designing the fiber sensor. Several types of structure used the fusion-splicing method. The method uses heat or electric arc to combine the fiber structure —for example, waist enlargement structure, lateral offset structure, etc. The first of these loss mechanisms, lateral misalignment, is the most significant contributor to the total loss in a fiber connection[21]. Lateral misalignment is also known as lateral offset. Lateral offset structure using the fusion splicing method has been used to design the fiber sensor for this project. As for the first step, the two ends of a fiber are ready to be spliced. Then, the end of the fiber is cut off to produce flat end surfaces. The end surfaces are placed as for splicing in which that is, they are positioned adjacent or abutting each other or abutting each other with their longitudinal axes parallel [22]. Lateral misalignment or lateral offset is the failure of the cross-sections of the two fiber cores to overlap perfectly that can cause power loss while transmitting the light inside the fiber. The optical power loss is due to Fresnel Reflection. Fresnel Reflection is related to step changes in refractive index at the jointed interface [23]. The step-change in refractive index is because of the small gap at the ends of each fiber being separated, which known as the air gap. Fresnel Reflection is a small portion of incident light that reflected back into the source fiber where it happens at the fiber interface. The ratio, R, which is the portion of the incident light that reflected back into the source fiber can be calculated using basic Fresnel formula. R is the fraction of the incident light reflected at the fiber n_1 is the refractive index of the core meanwhile, n_0 is the refractive index of the medium between the two fibers.

$$R = \left(\frac{n_1 - n_0}{n_1 + n_0}\right)^2 \tag{2.1}$$

In this step, the fibers are positioned in lateral offset, which the fibers are aligned where the axes of the core of the fiber end with the outer surface of the cladding of the fiber end. Meaning that the direction of the position is perpendicular to the longitudinal axes of the fiber ends, in which the lateral offset by the offset distance between the core and the cladding of the two fiber ends. Then, the heat is applied to the offset in which causing them to fuse together. The lateral offset connection of fiber, cause an imperfect transfer of optical signal from the transmitter to the receiver of the fiber. The imperfect transfer of the optical signal is known as 'fiber loss' at the offset region, which will be the sensing region in this project. Due to its high performance in sensing, some potential applications that used lateral offset fusion splicing sensor are gas composition detection in the industry [24], hydrostatic pressure sensor [25], vector bending sensor [26] and many more.

2.4.1 Measurement of Water Quality in Hydroponic System

As it is known, plants need water to grow. Thus, water is the primary concern in growing plants. In hydroponic, water plays an important role in supplying nutrients and minerals as the plant relies only on the water alone without any presence of soil. Nutrients and minerals can be consisting of Phosphorus (P), Nitrogen (N), Potassium (K), Iron (Fe) and many more. Other than the nutrients and minerals, the water quality supplied is important as the nutrients themselves; hence it is important to know what water quality is being supplied into the hydroponic system. Good water quality needs an ideal pH level and water temperature supplied to the hydroponic system.

The pH is a parameter that measures the acidity or alkalinity of a solution [27]. The pH of the hydroponic solution should be 5.5-6.5 [28]. Since hydroponic is a method that will not use any presence of soil, it is crucial to have an ideal pH level for the water since no soil can buffer and balances out the pH level of the supplied water to an acceptable level. Other than pH level, an ideal water temperature of the hydroponic water supplied also needs to be kept between 18 ºC and 26 ºC [29]. In addition, the water quality can greatly influence the hydroponic system. Without considering these two pH value and temperature value in providing a good water quality to the hydroponic system, it can cause bad performance in growing the plants and can cut off the nutrients that can be supplied to the root system inside water.

2.4.2 Hydroponic Crop System

Figure 2.9: The Hydroponic Crop System.

Hydroponic is a type of horticulture and a subset of hydroculture, one of the growing plants' methods. Typically, a crop system is using soil in growing plants. Still, the hydroponic crop system is an art that uses a mineral nutrient in an aqueous solvent, which is used as a base in growing plant without using any soil. In the Latin word, hydroponics referring to 'working water'. Meaning that, in this hydroponic crop system, water is an essential part of giving and providing nutrients, oxygen, and hydration to the plant.

The hydroponic system is believed as one of the crop systems that foster rapid growth, stronger yields with a superior plant quality because when the root system is directly exposed to water and nutrition, the plant does not have to exert any energy to sustain (photosynthesis) themselves. As a result, the energy of the root system that has been expended in acquiring food and nutrients can be redirected to the plant maturation in which the plant flourishes and blooms healthily. All hydroponic systems need to provide plant roots with enough nutrients, water and oxygen for good growth [28]. The plant captures the sunlight through its leaves in hydroponic, called chlorophyll (the green pigment that presents in the leaves). In this crop system, light's energy is used to split the water molecules that have been absorbed directly via the root system. Then, the hydrogen molecules will combine with carbon dioxide to produce carbohydrates, which helps the plant nourish itself. Hence, this is why it has proven the hydroponics crop system is more effective than another crop system due to its direct exposure to nutrient-filled water used in the system.

CHAPTER 3

METHODOLOGY

In this chapter, the implementation and the techniques required to achieve the project's objectives have been briefly explained. Other than that, all the function of materials and tools used for this project has been discussed in detail. Furthermore, this chapter also covers the hardware part, and the working operation of the project is explained in this chapter. Not just that, the step in developing the fiber optic sensor (FOS) fabrication based on the lateral offset displacement method are also explained in detail.

3.1 Project Methodology

For this project, the main task is to design and develop a fiber optic sensor (FOS) based on a lateral offset displacement sensor in measuring the water quality (temperature and pH) in a hydroponic crop system. As for the step in this project, the research has been done in finding any related journals to this project. Not just that, all the information of the tools and methods required for this project also has been gathered in order to be used for the aid of the constructions of the prototype of this project.

3.2 Project Flowchart

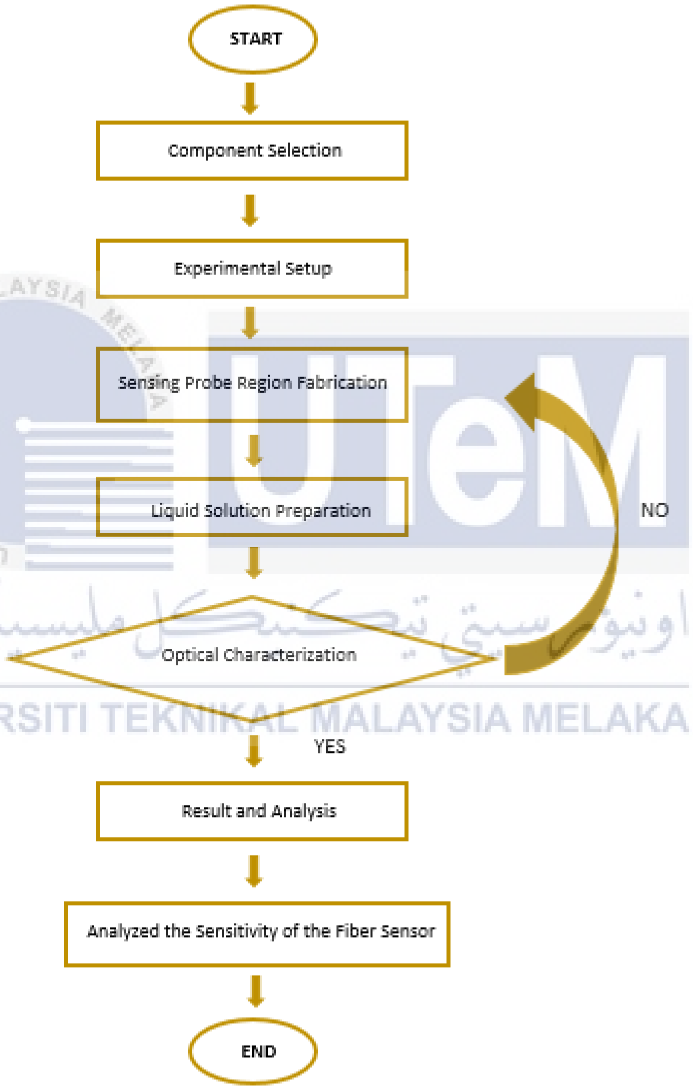


Figure 3.1: Overall Project Flowchart.

Figure 3.1 shows the whole flowchart process of the project. As for the first part of the flowchart process, the component of the project is selected, such as identifying a suitable material or equipment to be used while implementing this project. Thus, the component that has been chosen is Single Mode Optical Fiber at 1550 nm for its wavelength and Multimode Optical Fiber at 850 nm for its wavelength. Next, the experiment also has been set up to know the flow of the operation in this project. The example of the experimental optical setup is shown in Figure 3.5. In designing the sensor part, the fiber optic sensor (FOS) will be developed by using Single Mode Optical Fiber (SMF) and Multimode Optical Fiber (MMF). SMF is known as an optical fiber that carries a single mode of light, while MMF is known as an optical fiber that carries multiple modes of light. As a sensing region fabrication part, the fiber sensor part is fabricated at the center of the SMF and MMF based on lateral offset structure using the fusion-splicing method. There are variations in the sensing region in which Single Mode-Single Mode (SM-SM) and Multimode-Multimode (MM-MM) fiber mode configuration. Not just that, there are variations in the distance of the offset part of the sensing region. The exposed area of the sensing region after the fabrication process will act as a sensitivity part for the sensing element in this project.

Next, the liquid solution preparation is where the water quality of the hydroponic will vary for the water quality, such as the temperature and pH of the water for the analysis. The water sample is taken, the pH of the water is adjusted from 4.5 to 7.5, and the temperature of the water sample is adjusted from 16 º C to 32 º C. Each of the water sample solutions is measured with a digital refractometer for its refractive index (RIU). After that, the process will continue with the optical characterization. The input of the fiber will be connected Optical Light Source (OLS), and the output will be connected to Optical Power Meter (OPM) to get the optical signal, such as the optical power loss result during this optical characterization process. Other than OPM, Optical Spectrum Analyzer (OSA) also can be used. OSA has more function than OPM, which OSA can measure more than optical signal, such as to measure wavelength, power, and display the waveform. Though OSA is more efficient than OPM, there are limitations to using it, and as a result, the results obtained from it are inconsistent. As a result, OPM is the only reliable tool for getting results. After the optical characterization results are obtained, each result will be plotted on a graph to determine the best sensitivity of the best linear fit line of the results.

3.3 Method and Project Implementation

In this project, two types of fiber are chosen as fiber optic sensor (FOS), which is single mode optical fiber (SMF) and multimode optical fiber (MMF). The purpose of this project is to develop FOS based lateral offset structure using a fusion splicer machine. Thus, in this section, all the method and equipment used in developing the sensor region of fiber optic is explained.

3.3.1 Fabrication of the Fiber Sensor

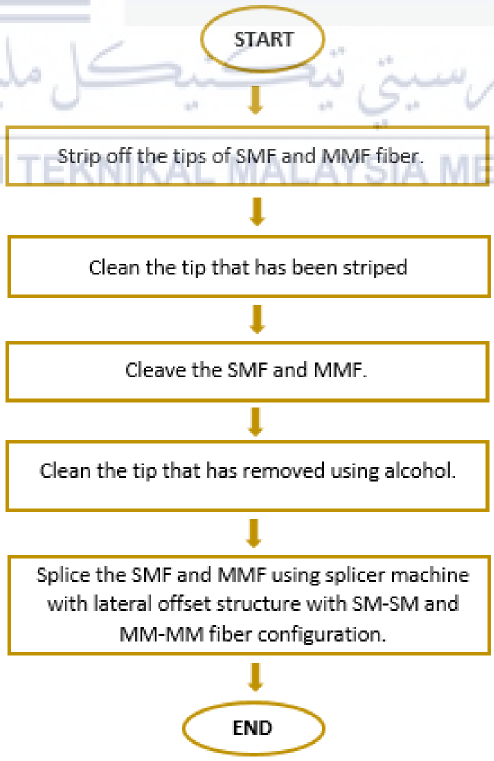


Figure 3.2: Fabrication Process of SM-SM and MM-MM.

Figure 3.2 shows the flow chart for the fabrication process of SM-SM and MM-MM. Fabrication is the process where SMF and MMF make the fiber as a sensor probe. Firstly, the outer layer of the optical fiber, which is the jacket, needs to be removed using the fiber cutter and slowly stripe off the optical fiber tip. After that, the area that has been stripped is cleaned using an alcohol solution. Then, the cladding of the fiber is removed to expose the core of the fiber, which act as the sensor. The core of the fiber will be cleave using a high precision cutter to ensure the tip of the core is 90 degrees straight, and the tip will be cleaned using alcohol after that. Once the tip is cleaned, the fiber is ready to be spliced using a splicer machine in a lateral offset structure. Lateral offset structure is where the core of the two fibers is in misalignment structure to create that 'fiber loss'.

3.3.2 The procedure of Setting on Normal Splicing in Fujikura FSM-18R

Splicing is the method where joining two optical fibers together. Normal splicing is known as a structure where the fiber is combined in a perfect alignment without creating any 'fiber loss' while transmitting light inside the fiber. A normal splicing structure is considered a fiber structure with no distance offset at all compared to the other fiber sensor constructed in a lateral offset structure. In this section, SMF and MMF will be spliced using splicer machine Fujikura FSM-18R with SM-SM and MM-MM mode fiber configuration. The procedure of setting the normal splicing is shown is briefly explained in this section.

Figure 3.3: Procedure of Setting up the Normal Fusion Splicing using Fujikura FSM 18-R

For the fiber sensor, SM-SM and MM-MM are developed based on lateral offset displacement sensor. At the end of fiber of SMF and MMF, the fiber sensor is then spliced with a pigtail probe in a normal fusion splicing structure to connect with the Optical Light Source and Optical Power Meter. The steps taken in doing the normal fusion splicing is started by switched ON the splicer machine Fujikura FSM-18R. Then, optic is placed into the correct position and get held by the fiber holder before it gets ready to be spliced.

Once the switch is on, the 'Home' screen appears, the splice mode of the splicer machine is automatically set to SM AUTO, which performs a normal splice in auto mode. The 'SET' button is pressed twice to set the splicing mode to set up the alignment of the fibers. Finally, after the two fibers have successfully combined in a normal splicing structure, 'FINISH' will appear on the screen. Thus, the hood of the splicer machine is open, and the fiber is carefully removed.

3.3.3 The procedure of Setting on Lateral Offset Method in Sumitomo Type-36

The most crucial part of this project is analyzing the performance of fiber optic sensor at different core distance of fiber optic sensor by lateral offset fiber structure. The two types of sensor, SMF and MMF, are constructed at a variety of distance. There are two types of fiber sensors, which is SM-SM and MM-MM. The fiber sensors constructed with a different offset distance, which for SM-SM is 11.57µm, and 18.72µm meanwhile for MM-MM, the offset distance is 2.21µm and 7.83µm. The splicing process of lateral offset structure is done using the fusion splicer machine Sumitomo TYPE-36. The procedures of setting up the distance of lateral offset are explained in details.

Figure 3.4: Procedure of Setting on Lateral Offset in Sumitomo Type-36.

The fiber sensor is developed with a lateral offset structure which act as sensing region. The steps for lateral offset structure is started by switched ON the fusion splicer machine Sumitomo Type-36. Then, the home screen appears. The 'SET' button is pressed until the splice mode is set up in 'Manual Mode'. The 'SET' button is then pressed again to adjust the fiber part in the splicer machine.

Next, the screen will show the screen for the two core of the fiber. Number ‘1’ button is pressed to set up the position in the x-axis of the fiber, while the number ‘2’ button is pressed to adjust the position of the fiber on the y-axis. Once the misalignment of the fiber is confirmed, the number ‘8’ button is pressed to change the ‘Spattering’ to ‘Splice’ mode. The ‘ARC’ button is pressed to start splicing. Finally, after the splicing process is done, and the hood of the machine can be open to remove the spliced fiber. The fiber is slowly placed on the board to prevent the spliced fiber from breaking.

3.3.4 Preparation of Solution

The solution that needs to be measure is prepared. Two samples of water quality of the hydroponic system are taken to vary the pH value of the water and the temperature of the water.

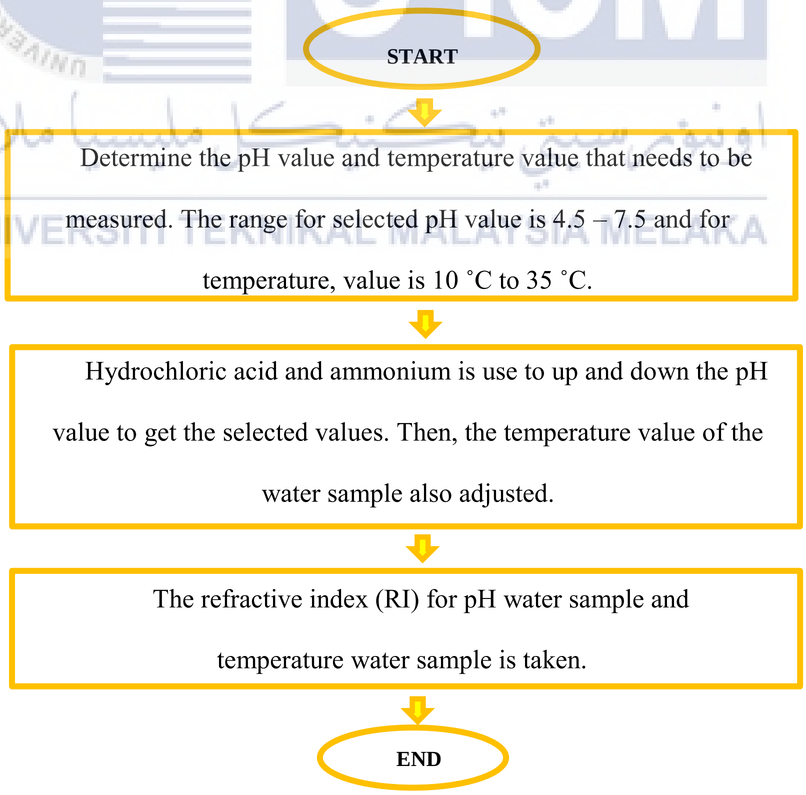


Figure 3.5: Flowchart for Preparing the Solution.

As shown in Figure 3.5, the water sample has been taken, and the pH value of the water is varied (increasing and decreasing) from 4.5 – 7.5. The pH value is adjusted using Hydrochloric Acid and Ammonium Acid to up and down the pH value of the water. Then, the adjusted pH water is measured using a digital pH meter. During the pH adjustment, the temperature of the water is remaining constant at room temperature, which is at 29 ˚C. Not just that, the temperature of the water sample also is adjusted from 10 ºC – 35 ºC using a heater and stirrer machine. A freezer is used in this section to get into certain values that lower than 20 ºC, and the pH of the water is remaining constant at 6.5. During the temperature adjustment, the temperature of the water sample is measured using a thermometer to get the reading of the temperature then a digital refractive meter is used for every each of the solutions in getting the reading of the refractive index (RIU).

3.4 Experimental Setup

Figure 3.6: The Block Diagram for Fiber Optic Sensing.

Figure 3.6 shows the optical block diagram for this project. For the input, the Optical Light Source is connected to the part of the end fiber. 1550 nm for the wavelength is used for single mode optical fiber (SMF), and 850 nm wavelength is used for multimode optical fiber (MMF). Then, the exposed area which has been spliced based on lateral offset structure will act as a sensing head (sensor) in this project, and it will be submerged into the water sample, which will measure the performance of the sensing region once it has been submerged into a variety of water quality (temperature and pH). The results obtained from the OPM, which is an optical signal, is transmitted to the optical power meter to get the reading. Figure 3.7 shows the experimental optical setup.

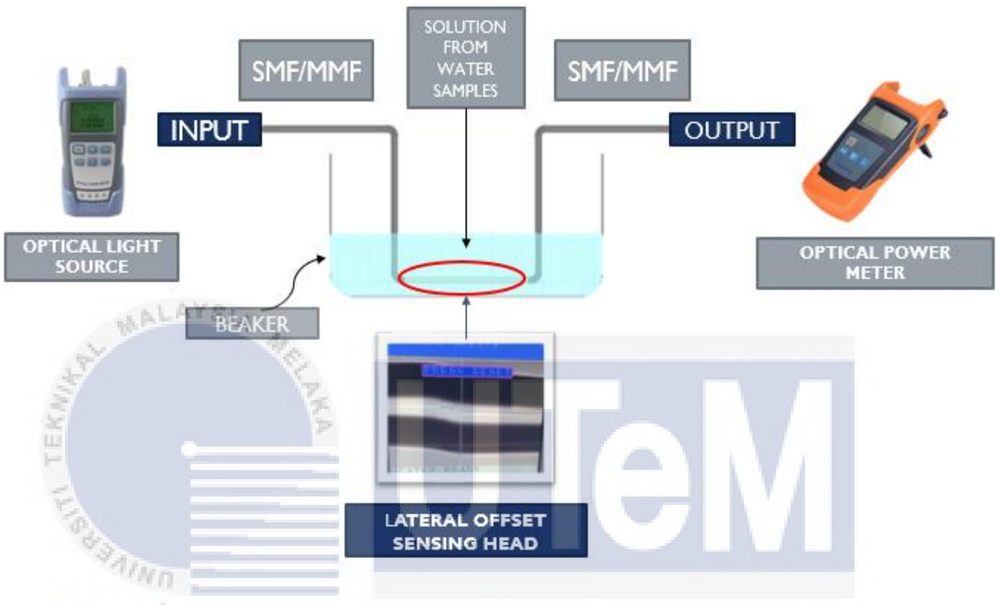


Figure 3.7: The Experimental Optical Setup.

3.5 Equipment and Tools

In developing this fiber optic sensor, some equipment and tools have been used. All the important equipment and tools required for this project has been explained with their functionalities.

Figure 3.8: **Multimode Optical Fiber (MMF)**

Figure 3.8 shows a Multimode Optical Fiber (MMF) that perform multiple modes of transmission designed to be operated at 850 nm and 1300 nm. SM-SM fiber mode configuration is used in this project.

Figure 3.9: Single Mode Optical Fiber (SMF)

Figure 3.9 shows a Single Mode Optical Fiber that perform a single mode of transmission designed to be operated at 1310 nm and 1550 nm. MM-MM fiber mode configuration is used in this project.

Figure 3.10: Pigtail probe for Single Mode and Multimode

Figure 3.10 shows the pigtail probe, which is used to connect the joints at both ends of the fiber and connect to the input and output of the fiber optic sensor in a normal fusion splicing structure for both SM-SM and MM-MM.

Figure 3.11: RUIYAN RY3200A Optical Power Meter

Figure 3.11 shows the optical power meter that is used to measure the optical signal for the single mode optical fiber SM-SM and multimode optical fiber MM-MM at wavelength 850 nm and 1550 nm. An optical power meter shows the output power in dBm or Watt.

Figure 3.12: JW3111 Optical Light Source

Figure 3.10 shows the optical light source used to provide laser light source for single mode optical fiber and multimode optical fiber (MMF) at wavelength 850 nm, 1310 nm and 1550 nm.

Figure 3.13: Optical Light Sources

Figure 3.13 shows the optical light source used to provide a laser light source for single mode optical fiber (SMF) at wavelength 1310 nm and 1550 nm.

Figure 3.14: DR-101 Digital Refractometer

Figure 3.14 shows the digital refractometer used to measure the refractive index of each of the solutions in pH and temperature water solutions.

Figure 3.15: ZEISS Axioskop 2 MAT (Image Analyser)

Figure 3.15 shows the image analyzer that used to observe and measure the offset distances of the fiber sensor that has been spliced at the two cores of the lateral offset structure.

Figure 3.16: SUMITOMO TYPE 36 Fiber Fusion Splicer

Figure 3.16 shows a Sumitomo Type 36, which is a manual splicer machine that used to set up the lateral offset structure manually.

Figure 3.17: Commercial Splicer Fujikura FSM-18R

Figure 3.17 shows the Fujikura FSM-18R, which is an auto splicer machine that used to set up the normal splicing structure, which the offset distance is at 0 μm.

Figure 3.18: Fiber Cleaver Fujikura CT-30

Figure 3.18 shows the fiber cleaver CT-30, which used to cleave the end of fiber optic fiber to make sure it is 90 degrees straight to ensure there is no error during the splicing process.

Figure 3.19: Digital Display Heating and Stirrer Machine

Figure 3.19 shows the digital heating and stirrer machine is to heat up the water solutions to increase the temperature of the water solutions.

Figure 3.20: Thermometer

Figure 3.20 shows the thermometer is used to measure the temperature of the water solutions.

Figure 3.21: Digital Thermometer

Figure 3.21 shows the digital thermometer that is used to compare the results of the temperature obtained from the conventional thermometer.

Figure 3.22: Ammonium Acid

Figure 3.22 shows the ammonium acid that is used to increase the pH of the water solutions.

Figure 3.23: Hydrochloric Acid

Figure 3.23 shows the hydrochloric acid that is used to lower the pH of the water solutions.

Figure 3.24: Digital PH Meter

Figure 3.24 shows a digital pH meter that is used to measure the pH value of the pH water solutions.

CHAPTER 4

RESULTS AND DISCUSSION

All the data and results obtained throughout the project has been tabulated and analyzed in this chapter. The sensitivity of both fiber sensor SM-SM and MM-MM with different offset distances with lateral offset displacement has been observed explained in this chapter.

4.1 Refractive Indices of the Solutions

Before the SM-SM and MM-MM fiber sensors were tested, the pH water solution (pH) and temperature water solution (ºC) was prepared for measurement purposes. There were nine solutions with different pH values and nine solutions with different temperature value. These variations of pH values and temperature values then are tested for the fiber sensor SM-SM and MM-MM.

4.1.1 PH Water Solution

For the pH solution, the water sample is taken. The water is then mixed with a few drops with acid, which is Ammonium, to raise the pH value of the water, while Hydrochloric Acid is used to lower the pH value of the water. According to H. Singh [30], The nutrient solution's pH was maintained between 5.5 and 6.5. The ideal pH value for hydroponic is between 4.5 and 6.5. Thus, in this project, the pH water is varied by increasing and decreasing the pH value ranging from 4.5 to 7.5. The pH value of 4.5 to 7.5 is the range of pH value which from the lowest and the highest, respectively from the ideal pH value of the hydroponic crop system. This variation of pH value is used for the measurement process using a lateral offset fiber sensor. Therefore, nine solutions with different pH values were prepared during this project, and the refractive index of each solution prepared is measured using a digital refractometer. The results have been recorded as shown in Table 4.1.

Table 4.1: Refractive Index of pH Water Solutions

pH Value	Refractive Index of pH Water Solution (RIU)
4.5	1.3324
4.9	1.3326
5.4	1.3329
5.6	1.3331
5.9	1.3332
6.4	1.3334
6.6	1.3335
7.0	1.3337
7.5	1.3340

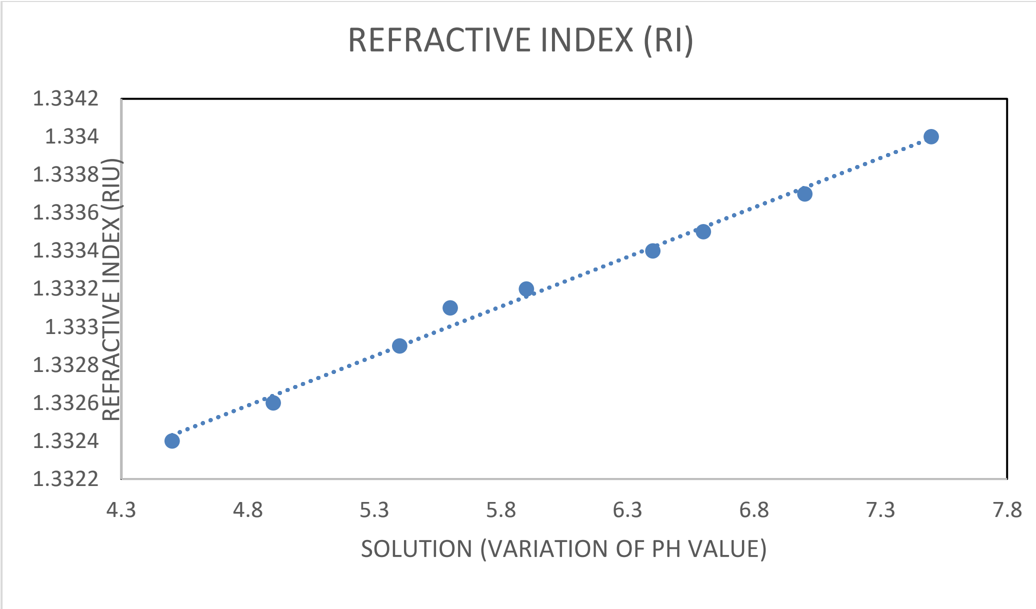


Figure 4.1: The pH Value of Solution Versus the Refractive Index of Different pH Water (RIU)

Table 4.1 and Figure 4.1 show the tabulated data and graph line for the pH water solutions. The results show that the relationship between refractive index (RI) and pH value is linearly increasing. According to A. El Hamidi et al.[31], the refractive index increases slightly when the pH increases to pH = 9.5, where it reaches its maximum. Based on the results obtained in Table 4.1 and Figure 4.1, it can clearly be seen the pH value used is only until 7.5. Thus, the refractive index slightly increased towards the pH value in this project due to the free carrier density of the water.

4.1.2 Temperature Water Solution

As for the temperature water solution, the water sample is taken. The value of the temperature used is ranging from 16 °C to 32 °C. According to S. Raghul [32], the ideal water temperature for hydroponics is between 18 °C and 26 °C. Thus, in this project, the temperature water is varied by increasing and decreasing the temperature value ranging from 16 °C to 32 °C. The temperature value of 16 °C to 32 °C is the range of temperature value which from the lowest and the highest, respectively from the ideal temperature value of the hydroponic crop system. This variation of temperature value is used for the measurement process using a lateral offset fiber sensor. The water temperature is adjusted until it reaches a specific value needed for measurement purposes. To increase the temperature of the water, the water is heated up using the digital display heater and stirrer machine until it reaches 32 ºC. Meanwhile, the freezer is used to get a lower temperature value which less than 22 ºC. Therefore, there are nine solutions with different temperature values has been prepared. The value is then measured with a digital refractometer to get the refractive index of each solution. The refractive index of each solution is shown in Table 4.2.

Table 4.2: Refractive Index of Temperature Water Solutions

Temperature (˚c)	Refractive Index Temperature Water Solution (RIU)
16	1.3340
18	1.3337
20	1.3335
22	1.3333
24	1.3332
26	1.3329
28	1.3328
30	1.3327
32	1.3325

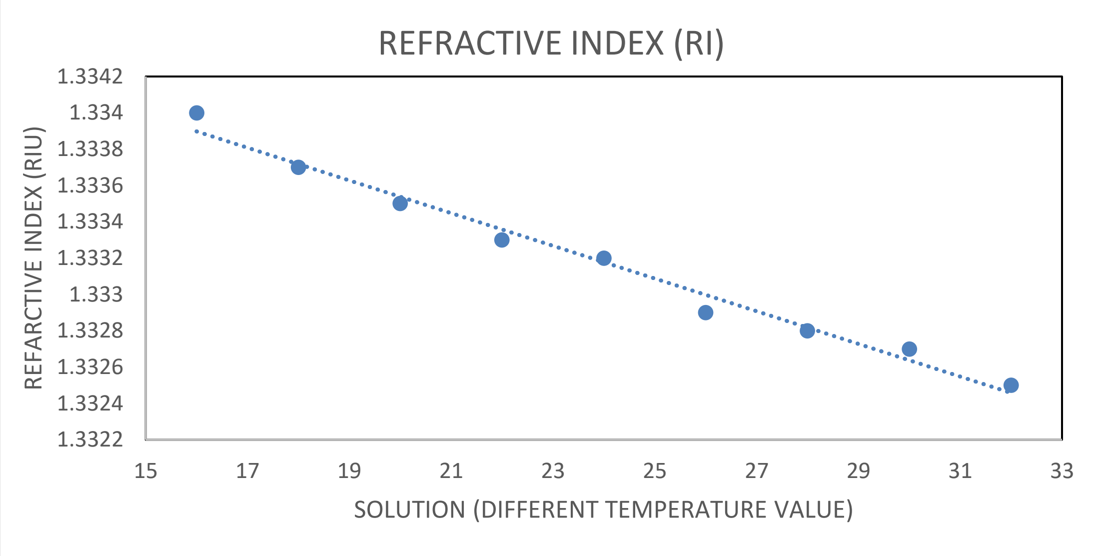


Figure 4.2: The Temperature Value of Solution Versus the Refractive Index of Different pH Water (RIU)

Table 4.2 and Figure 4.2 show the tabulated data and the graph line of the temperature water solution. From the results, it can be seen that the relationship between the refractive index (RIU) and temperature is linearly decreasing. It is known that the refractive index (RI) of the water decreases when the temperature increases [33][34]. Based on the results obtained in Table 4.2 and Figure 4.2, it can be seen that the temperature water range 16 ºC – 32 ºC has obtained an increasing refractive index, which the range of the refractive index (RIU) is 1.3340 RIU – 1.3325 RIU. With the increase of temperature, the speed of light in the medium increase, which causes the refractive index of the medium to decrease.

4.2 Analysis of Lateral Offset Sensor Structure

The analysis of this project is taken from the observation of output optical power (dBm) obtained from both fiber sensors for the fiber sensors for both SM-SM and MM-MM with a different lateral offset distance. The offset distances of both fiber sensors are developed with two different offset distances for each fiber sensors, which is for SM-SM the offset distances are 11.57 µm, and 18.72 µm meanwhile, for MM-

MM, the offset distances are 2.21 µm and 7.83 µm, as shown in Figure 4.4 and Figure 4.5. The offset distances is because of the misalignment spliced joint between the SMF and MMF. The input wavelength used in the fiber sensor is 1550 nm for SM-SM, and 850 nm is used for the MM-MM. All the output optical power values obtained in dBm have been recorded as shown in Table 4.3 until Table 4.14 according to the different offset distances of fiber sensors, respectively. Not just that, the graphs of the highest sensitivity to lower sensitivity of the fiber sensor according to its different offset distances in pH and temperature water solution are shown from Figure 4.6 until Figure 4.9.

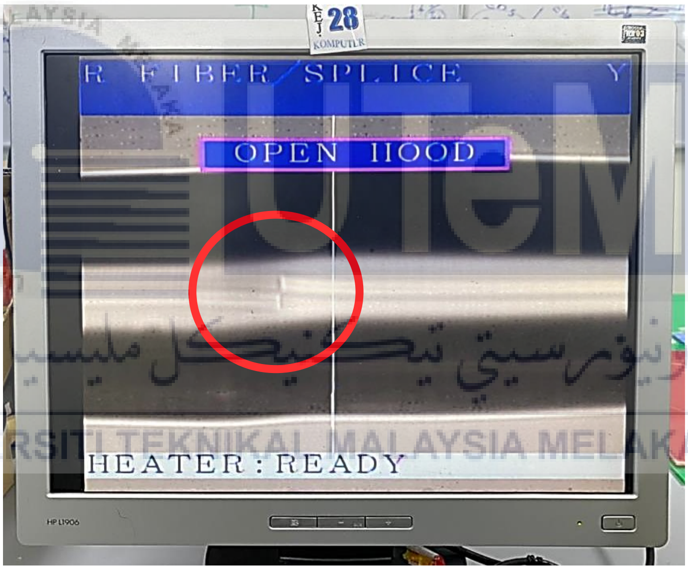


Figure 4.3: The Misalignment Spliced Joint of Fiber

4.2.1 The Offset Distance of Fiber Sensor

In order to identify the sensitivity of the fiber sensor, the offset distance of the fiber sensor was developed with different distances for both fiber sensor SM-SM and MM-MM fiber sensor. Figure 4.4 and Figure 4.5 below shows the offset distances that have been developed in this project.

Figure 4.4: The Offset Distance in SM-SM Fiber Sensor

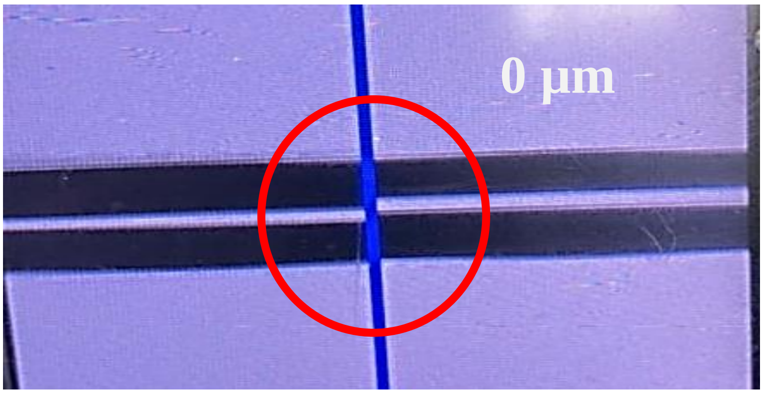
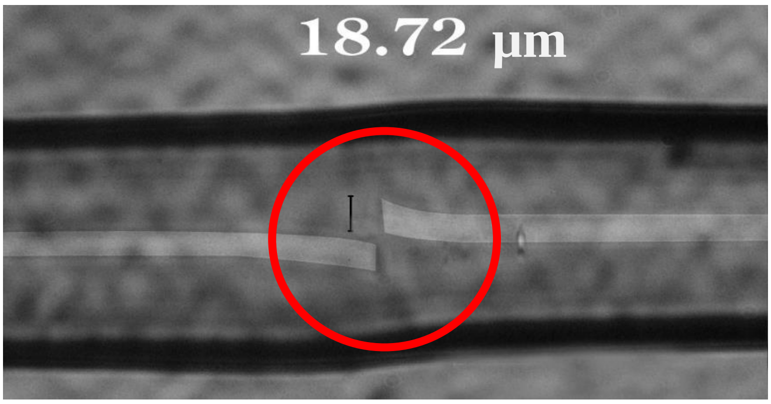
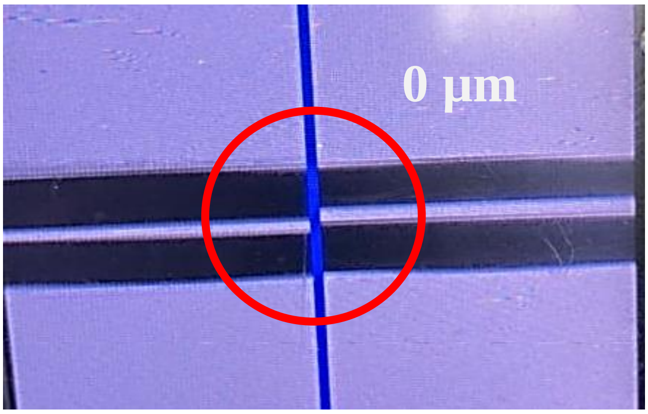
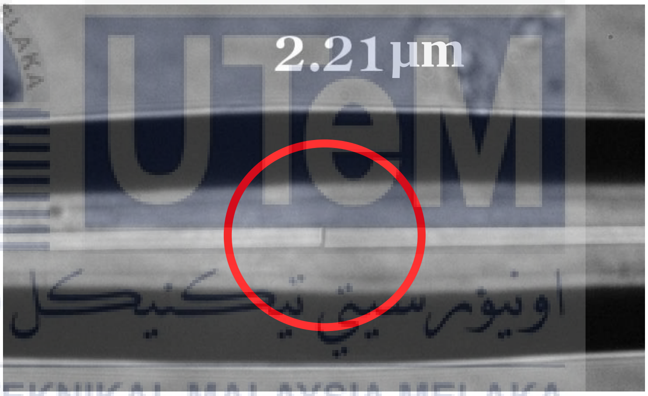
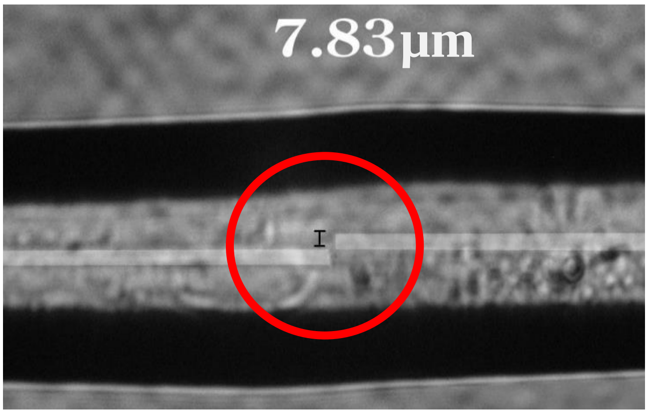
Fiber Type	**Offset Distance (µm)**
	No Distance 
SM-SM	11.57 µm 
	18.72 µm 

Figure 4.5: The Offset Distance in MM-MM Fiber Sensor

<table>
<tr><th>Fiber Type</th><th>Offset Distance (µm)</th></tr>
<tr><td rowspan="3">MM-MM</td><td>No Distance

</td></tr>
<tr><td>2.21 µm

</td></tr>
<tr><td>7.83 µm

</td></tr>
</table>

As shown in Figure 4.4 shows the offset distance for the SM-SM fiber sensor. The offset distance of 0 µm has been set up using auto splicer machine Fujikura FSM 18-R. Meanwhile, the other offset distance such as 11.57 µm and 18.72 µm has been set up manually using splicer machine Sumitomo Type-36.

Figure 4.5 shows the offset distance for the MM-MM fiber sensor. The steps taken was the same as in the SM-SM but with a different offset distance. For the offset distance at 0 µm, the steps were set up using the auto splicer machine Fujikura FSM 18-R. Then, the other two offset distances, which are 2.21 µm and 7.83 µm, set up using set up manually using the splicer machine Sumitomo Type-36.

4.2.2 Tabulated Data of Output Power (dBm) with a Different Offset Distance of Fiber Sensor.

Table 4.3 until Table 4.14 shows overall data collections for the output power (dBm) with a different offset distance in each fiber sensor in a different type of solutions: pH water solutions and temperature water solutions. The offset distances used in this project is 0 µm, 11.57 µm and 18.52 µm for SM-SM fiber sensor configuration and 0 µm, 2.21 µm and 7.83 µm for MM-MM fiber sensor configuration. All the results of the output power are shown in Table 4.3 until Table 4.14 below.

Table 4.3: The Optical Output Power (dBm) with the Different Distances of Lateral Offset Structure in SM-SM Fiber Sensor for PH Water Solution.

PH Value of the Solutions (pH)	Offset Distance of Fiber Sensor (μm)	Output Optical Power (dBm)
4.5	No distance	-8.13
4.9	No distance	-8.65
5.4	No distance	-9.01
5.6	No distance	-8.73
5.9	No distance	-8.68
6.4	No distance	-9.04
6.6	No distance	-9.15
7	No distance	-8.62
7.5	No distance	-9.29

Table 4.4: The Optical Output Power (dBm) with the Different Distances of Lateral Offset Structure in SM-SM Fiber Sensor for PH Water Solution.

PH Value of the Solutions (pH)	Offset Distance of Fiber Sensor (μm)	Output Optical Power (dBm)
4.5	11.57	-17.48
4.9	11.57	-17.62
5.4	11.57	-17.33
5.6	11.57	-17.49
5.9	11.57	-16.98
6.4	11.57	-17.26
6.6	11.57	-17.96
7	11.57	-18.30
7.5	11.57	-18.56

Table 4.5: The Optical Output Power (dBm) with the Different Distances of Lateral Offset Structure in SM-SM Fiber Sensor for PH Water Solution.

PH Value of the Solutions (pH)	Offset Distance of Fiber Sensor (μm)	Output Optical Power (dBm)
4.5	18.72	-22.15
4.9	18.72	-22.35
5.4	18.72	-23.58
5.6	18.72	-22.25
5.9	18.72	-24.38
6.4	18.72	-24.62
6.6	18.72	-22.59
7	18.72	-23.75
7.5	18.72	-23.96

Table 4.6: The Optical Output Power (dBm) with the Different Distances of Lateral Offset Structure in SM-SM Fiber Sensor for Temperature Water Solution.

Temperature Value of the Solutions (°C)	Offset Distance of Fiber Sensor (μm)	Output Optical Power (dBm)
16	No distance	-7.93
18	No distance	-7.89
20	No distance	-8.23
22	No distance	-7.94
24	No distance	-8.13
26	No distance	-8.35
28	No distance	-8.22
30	No distance	-8.56
32	No distance	-8.72

Table 4.7: The Optical Output Power (dBm) with the Different Distances of Lateral Offset Structure in SM-SM Fiber Sensor for Temperature Water Solution.

Temperature Value of the Solutions (ºC)	Offset Distance of Fiber Sensor (µm)	Output Optical Power (dBm)
16	11.57	-17.35
18	11.57	-17.82
20	11.57	-17.22
22	11.57	-17.51
24	11.57	-17.84
26	11.57	-18.23
28	11.57	-17.48
30	11.57	-18.27
32	11.57	-18.66

Table 4.8: The Optical Output Power (dBm) with the Different Distances of Lateral **Offset Structure in SM-SM Fiber Sensor for Temperature Water Solution.**

Temperature Value of the Solutions (ºC)	Offset Distance of Fiber Sensor (µm)	Output Optical Power (dBm)
16	18.72	-22.29
18	18.72	-22.48
20	18.72	-22.51
22	18.72	-22.19
24	18.72	-22.67
26	18.72	-22.78
28	18.72	-23.96
30	18.72	-24.15
32	18.72	-24.46

Table 4.9: The Optical Output Power (dBm) with the Different Distances of Lateral Offset Structure in MM-MM Fiber Sensor for PH Water Solution.

PH Value of the Solutions (pH)	Offset Distance of Fiber Sensor (µm)	Output Optical Power (dBm)
4.5	No distance	-30.43
4.9	No distance	-30.27
5.4	No distance	-30.06
5.6	No distance	-30.41
5.9	No distance	-30.21
6.4	No distance	-30.88
6.6	No distance	-30.96
7	No distance	-30.82
7.5	No distance	-30.87

Table 4.10: The Optical Output Power (dBm) with the Different Distances of Lateral Offset Structure in MM-MM Fiber Sensor for PH Water Solution.

PH Value of the Solutions (pH)	Offset Distance of Fiber Sensor (µm)	Output Optical Power (dBm)
4.5	2.21	-36.63
4.9	2.21	-31.08
5.4	2.21	-33.73
5.6	2.21	-35.24
5.9	2.21	-34.72
6.4	2.21	-35.72
6.6	2.21	-34.10
7	2.21	-35.00
7.5	2.21	-35.85

Table 4.11: The Optical Output Power (dBm) with the Different Distances of Lateral Offset Structure in MM-MM Fiber Sensor for PH Water Solution.

PH Value of the Solutions (pH)	Offset Distance of Fiber Sensor (μm)	Output Optical Power (dBm)
4.5	7.83	-35.47
4.9	7.83	-35.50
5.4	7.83	-38.64
5.6	7.83	-36.87
5.9	7.83	-36.93
6.4	7.83	-37.53
6.6	7.83	-39.59
7	7.83	-38.45
7.5	7.83	-37.10

Table 4.12: The Optical Output Power (dBm) with the Different Distances of Lateral Offset Structure in MM-MM Fiber Sensor for Temperature Water Solution.

Temperature Value of the Solutions (°C)	Offset Distance of Fiber Sensor (μm)	Output Optical Power (dBm)
16	No distance	-30.21
18	No distance	-30.56
20	No distance	-30.62
22	No distance	-30.77
24	No distance	-30.58
26	No distance	-30.81
28	No distance	-31.09
30	No distance	-31.14
32	No distance	-31.27

Table 4.13: The Optical Output Power (dBm) with the Different Distances of Lateral Offset Structure in MM-MM Fiber Sensor for Temperature Water Solution.

Temperature Value of the Solutions (ºC)	Offset Distance of Fiber Sensor (µm)	Output Optical Power (dBm)
16	2.21	-33.80
18	2.21	-33.77
20	2.21	-33.29
22	2.21	-33.91
24	2.21	-34.03
26	2.21	-34.28
28	2.21	-34.52
30	2.21	-34.61
32	2.21	-34.77

Table 4.14: The Optical Output Power (dBm) with the Different Distances of Lateral Offset Structure in MM-MM Fiber Sensor for Temperature Water Solution.

Temperature Value of the Solutions (ºC)	Offset Distance of Fiber Sensor (µm)	Output Optical Power (dBm)
16	7.83	-37.06
18	7.83	-37.19
20	7.83	-37.32
22	7.83	-37.68
24	7.83	-38.33
26	7.83	-37.21
28	7.83	-38.79
30	7.83	-39.24
32	7.83	-39.84

Table 4.3, Table 4.4 and Table 4.5 shows the results obtained for the SM-SM fiber sensor for pH water solutions. These tables show the results of the SM-SM fiber sensor for the offset distance at 0 µm, 11.57 µm and 18.72 µm in pH water solutions. As for

the offset distance of 0 µm, it can be seen that the fiber sensor is in the perfect joint fiber since there is no misalignment in that structure. Because of that, it has a better light transmission and lowers ‘fiber loss’ in it. Thus, lower ‘fiber loss’ creates a lower sensitivity in fiber sensor. Thus, the signal strength becomes weaker [35]. It can be seen that the output power (dBm) in pH water solutions produced lower outputs compared to other offset distance such as 11.57 µm and 18.72 µm in the SM-SM fiber sensor. The other two distances, which is 11.57 µm and 18.72 µm, were where the lateral offset misalignment had been applied to this fiber structure. The offset area is where the region that created a ‘fiber loss’ in that fiber sensor. The ‘fiber loss’ created can cause a sensing sensitivity of the fiber. From the tables, the results of output power (dBm) obtained in pH water solutions for the offset distance at 11.57 µm are higher compared to the output of offset distance at 0 µm, but lower in output if it's compared with the higher offset distance at 18.72 µm.

Next, Table 4.6, Table 4.7 and Table 4.8, the results for the temperature water solutions. The offset distance of the fiber sensor is the same as in pH water solutions which is 0 µm, 11.57 µm and 18.72 µm. For the offset distance at 0 µm, output power (dBm) produced is the same as the SM-SM fiber sensor in pH water solutions. The output power (dBm) produced are the lowest than the other offset distance for 11.57 µm and 18.72 µm which produced a higher output as the offset distances getting larger.

Then, referring to Table 4.9, 4.10 and Table 4.11, these tables show the results of the output power (dBm) for the MM-MM in pH water solutions. The offset distances applied to this MM-MM fiber sensor are 0 µm, 2.21µm and 7.83 µm. The results show the same as in the SM-SM fiber, in which the output power (dBm) produced at the offset distance of 0 µm is the lowest compared to the other two offset distances, which at 2.21µm and 7.83 µm. Due to the lateral offset distance that has been applied at the sensing region at the offset distance 2.21 µm and 7.83 µm. The output power (dBm) produced is higher at the largest offset distance compared to the output power (dBm) produced at 0 µm.

Lastly, for Table 4.12, Table 4.13 and Table 4.14, the results show the output power (dBm) obtained for the MM-MM fiber sensor with the same offset distances in pH water solutions, which the offset distances are 0 µm, 2.21 µm and 7.83 µm. The results show the MM-MM fiber sensor in temperature water solutions. The highest offset distance, which at 7.83 µm, produces the highest output power (dBm), compared to the other two offset distances.

4.3 Best Linear Fit Graph of the Output Power (dBm) with a Different Offset Distance.

In this section, the results obtained from the tabulated data in section 4.2.2, all the data has been plotted in a graph as shown in Figure 4.6 until Figure 4.9. The best linear fit line has been observed to analyze the best structure of the fiber sensor configuration. The slope in this graph represents the sensitivity of each fiber sensor, SM-SM and MM-MM, respectively. This can help in analyzing the graph reading pattern and sensitivity of each fiber.

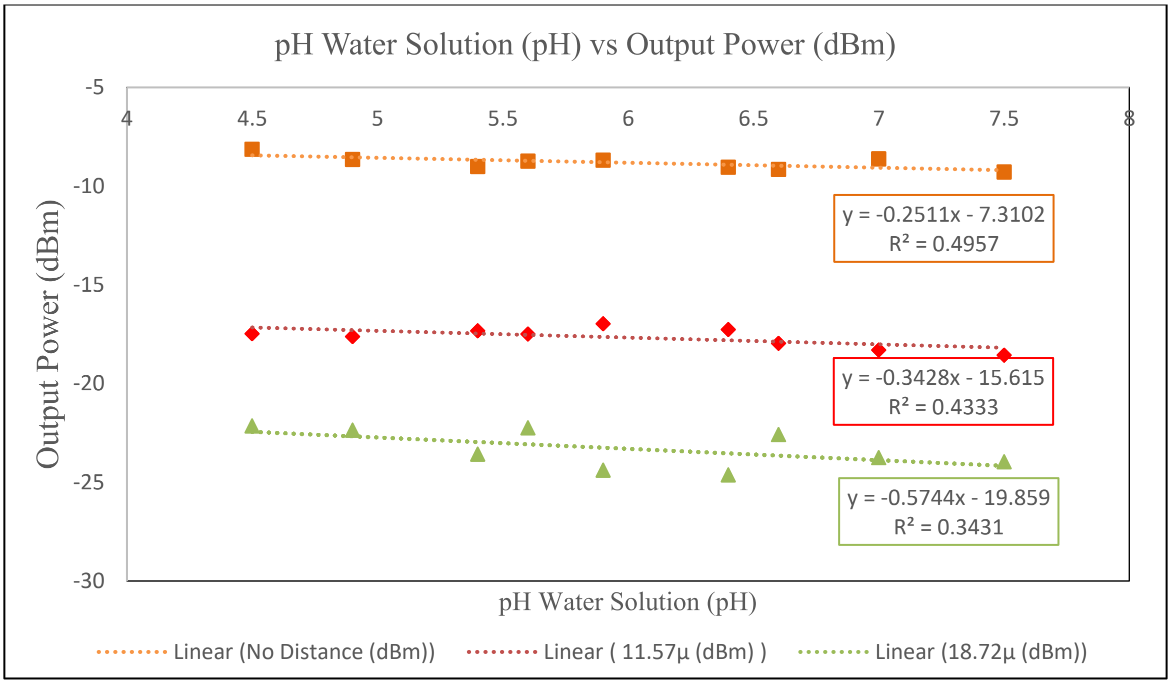


Figure 4.6: The PH Values of Solutions (pH) Versus Output Optical Power (dBm) with Different Offset Distance of SM-SM Fiber Sensor.

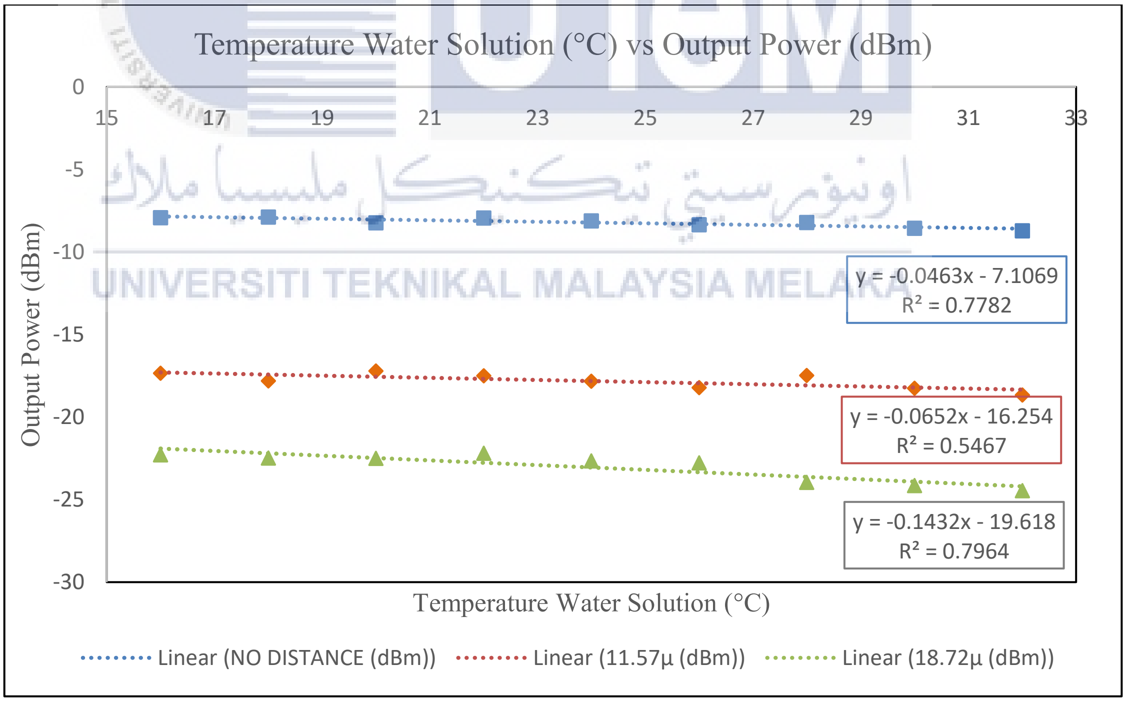


Figure 4.7: The Temperature Values of Solutions (°C) Versus Output Optical Power (dBm) with Different Offset Distance of SM-SM Fiber Sensor.

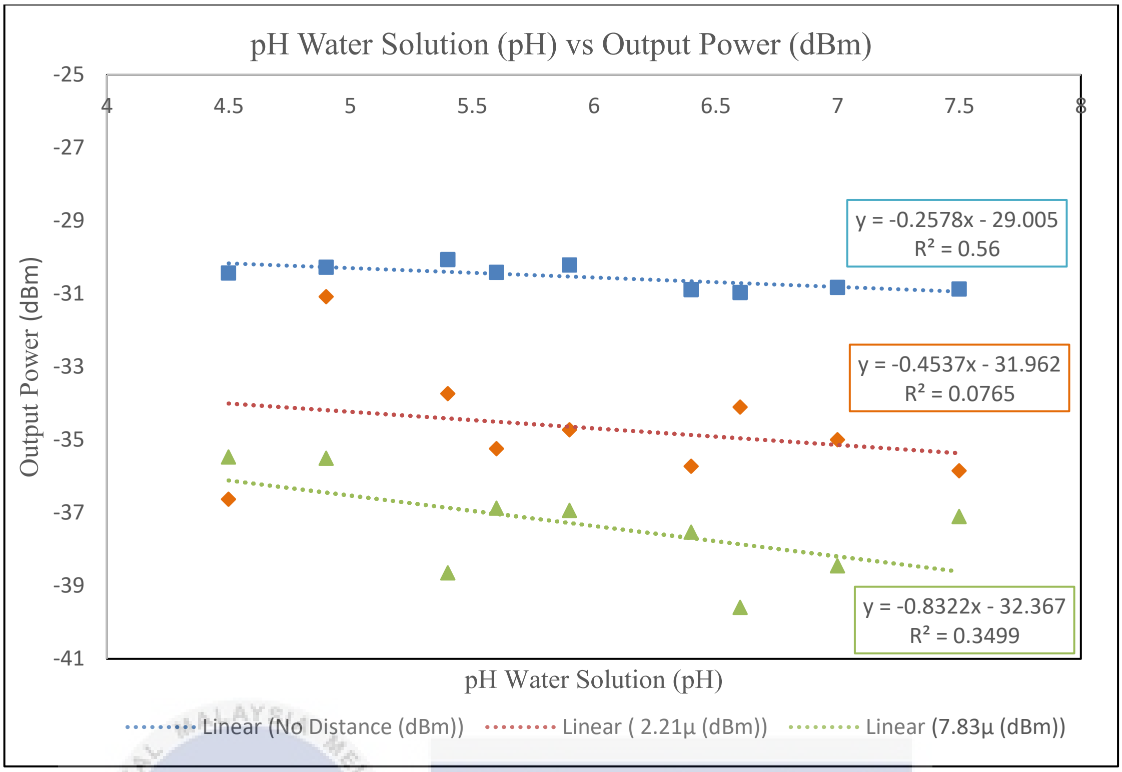


Figure 4.8: The PH Values of Solutions (pH) Versus Output Optical Power (dBm) with Different Offset Distance of MM-MM Fiber Sensor.

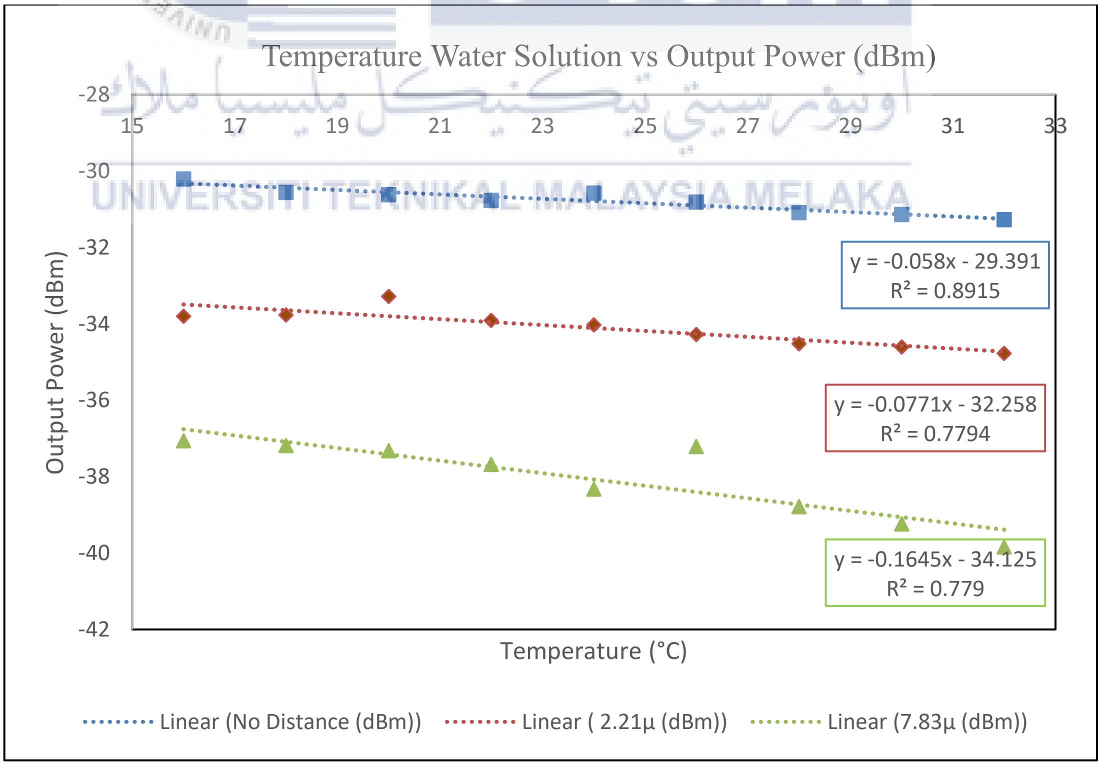


Figure 4.9: The Temperature Values of Solutions (°C) Versus Output Optical Power (dBm) with Different Offset Distance of MM-MM Fiber Sensor.

Figure 4.6 and Figure 4.8 show the linear best-fit graph of the SM-SM fiber sensor and MM-MM fiber sensor in pH water solutions. The offset distance for SM-SM fiber developed is 0 µm, 11.57 µm and 18.72 µm. Meanwhile, the offset distance developed in the MM-MM fiber sensor is 0 µm, 2.21 µm and 7.83 µm. When the offset distance is at 0 µm, a small amount of light enters the outer cores of the fiber. With the increase of the offset distance, the light entering the cladding gradually increases [36]. The larger offset distance can promote to a higher energy loss of the fiber sensor. The results show that the largest offset produces the highest output power (dBm). The graphs in Figure 4.6 and Figure 4.8 show the linearly decrease for SM-SM and MM-MM fiber sensor in pH water solutions. W. Li et al. [37] indicating a decreased linearity of the optical pH sensor. All sensors with sensing matrix of different stirring time show a linearly decreasing behaviour of output power with increasing pH value. [38] However, the optical output power is usually different for different pH sensors, although the same pH sensor will have the same change of optical output power responding to the same pH range. [39]

Figure 4.7 and Figure 4.9, it show the linear best-fit graph of the SM-SM fiber sensor and MM-MM fiber sensor in temperature water solutions. The offset distance for SM-SM fiber developed are 0 µm, 11.57 µm and 18.72 µm meanwhile the offset distance developed in MM-MM fiber sensor is 0 µm, 2.21 µm and 7.83 µm. The results are shown in Figure 4.7 and Figure 4.9, for offset distance at 0 µm has the lowest output power (dBm) due to less amount that enters the cladding area of the fiber. Compared to the other two offset distances, offset distance at 18.72 µm for SM-SM fiber sensor and offset distance at 7.83 µm fiber sensor has the highest output power (dBm). The transmission loss will increase with the increase of the offset distance [36]. Higher transmission loss provides better sensitivity. The graph shows that both graphs in SM-SM and MM-MM are both linearly decreasing. According to S. Alawsi [40], it is shown that the behaviour of the transmissions with respect to temperature indicates that the transmitted signal decrease with increasing the temperature of the PCF. This is due to the collisions between the molecules of the silica and the light signal that will losses the signal part of its motion power.

4.4 Sensitivity of SM-SM and MM-MM Fiber Sensors

In this part, the sensitivity of the fiber sensors has been observed and analyzed from the results obtained from the optical power meter (OPM). The steepest slope in the graph represents the highest sensitivities of the fiber sensor. Each graph has a best-fit linear line that represents in the general mathematical equation is:

$$y = mx + c \tag{4.1}$$

Where y represents the output optical power, x is the value of the solution, which refers to the pH and temperature of the water. Not just that, m shows the gradient or slopes of the graph that resembles the sensitivity of fiber, and c is the y-intercept of the graph. The sensitivity of both fiber sensors, SM-SM and MM-MM shown in Table 4.15.

Table 4.15: The Sensitivity of SM-SM and MM-MM Fiber Sensor

Solutions	**Sensitivity for SM-SM and MM-MM**					
	SM-SM			**MM-MM**		
	0 (µm)	**11.57 (µm)**	**18.72 (µm)**	**0 (µm)**	**2.21 (µm)**	**7.83 (µm)**

PH Water Solution (pH)	-0.2511	-0.3428	-0.5744	-0.2578	-0.4537	-0.8322
Temperature Water Solution (ºC)	-0.0463	-0.0652	-0.1432	-0.0580	-0.0771	-0.1645

From the table shown in Table 4.15, it can be seen that the data tabulated are obtained from the steepest slope that has the highest sensitivity of fiber sensor. As shown in Figure 4.4, the steepest slope for the SM-SM fiber sensor in pH water solution is -0.5744 dBm/pH, which the offset distance has the largest distance at 18.72 µm. Meanwhile, the lowest sensitivity is the -0.2511 dBm/pH with zero offset distance. In temperature water solution, the result is the same as in pH water solution. The highest and lowest sensitivity is -0.1432 dBm/ºC and -0.0463 dBm/ºC, that the offset distance is at 18.72 µm and zero offset distance, respectively.

As for the MM-MM fiber sensor, the highest sensitivity is at the lowest sensitivity of -0.8322 dBm/pH in the pH water solution. The offset distance is at 7.83 µm, and the lowest sensitivity is -0.2578 dBm/pH, which the offset distance is zero offset distance. Meanwhile, in temperature water solution, the result is the same as in pH water solution. The highest sensitivity shows at the largest offset distance at 7.83 µm, and the lowest sensitivity is at the smallest offset distance or no offset distance. The highest sensitivity and lowest sensitivity for MM-MM fiber sensor in temperature water solution are -0.1645 dBm/º C and -0.0580 dBm/ºC, respectively. Therefore, the offset distance can affect the sensitivity of the fiber sensors.

4.5 Comparison of Sensitivity between SM-SM and MM-MM

Table 4.16: The Comparison of Sensitivity in SM-SM and MM-MM Fiber Sensor

Solutions	SM-SM	MM-MM
PH of the water	-0.2511	-0.2578
	-0.3428	-0.4537
	-0.5744	-0.8322
Temperature of water	-0.0463	-0.0580
	-0.0652	-0.0771
	-0.1432	-0.1645

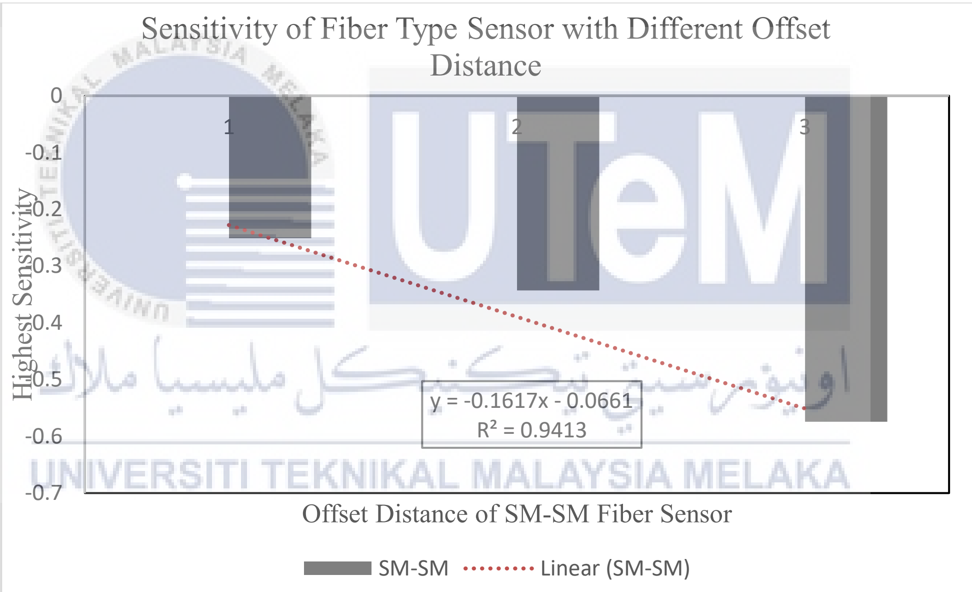


Figure 4.10: The Graph of Highest Sensitivity with Different Offset Distance for SM-SM Fiber Sensor in PH Water Solutions.

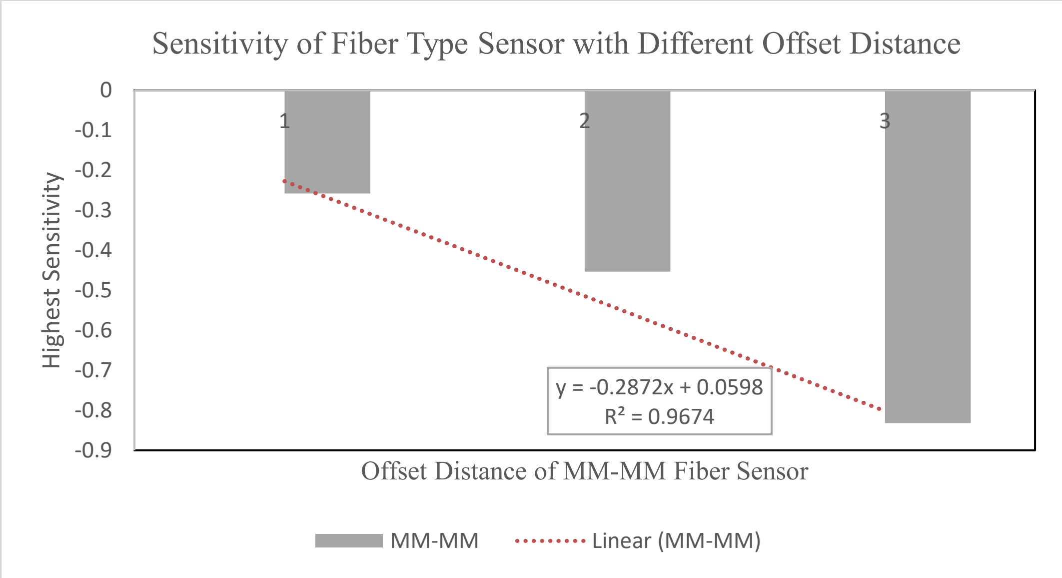


Figure 4.11: The Graph of Highest Sensitivity with Different Offset Distance for MM-MM Fiber Sensor in PH Water Solutions.

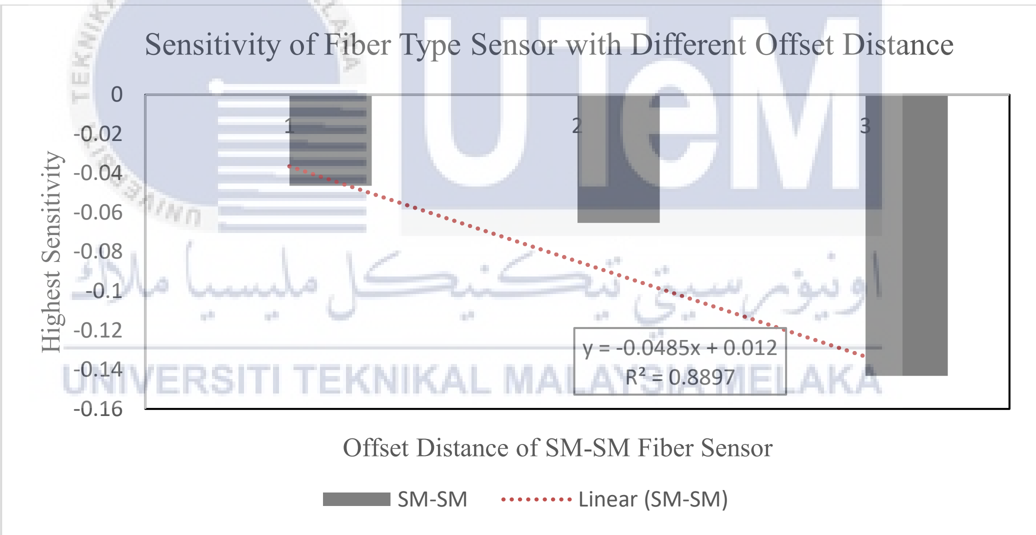


Figure 4.12: The Graph of Highest Sensitivity with Different Offset Distance for SM-SM Fiber Sensor in Temperature Water Solutions.

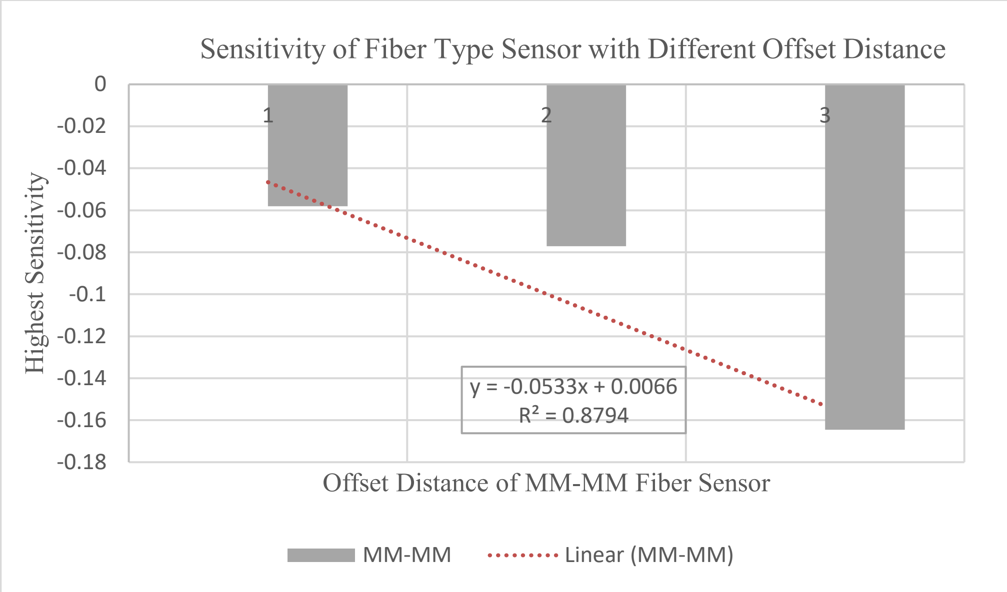


Figure 4.13: The Graph of Highest Sensitivity with Different Offset Distance for MM-MM Fiber Sensor in Temperature Water Solutions.

The sensitivity of both fiber sensors can be obtained by referring to the slopes of the graph in Figure 4.10 until Figure 4.13 above, which has been plotted according to tabulated data in Table 4.16. The slope represents the sensitivity of fiber sensors, and the steepest slope has the highest sensitivity of the fiber sensor. For comparison in SM-SM and MM-MM fiber sensor sensitivity, the highest sensitivities in pH water solutions are 0.5744 dBm/pH and -0.8322 dBm/pH, which both have the largest offset distances 18.72 µm and 7.83 µm. As for the temperature water solution, the results is the same as in the pH water solution. The ones with the largest offset distance produced higher output power (dBm). For both SM-SM and MM-MM, the highest sensitivities are -0.1432 dBm/ºC and -0.1645 dBm/ºC, which both of them also has the largest offset distances at 18.72 µm and 7.83 µm.

For comparison, the sensitivity of the different fiber type sensor has been obtained. The steepest slopes resemble the highest sensitivity of the fiber sensor. Referring to

Table 4.16 and Figure 4.10, the MM-MM fiber sensor has the best fiber structure with the highest sensitivity compared to the SM-SM fiber sensor. MM-MM has obtained the highest sensitivity in both solutions for pH and temperature solutions compared to SM-SM. The sensitivity obtained for the MM-MM fiber sensor in both solutions is -0.2872 dBm/pH and -0.0533 dBm/°C.

Meanwhile, in the SM-SM fiber sensor, the sensitivity obtained for both solutions are -0.1617 dBm/pH and -0.0485 dBm/°C. Even though the offset distance of MM-MM is shorter compared to SM-SM, the highest sensitivities have been obtained at the highest offset distance in MM-MM for both solutions. This is because the MM-MM fiber sensor has a different structure where its core size is larger than SM-SM, and they are also known as multi-mode carriers in light transmission compared to the SM-SM, which has a single mode of light transmission. Thus, MM-MM can excite more compared to SM-SM.

4.6 Conclusion

Throughout the project, the sensitivity of the fiber sensor can be obtained by varying the offset distance of the fiber sensor. It can be clearly seen that the offset distances really can affect the sensitivity of the fiber sensor. In this project, the highest offset, which is at 18.72 μm of SM-SM, produces the highest output power (dBm) because of its offset distance was the highest among the others in the SM-SM fiber sensor.

Not just that, in the MM-MM fiber sensor, the highest offset distance, which is at 7.83 μm also produce the highest output power (dBm). It has proved that the larger the offset distance, the higher the sensitivity of the fiber sensor. A larger offset distance can cause more lights to enter the cladding of the fiber cause higher energy loss. If more light energy enters the cladding, the energy difference between the cladding and the core becomes smaller, which improves the extinction ratio and forms multi-path interference effectively [36].

In conclusion, two main parameters are important in providing better sensitivity to the fiber sensor. Firstly, the offset distance of the fiber sensor. Secondly, the fiber structure in developing the fiber sensor. In providing a better sensitivity of a fiber sensor, the highest offset distance using MM-MM fiber sensor configuration is a must due to its higher sensitivity and multi mode of light transmission. Due to its low cost of fabrication makes this fiber sensor suitable to be applied in any real field applications with good linearity and sensitivity.

CHAPTER 5

CONCLUSION AND FUTURE WORKS

5.1 Conclusion

In conclusion, optical fiber is used in transmitting lights between the fiber ends. Optical fibers are widely used in communications where the transmissions of light over long distances have higher bandwidths and transmits faster speed than electrical cables. Optical fiber is known for its flexibility and robustness towards the environment. Since then, optical fiber has been widely used in varieties of industries for many applications. Other than communications, optical fiber also are very popular in sensing applications. Optical fiber is used to measure many parameters of physical properties such as temperature, mechanical strain, pH, humidity and many more. Due to its small size, optical fiber is suitable to be used in many areas that are hard to reach, such as pipelines. Compared to other electronic sensors, optical fiber provides less harm to the environment with its low installation cost.

In this project, two types of fiber optic have been used: single mode optical fiber (SMF) and multimode optical fiber (MMF). SMF carries a single light transmission. Meanwhile, MMF carries multiple lights during transmission. These two types of fibers are used in developing the fiber sensor by splicing both ends of two fibers. Both structures are constructed by the splicing fusion method with very simple and easy fabrication steps.

For this project, two objectives have been successfully achieved. The first objective is to design and develop a device to measure the water quality of a hydroponic system using a single mode and multimode fiber optic sensor application based on lateral offset displacement. For the first objective, two types of fibres have been used in developing an optical fiber sensor based on a lateral offset displacement sensor. SM-SM fiber mode configuration and MM-MM fiber mode configuration are used to develop the fibre sensor's structure. Both ends of the two fibers for SMF and MMF are fusion spliced in offset distance (mismatch alignment) to create the 'fiber loss' in the fiber sensor. The 'fiber loss' created acts as a sensing region in measuring the water quality for this project. For SM-SM and MM-MM fiber sensor, the splicing is done using the auto splicer Fujikura FSM-18R and also manual splicer machine Sumitomo Type-36. These two machines are used in setting up the offset distance between the fiber sensors. Thus, these two fiber types, SM-SM and MM-MM fiber structure, have been successfully developed.

Next, the second objective is to analyze the sensing response of the sensor towards the pH and temperature. After the fiber sensor of SMF and MMF was successfully done, the fiber sensor was tested in different solutions. There are two types of solutions which are pH water solution and temperature water solution. Both solutions are varied their pH value and temperature value to analyze the sensing response at the offset distance of the fiber toward the solutions. The two fiber structures, SM-SM and MM-MM fiber sensor have also been developed with a variety of offset distance. For the SM-SM fiber sensor, the offset distance developed was at 0 µm, 11.57 µm and 18.72 µm. Meanwhile, the offset distance developed for the MM-MM fiber sensor was at 0 µm, 2.21 µm, and 7.83 µm. The sensitivity of both fiber sensors was observed with a different offset distance in a different type of solutions. The highest sensitivity obtained in this project is -0.2872 dBm/pH and -0.0533 dBm/°C for both solutions in the MM-MM fiber sensor, which the offset distance is at 7.83 µm. From the experiment result, the offset distance can impact the sensitivity of the fiber sensor. It can be conclude that this SM-SM and MM-MM fiber sensor based on lateral offset displacement can be applied in sensing applications. The second objective also achieved.

5.2 Future Work

An optical sensor such as SM-SM and MM-MM fiber sensor can be used in different kind of industries such as agricultural industries, food industries and many more. This project has proved that this sensor developed based on lateral offset displacement can be used as a sensing device to measure different liquids. Not only to liquid but these sensors also can be used in measuring other parameters such as temperature, humidity, ph and pressure. It has been known that the main structure of fiber is made of glass. Thus, these sensors provide boundless performance capabilities and robustness, but it is also safe to be used in the environment as it is immune to electromagnetic interference.

For further improvement of the fiber sensor, SM-SM sensors can be improvised their functionality by connecting it with the Internet of Things (IoT). This is because it can create a good development by connecting the optical fiber with electronic, hardware, software over the whole internet in providing efficiency for sensing device. With IoT, the sensing device of optical fiber can be more convenient and easier in imaging and sensing applications. IoT can provide a monitoring system for the user, making the user access the system from afar. Due to its extensive data transmission and high-speed transmission, IoT is highly suitable and compatible if combined together. Other than IoT, this fiber sensor also can be improvised by making it a portable fiber sensor as it can offers lower cost compared to the recent optical fiber sensor technology. With its compact size and easy to use configuration, this fiber sensor can be combined with an IoT system to get faster data analysis in sensing.

In the future, this project can be useful in any agricultural industries to measure the temperature and pH of the water source used in hydroponic. Not only to hydroponics system, but this sensing device also can be used in any part of agricultural industries such as measuring the moisture of soil, the humidity and many more. Not just that, this project also can be applied in water supply company such as Syarikat Bekalan Air Selangor Sdn. Bhd (SYABAS) to measure the water quality during distillation and cleaning of water. Then, this project also can be applied in any medical applications, such as measuring pH and temperature for the human body.

REFERENCES

[1] SIEGMUND WP, “Fiber optics,” pp. 90–98, 1968.

[2] P. Khandelwal, “Optical Fiber Sensors: Classification & Applications,” vol. II, no. Vii, pp. 22–25, 2013, [Online]. Available: www.ijltemas.in.

[3] A. Overview, “Optical Fibers Single Mode vs . Multimode Fiber Optic Cabling :,” pp. 1–4, 2019.

[4] C. Emslie, “Polymer optical fibres,” *J. Mater. Sci.*, vol. 23, no. 7, pp. 2281–2293, 1988, doi: 10.1007/BF01111879.

[5] B. Srinivasan and D. Venkitesh, “Distributed fiber-optic sensors and their applications,” *Opt. Fiber Sensors Adv. Tech. Appl.*, pp. 309–358, 2017, doi: 10.1201/b18074.

[6] K. T. V. Grattan and Y. N. Ning, “Classification of optical fiber sensors,” *Opt. Fiber Sens. Technol.*, vol. 2, pp. 1–35, 1998, doi: 10.1007/978-1-4615-5787-6_1.

[7] J. F. Ready, “Chapter 22 Fiber Optics A . Structures,” *Ind. Appl. Lasers*, pp.

530–545, 1997.

[8] C. MICHIE, “Optical Fiber Sensors for Advanced Composite Materials,” *Compr. Compos. Mater.*, pp. 475–491, 2000, doi: 10.1016/b0-08-042993-9/00154-6.

[9] J. Castrellon-Uribe, “Optical Fiber Sensors: An Overview,” *Fiber Opt. Sensors*, no. February 2012, 2012, doi: 10.5772/28529.

[10] Fawzi. W. A, “Reflective and Beam – Through Types of Fiber Optic Sensor for Displacement Measurement Reflective and Beam – Through Types of Fiber Optic Sensor for Displacement Measurement,” 2010.

[11] M. A. Mentzer, “Fiber optic sensors,” *Photonic Devices Syst.*, vol. 2, no. 6, pp. 247–277, 2017, doi: 10.1201/9780203743515.

[12] J. A. C. Heijmans, L. K. Cheng, and F. P. Wieringa, “Optical fiber sensors for medical applications - Practical engineering considerations,” *IFMBE Proc.*, vol. 22, pp. 2330–2334, 2008, doi: 10.1007/978-3-540-89208-3_559.

[13] S. Addanki, I. S. Amiri, and P. Yupapin, “Review of optical fibers-introduction and applications in fiber lasers,” *Results Phys.*, vol. 10, no. June, pp. 743–750, 2018, doi: 10.1016/j.rinp.2018.07.028.

[14] L. Dziuda, F. W. Skibniewski, M. Krej, and J. Lewandowski, “Monitoring respiration and cardiac activity using fiber Bragg grating-based sensor,” *IEEE Trans. Biomed. Eng.*, vol. 59, no. 7, pp. 1934–1942, 2012, doi: 10.1109/TBME.2012.2194145.

[15] G. K. Schwalfenberg, “The alkaline diet: Is there evidence that an alkaline pH diet benefits health?,” *J. Environ. Public Health*, vol. 2012, 2012, doi: 10.1155/2012/727630.

[16] N. Sabri, S. A. Aljunid, M. S. Salim, and S. Fouad, “Fiber optic sensors: Short review and applications,” *Springer Ser. Mater. Sci.*, vol. 204, no. December, pp. 299–311, 2015, doi: 10.1007/978-981-287-128-2_19.

[17] L. Wong *et al.*, “Leak detection in water pipes using submersible optical optic-based pressure sensor,” *Sensors (Switzerland)*, vol. 18, no. 12, pp. 1–17, 2018, doi: 10.3390/s18124192.

[18] M. Shanafield, E. W. Banks, J. W. Arkwright, and M. B. Hausner, “Fiber-Optic Sensing for Environmental Applications: Where We Have Come From and What Is Possible,” *Water Resour. Res.*, vol. 54, no. 11, pp. 8552–8557, 2018, doi: 10.1029/2018WR022768.

[19] L. Kerkeni *et al.*, “We are IntechOpen , the world ’ s leading publisher of Open Access books Built by scientists , for scientists TOP 1 %,” *Intech*, no. tourism, p. 13, 2016, [Online]. Available: https://www.intechopen.com/books/advanced-biometric-technologies/liveness-detection-in-biometrics.

[20] J. Liu *et al.*, “A wide-range displacement sensor based on plastic fiber macro-bend coupling,” *Sensors (Switzerland)*, vol. 17, no. 1, pp. 1–8, 2017, doi: 10.3390/s17010196.

[21] W. B. Spillman and E. Udd, “Connectors and Splices,” *F. Guid. to Fiber Opt.*

Sensors, pp. 1–12, 2015, doi: 10.1117/3.1002803.ch15.

[22] R. U. S. A. Data, F. Application, P. Data, D. Dynamic, S. Detectors, and I. Appli, "United States Patent (19)," no. 19, 1998.

[23] M. Faisal, "Fiber Joints and Couplers ; Cable Design."

[24] D. W. Duan, Y. J. Rao, L. C. Xu, T. Zhu, D. Wu, and J. Yao, "In-fiber Mach-Zehnder interferometer formed by large lateral offset fusion splicing for gases refractive index measurement with high sensitivity," *Sensors Actuators, B Chem.*, vol. 160, no. 1, pp. 1198–1202, 2011, doi: 10.1016/j.snb.2011.09.048.

[25] D. Chen and X. Cheng, "Hydrostatic pressure sensor based on a gold-coated fiber modal interferometer using lateral offset splicing of single mode fiber," *Prog. Electromagn. Res.*, vol. 124, no. December 2011, pp. 315–329, 2012, doi: 10.2528/PIER11122307.

[26] J. Amorebieta *et al.*, "Compact omnidirectional multicore fiber-based vector bending sensor," *Sci. Rep.*, vol. 11, no. 1, pp. 1–11, 2021, doi: 10.1038/s41598-021-85507-9.

[27] L. I. and F. C., "Nutrient Solutions for Hydroponic Systems," *Hydroponics - A Stand. Methodol. Plant Biol. Res.*, no. March, 2012, doi: 10.5772/37578.

[28] S. Parks and C. Murray, "Leafy Asian vegetables and their nutrition in hydroponics," *Clin. Exp. Dermatol.*, vol. 31, no. 3, pp. 361–364, 2006.

[29] M. Griffiths, "The Design and Implementation of a Hydroponics Control System.," p. 74, 2014, [Online]. Available:

http://www.theseus.fi/bitstream/handle/10024/81080/Griffiths_Mark.pdf;jsessionid=52F21B3031C87BF1FC364D3EB546AAD3?sequence=1.

[30] H. Singh, B. Dunn, and M. Payton, "Hydroponic pH Modifiers affect Plant Growth and Nutrient Content in Leafy Greens," *J. Hortic. Res.*, vol. 27, no. 1, pp. 31–36, 2019, doi: 10.2478/johr-2019-0004.

[31] A. El Hamidi *et al.*, "Refractive index controlled by film morphology and free carrier density in undoped ZnO through sol-pH variation," *Optik (Stuttg).*, vol. 158, pp. 1139–1146, 2018, doi: 10.1016/j.ijleo.2018.01.011.

[32] S. Raghul, B. V Sribalaji, K. Vishnubalan, and A. Velu, "Auto Hydroponic Growth Chamber for Precision Agriculture," vol. 10, no. 6, 2021, doi: 10.15680/IJIRSET.2021.1006035.

[33] L. Li *et al.*, "All-fiber Mach-Zehnder interferometers for sensing applications References and links 'Sandwiched long-period gratings for simultaneous measurement of refractive index and temperature,' IEEE Photon," *Technol. Lett*, vol. 17, no. 11, pp. 2397–2399, 2005.

[34] P. Lu, L. Men, K. Sooley, and Q. Chen, "Tapered fiber Mach-Zehnder interferometer for simultaneous measurement of refractive index and temperature," *Appl. Phys. Lett.*, vol. 94, no. 13, pp. 18–21, 2009, doi: 10.1063/1.3115029.

[35] I. Fiber and C. Attenuation, "Tutorials Of Fiber Optic Products Understanding Losses in Optical Fiber," pp. 1–3, 2021.

[36] S. Xu, H. Chen, and W. Feng, "Fiber-optic curvature and temperature sensor

based on the lateral-offset spliced SMF-FCF-SMF interference structure," *Opt. Laser Technol.*, vol. 141, no. April, 2021, doi: 10.1016/j.optlastec.2021.107174.

[37] W. Li, H. Cheng, M. Xia, and K. Yang, "An experimental study of pH optical sensor using a section of no-core fiber," *Sensors Actuators, A Phys.*, vol. 199, pp. 260–264, 2013, doi: 10.1016/j.sna.2013.06.004.

[38] A. K. Pathak, V. Bhardwaj, R. K. Gangwar, M. De, and V. K. Singh, "Fabrication and characterization of TiO2 coated cone shaped nano-fiber pH sensor," *Opt. Commun.*, vol. 386, no. November 2016, pp. 43–48, 2017, doi: 10.1016/j.optcom.2016.11.021.

[39] S. Dong, M. Luo, G. Peng, and W. Cheng, "Broad range pH sensor based on sol-gel entrapped indicators on fibre optic," *Sensors Actuators, B Chem.*, vol. 129, no. 1, pp. 94–98, 2008, doi: 10.1016/j.snb.2007.07.078.

[40] S. M. K. Alawsi and M. A. Jabbar, "Refractive Index and Temperature Sensor Using HC-1550 Infiltrating by Different Liquid Crystal," *Opt. Photonics J.*, vol. 08, no. 03, pp. 29–39, 2018, doi: 10.4236/opj.2018.83004.