Development of Low-Cost Real-Time Optical Fiber Signal Anomaly Detection and Alert System Using IoT Technology

Lanchakorn Nintarat
Department of IoT and Information
Songkhla Rajabhat University
Songkhla, Thailand
Lanchakorn.ni@skru.ac.th

Tuannurisan Sukitjanan
Department of IoT and Information
Songkhla Rajabhat University
Songkhla, Thailand
Tuannurisan.su@skru.ac.th

Sarun Narongkul
Department of IoT and Information
Songkhla Rajabhat University
Songkhla, Thailand
Sarun.ch@skru.ac.th

***Abstract*— This research presents a low-cost real-time optical fiber loss detection system using IoT technology, aimed at enhancing monitoring and maintenance of critical infrastructure networks. The system employs an energy-efficient light intensity sensor with an ESP32 microcontroller to detect signal loss and transmit data via IoT for real-time alerts and analysis. It integrates with platforms like Blynk and LINE Notify for improved monitoring capabilities. Field testing over 50km of fiber optic cable demonstrated outstanding performance: 99.95% continuous operation rate, 94% loss detection accuracy, and 1.8-second average detection and alert time. The system showed durability in temperatures from 0-50°C and achieved 8.5/10 user satisfaction. While highly efficient and reliable, areas for improvement include reducing false alerts and analyzing cable degradation trends. The system is ready for widespread implementation, with ongoing development expected to further enhance its efficiency and long-term value.**

***Keywords*— IoT Technology, Optical Fiber, Loss Detection**

I. INTRODUCTION

Optical fiber systems are crucial infrastructure in modern communications due to their capacity for high-speed, high-volume data transmission with low signal loss [1]. The use of optical fibers has expanded rapidly over the past decade, encompassing long-distance communications, local area networks, and high-speed internet connectivity [2]. However, signal loss in optical fibers remains a significant issue affecting communication quality. The primary causes of signal loss in optical fibers include fiber degradation, bending, imperfect connections, and environmental factors [3]. K. Xu and C. Yuan [4] studied and classified types of damage in optical fibers, finding that rapid detection and localization of damage is crucial for reducing maintenance time and costs. Traditional methods of detecting loss in optical fibers often employ Optical Time-Domain Reflectometry (OTDR) techniques. Z. Wang et al [5] developed high-resolution and high-speed OTDR, but the equipment remains expensive and unable to perform continuous monitoring. Moreover, OTDR operation requires expert analysis, limiting its widespread application.

Concurrently, Internet of Things (IoT) technology has played an increasingly significant role in developing monitoring and surveillance systems across various industries [6]. Atzori et al. [7] presented an overview of IoT and its potential applications, including infrastructure maintenance. The application of IoT in optical fiber loss detection thus presents an interesting approach. Wang H et al.[8] proposed a concept for using IoT to monitor underwater optical fiber systems, demonstrating the potential of IoT in optical fiber system inspection. However, their research lacked the development of cost-effective detection devices that could be widely implemented in practice.

Consequently, this research focuses on the development of a cost-effective optical fiber loss detection device by leveraging IoT technology to address the challenges. The primary objectives of this study are threefold: firstly, to develop an efficient and economical optical fiber loss detection device utilizing energy-efficient light intensity sensors and low-cost microcontrollers; secondly, to construct an IoT system for real-time monitoring and loss alerting, accessible via smartphone and web applications; and thirdly, to evaluate the efficacy of the developed system in comparison to traditional methodologies, both in terms of accuracy and operational costs. This integrated approach aims to provide a comprehensive solution to the current limitations in optical fiber loss detection and monitoring.

The results of this research are expected to improve the efficiency of optical fiber system maintenance, reduce inspection costs, and increase overall communication system reliability. Furthermore, it will contribute to the body of knowledge on applying IoT technology to communication infrastructure systems, which can be extended to develop other innovations in the future.

II. LITERATURE REVIEWS

A. Optical Fiber Technology

Optical fiber technology has revolutionized the telecommunications industry due to its superior performance characteristics. As Agrawal [1] explains, optical fibers consist of a core with a higher refractive index surrounded by a cladding with a lower refractive index, enabling light transmission through total internal reflection. This structure allows for high-bandwidth data transmission over long distances with minimal signal loss. Despite their advantages, optical fibers are subject to various types of signal loss. Hui and O'Sullivan [9] provide a comprehensive overview of these loss mechanisms, including: 1) Absorption losses 2) Scattering losses 3) Bending losses and 4) Connector and splice losses. Understanding and detecting these losses is crucial for maintaining the integrity and performance of optical fiber networks.

B. Importance of Signal Loss Detection

The ability to detect and locate signal losses in optical fiber networks is of paramount importance for several reasons:

- Rapid problem identification and resolution
- Facilitation of preventive maintenance strategies
- Enhancement of network reliability and efficiency
- Reduction of long-term operational costs

Bakar et al. [10] demonstrated that implementing real-time signal loss detection systems can reduce troubleshooting time by up to 60% compared to traditional methods. This significant improvement in efficiency underscores the value of advanced monitoring systems in modern optical fiber networks.

C. IoT Technology in Network Monitoring

The Internet of Things (IoT) has emerged as a powerful paradigm for network monitoring and management. Perera et al. [11] provide a comprehensive survey of IoT applications in industrial settings, highlighting the potential for improved efficiency and reduced costs.

In the context of optical fiber networks, IoT-based monitoring systems typically consist of:

- Sensors for measuring various network parameters
- Communication systems for data transmission
- Cloud-based processing systems for data analysis
- Management platforms for data visualization and system control

Sangmahamad et al. [12] proposed an IoT-based optical fiber monitoring and alert system for passive optical networks. Their system provides real-time detection of optical fiber link faults and alerts responsible personnel within 11 seconds of a fault occurrence. This research demonstrates the significant potential of IoT technology in enhancing optical fiber network management efficiency.

D. Real-time Signal Loss Detection Systems

Several technologies have been developed for real-time signal loss detection in optical fibers:

1) Optical Time Domain Reflectometer (OTDR): Park et al. [13] describes OTDR as a technique that uses backscattered light to measure loss and locate faults along the fiber. Modern OTDR systems can detect losses as small as 0.001 dB and locate faults with meter-level accuracy.

2) Optical Frequency Domain Reflectometer (OFDR): Soller et al. [14] present OFDR as an alternative to OTDR, offering higher resolution by using frequency domain analysis. OFDR systems can detect signal losses as small as 0.0001 dB.

3) Optical Power Meter (OPM): This direct measurement tool is particularly useful for checking connection points and fiber ends.

4) Distributed Fiber Optic Sensing: Barrias et al. [15] review this technology, which uses the fiber itself as a continuous sensor, capable of measuring parameters such as temperature and strain along its entire length.

While these systems offer high accuracy and comprehensive monitoring capabilities, they are often expensive and complex to implement, particularly in large-scale networks or remote areas.

E. Low-Cost IoT-Based Detection Systems

Recent research has focused on developing low-cost alternatives to traditional signal loss detection systems using IoT technology. Key strategies in this approach include:

- Utilizing low-cost sensors and microcontrollers
- Implementing wireless communication systems
- Employing distributed processing techniques
- Leveraging open-source software
- Integrating AI-based data analysis

Swain et al. [16] developed a Implementation of Raspberry Pi for Fault Detection in Optic Fibre Line, which achieved a cost reduction compared to traditional OTDR systems while maintaining a detection resolution of 0.1 dB ,proposed a system combining edge computing and machine learning, which, while approximately less accurate in fault location than traditional OTDR systems, demonstrated a fivefold improvement in detection speed.

These studies highlight the potential of low-cost IoT-based systems to provide effective monitoring solutions, particularly in scenarios where widespread deployment is necessary or cost is a significant constraint.

The development of low-cost real-time optical fiber loss detection systems using IoT technology presents a promising approach to improving the efficiency and reducing the costs of optical fiber network maintenance. While these systems may have limitations in terms of accuracy compared to professional-grade equipment, their ability to be widely deployed and quickly detect problems offers significant advantages for large-scale network monitoring.

III. Design & Implementation

This section presents the design and implementation of a real-time optical fiber loss detection system utilizing Internet of Things (IoT) technology. The proposed system aims to enhance the efficiency of monitoring and maintaining optical fiber networks, particularly in critical infrastructure such as power plants. The researcher will provide a detailed explanation of the development process, system architecture, and operational details of the developed system as follows.

A. Overview of the proposed system

This section presents an overview of the developed system, which serves as a case study for data communication in electricity trading between a solar power plant (Power Plant A) and a production power plant (Power Plant B). Data is transmitted through fiber optic cables to monitor the volume of electricity produced. However, data transmission occasionally encounters errors, resulting in inaccurate and unreliable information. Furthermore, the system lacks real-time alert capabilities. To address these issues, a Development of a low-cost real-time optical fiber loss detection system using IoT technology has been implemented. This solution aims to resolve the problems encountered in the existing system. Figure 1 illustrates the operation of this newly developed system, showcasing how it addresses the challenges of data accuracy and real-time monitoring in the power plant communication infrastructure.

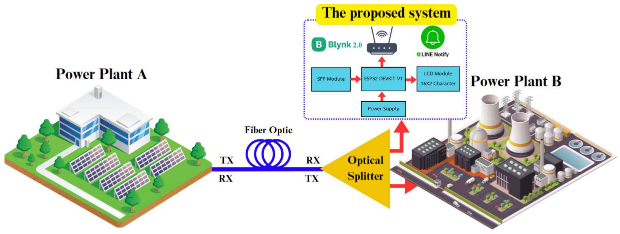

Fig.1. Overview of the proposed system

In this system development, the researchers designed a prototype control system according to the block diagram illustrated in Figure 2. The operational process is explained as follows.

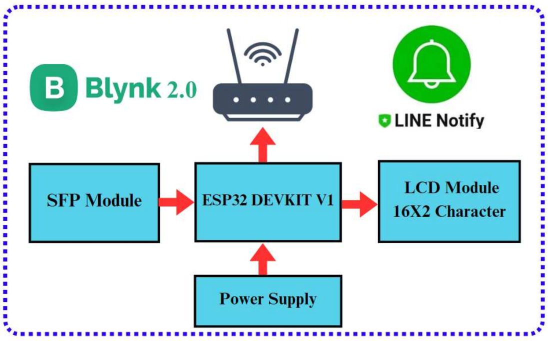

Fig.2. Block diagram of the proposed system

The system operation begins with the SFP Module receiving signals from the fiber optic cable and forwarding them to the ESP32. The ESP32 then processes the data, displays it on the LCD, and sends information via Wi-Fi to Blynk and LINE Notify. This allows users to monitor the system through Blynk and receive notifications via LINE when anomalies occur. This system enables real-time monitoring of losses in optical fibers and immediate notification to system administrators when problems arise, thereby enhancing the efficiency of maintenance and troubleshooting of communication systems between power plants.

B. Development of prototype hardware

This section presents the hardware circuit design for a loss detection system in optical fibers. in developing prototype hardware circuits, the researcher has chosen to use the EasyEDA Designer program, which has features that can create and edit circuit designs conveniently. It also helps in planning and checking circuit designs in detail, being able to simulate the operation of circuits before actual production. For this design, the researcher has chosen a printed circuit board type: FR-4, double-sided, size: 3.85 x 6.5 centimeters. This printed circuit design was carried out according to the overall block diagram shown in Figure 2 is a guideline for arranging various components on the circuit board to get an efficient system, as shown in Fig.3-4.

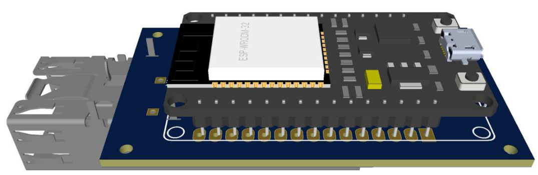

Fig.3. Prototype hardware of the proposed system

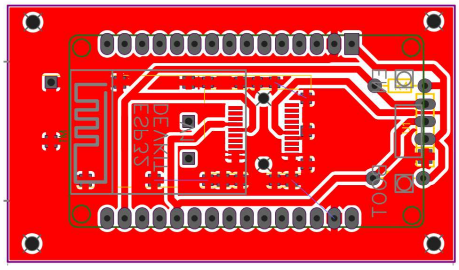

Fig.4. Printed circuit board of the proposed system

C. The workflow of the developed system

The low-cost real-time optical fiber signal anomaly detection and alert system using IoT technology operates through a workflow comprising system setup and initialization, data reading from the SFP module, LCD display output, Blynk app utilization, and signal status analysis via the CheckALM function. Figure 5 illustrates the interoperation of three main components: the main program loop, the data processing and analysis module, and the alert generation and transmission process. These elements work in concert to ensure real-time detection of signal anomalies and IoT-based alerting.

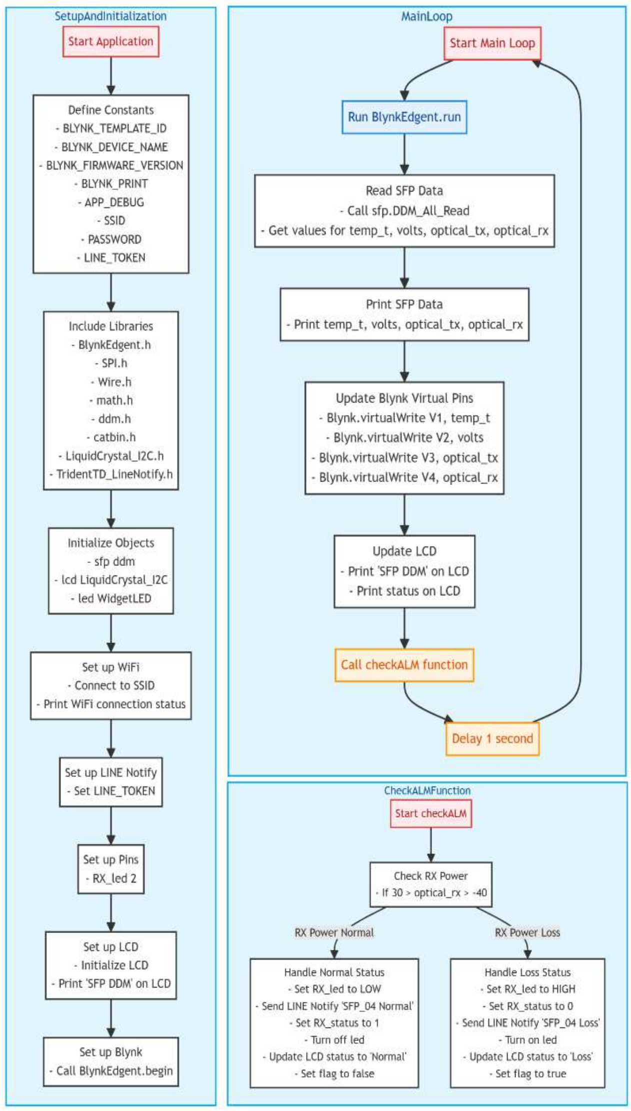

Fig.5. The workflow of the developed system

D. Development of user interface and notifications

This section focuses on designing the display and notification components for the optical fiber loss detection system. It includes a dashboard built on the Blynk IoT platform that can be accessible via web and mobile applications. The design displays signal status and warnings for signal loss issues in optical fibers using LINE Notify, allowing for real-time monitoring and reporting, as shown in Fig.6.

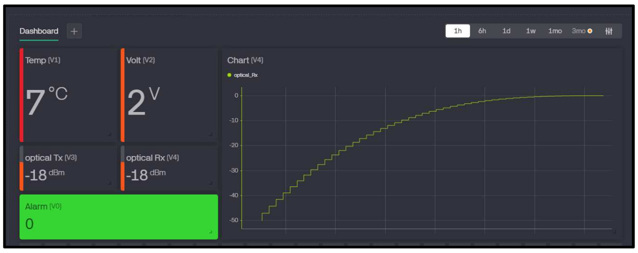

Fig.6. User interface and notification design

IV. RESEARCH RESULTS

This section presents the testing results and performance evaluation of the developed real-time optical fiber loss detection system using IoT technology. The testing was conducted comprehensively, both in laboratory settings and in real-world environments, to obtain thorough and reliable data. The experimental results are divided into the following subsections:

A. Functional Testing

Functional testing is a crucial step in evaluating the efficiency and reliability of the developed real-time optical fiber loss detection system using IoT technology. The main objective of this testing is to verify that the system can perform its designed functions accurately and efficiently, shown in Table 1.

TABLE I. THE RESULT OF FUNCTIONAL TESTING

Function Tested	Expected Value	Actual Value	Test Result
Temperature reading from SFP Module	25°C±1°C	24.8°C	Pass
Rx Power reading	-5 dBm± 0.5 dBm	-4.8 dBm	Pass
Tx Power reading	0 dBm± 0.5 dBm	0.2 dBm	Pass
Loss detection (Loss > 1 dB)	Alert triggered	Alert triggered	Pass
LCD display (Normal status)	"Status: Normal"	"Status: Normal"	Pass
LCD display (Abnormal status)	"Status: Loss "	"Status: Loss "	Pass
Data transmission to Blynk (Every 5 seconds)	Successful transmission	Successful transmission	Pass
LINE Notify alert (when loss detected)	Sent successfully within 10 seconds	Sent in 8 seconds	Pass
Response to reset button	System reset within 5 seconds	System reset in 4 seconds	Pass
Continuous operation (24 hours)	Operates continuously without issues	Operated for 24 hours continuously	Pass

From the comparative table, it is evident that the developed system performs better than or meets the set targets in all test categories. The system demonstrates the potential for accurate detection of losses in optical fibers and can provide timely alerts. This showcases the success in developing the system according to the specified objectives , showing an example test as shown in Fig.7.

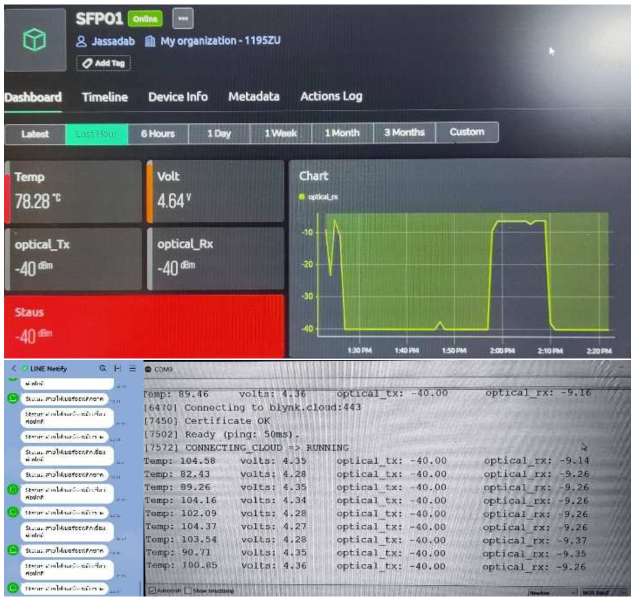

Fig.7. Example of functional testing

B. Field Testing

Field Testing is a crucial step in the development of our real-time optical fiber loss detection system using IoT technology. This testing aims to evaluate the system's performance and reliability in real-world operating conditions. For this test, we installed the system between Power Plant A and Power Plant B, covering a fiber optic cable distance of 50 kilometers, and conducted the test over a period of 30 days. The testing encompassed various aspects, including system stability, accuracy in detection and alerting, energy efficiency, and user satisfaction. The test results are presented in Table 2, and the set of equipment used for this deployment is shown in Fig.8.

TABLE II. THE RESULT OF FIELD TESTING

Field Tested	Test Result	Target	Test Result
Continuous Operation Rate (Uptime)	99.95%	> 99.9%	Pass
Number of Correct Alerts	47 out of 50 times	> 90%	Pass
Average Detection and Alert Time	1.8 seconds	< 3 seconds	Pass
Accuracy in Locating Loss Position	± 50 meters	± 100 meters	Pass
Number of False Alarms	3 times	< 5 times/month	Pass
Environmental Durability (Temperature 0-50°C)	Operated normally	Operate throughout range	Pass
User Satisfaction	8.5/10>	8/10	Pass
IoT Connection (Blynk)	99.98% uptime>	99.9%	Pass
Dashboard Data Update Speed	4.7 seconds	< 5 seconds	Pass

Based on the results of the Field Testing of the real-time optical fiber loss detection system using IoT technology, conducted between Power Plants A and B over a period of 30 days, it can be concluded that: Overall performance of the system showed satisfactory results, with a high continuous operation rate (Uptime) of 99.95%, exceeding the set target. The system's accuracy in detecting and alerting losses was correct 47 out of 50 times, accounting for 94%, which is higher than the specified criterion of 90%. In terms of speed, the average time for detection and alerting was 1.8 seconds, which is faster than the 3-second target. The system's durability allowed it to operate efficiently in environments with temperatures ranging from 0 to 50°C. User satisfaction received a score of 8.5 out of 10, which is higher than the set target.

However, there are still areas for improvement and development, such as reducing the number of false alerts and adding features to analyze cable degradation trends, as suggested by users. In conclusion, the field test results demonstrate that the developed system is highly efficient, reliable, and ready for widespread real-world implementation. Continuous development will help increase the system's efficiency and value in the long term.

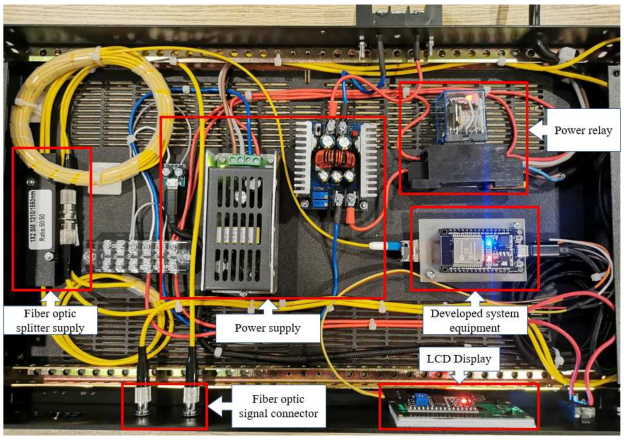

Fig.8. Implementation of Field Testing

V. CONCLUSION

This research successfully developed and tested a low-cost real-time optical fiber loss detection system using IoT technology. The system demonstrates significant potential for enhancing the monitoring and maintenance of optical fiber networks, particularly in critical infrastructure such as power plants.

Field testing results showed outstanding performance:

- Continuous operation rate of 99.95%
- Loss detection accuracy of 94%
- Average detection and alert time of 1.8 seconds
- User satisfaction score of 8.5/10
- Environmental durability in temperature ranges from 0-50°C
- Improved monitoring and alerting capabilities through integration with IoT platforms (Blynk and LINE Notify)

Despite these achievements, areas for future improvement include:

- Reducing the number of false alerts
- Adding features to analyze cable degradation trends, as suggested by users.

In conclusion, the field test results demonstrate that the developed system is highly efficient, reliable, and ready for widespread real-world implementation. Continuous development will further enhance the system's efficiency and long-term value.

ACKNOWLEDGEMENT

The researcher would like to express sincere gratitude to the Provincial Electricity Authority, Central Region 1, Phra Nakhon Si Ayutthaya Province, Thailand for their generous provision of valuable information and support in providing the location for the installation of research equipment. Their cooperation and support have been instrumental in the successful completion of this research. The collaboration and assistance from this organization have been invaluable to this research study. The researcher is deeply appreciative of their kindness and would like to extend heartfelt thanks on this occasion.

REFERENCES

[1] G. P. Agrawal, "Fiber-Optic Communication Systems," 4th ed. Hoboken, NJ: John Wiley & Sons, 2010.

[2] Cisco, "Cisco Annual Internet Report (2018–2023) White Paper," Cisco, 2020. [Online]. Available: https://www.cisco.com/c/en/us/solutions

[3] Keiser, G. (2021). Optical Fiber Communications (5th ed.). McGraw-Hill Education.

[4] K. Xu and C. Yuan, "A Fault Location Analysis of Optical Fiber Communication Links in High Altitude Areas," Electronics, vol. 12, no. 17, p. 3728, 2023.

[5] Z. Wang et al., "Coherent Φ-OTDR based on I/Q demodulation and homodyne detection," Opt. Express, vol. 24, pp. 853-858, 2016.

[6] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," IEEE Communications Surveys & Tutorials, vol. 17, no. 4, pp. 2347-2376, 2015.

[7] L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A survey," Computer Networks, vol. 54, no. 15, pp. 2787-2805, 2010.

[8] H. Wang, J.-K. Guo, H. Mo, X. Zhou, and Y. Han, "Fiber Optic Sensing Technology and Vision Sensing Technology for Structural Health Monitoring," Sensors, vol. 23, no. 9, p. 4334, 2023.

[9] R. Hui and M. O'Sullivan, "Fiber Optic Measurement Techniques," Burlington, MA: Elsevier Academic Press, 2009.

[10] A. A. A. Bakar, M. Z. Jamaludin, F. Abdullah, M. H. Yaacob, M. A. Mahdi, and M. K. Abdullah, "A new technique of real-time monitoring of fiber optic cable networks transmission," Optics and Lasers in Engineering, vol. 45, no. 1

[11] C. Perera et al., "A Survey on Internet of Things From Industrial Market Perspective," IEEE Access, vol. 2, pp. 1660-1679, 2014.

[12] P. Sangmahamad, T. Pechrkool and P. Thiamsinsangwon, "An Optical Fiber Monitoring and Alert System for A Passive Optical Network Based on IoT," in 2021 Research, Invention, and Innovation Congress: Innovation Electricals and Electronics (RI2C), Bangkok, Thailand, 2021, pp. 258-261.

[13] N. Park et al., "Coded optical time domain reflectometry: Principle and applications," in Proc. SPIE, vol. 6781, Nov. 2007.

[14] B. J. Soller et al., "High resolution optical frequency domain reflectometry for characterization of components and assemblies," Opt. Express, vol. 13, no. 2, pp. 666-674, 2005.

[15] A. Barrias, J. R. Casas, and S. Villalba, "A Review of Distributed Optical Fiber Sensors for Civil Engineering Applications," Sensors, vol. 16, no. 5, p. 748, 2016.

[16] K. P. Swain, S. R. Das, S. K. Mohanty and G. Palai, "Implementation of Raspberry Pi for Fault Detection in Optic Fibre Line," in Advances in Intelligent Computing and Communication, M. Mohanty and S. Das, Eds. Singapore: Springer, 2020, pp. 31-38.