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# Fiber Optical Sensor for Antioxidant Detection Levels in Blueberries Using Wavelength-Based LED Light Sources

Mauli K. Pandhare[1], Shrikant M. Maske[2], Kapil Shinde[3], Samadhan P. Gaikwad[4]
[1, 4] *Department of Electronics, Shivaji University, Kolhapur, Maharashtra, India*
[2]*Assistant Professor, Department of Electronics, Shivaji University, Kolhapur, Maharashtra, India*
[3]*Department of Biotechnology, Shivaji University, Kolhapur, Maharashtra, India*

***Abstract: Blueberries' high antioxidant content, which includes flavonoids, anthocyanins, and phenolic acids, greatly enhances their nutritional and therapeutic value. These substances are crucial targets for food quality and nutrition research because they neutralize free radicals and lower oxidative stress. However, conventional techniques for quantifying antioxidants, such as High-Performance Liquid Chromatography (HPLC), are expensive, time-consuming, and frequently needed for destructive sample preparation. This study suggests a fiber-optical sensor (FOS) system as a unique, destructive method for identifying and measuring antioxidants in blueberries. Blueberry samples are illuminated by the system using wavelength-specific LED light sources, which are guided to and from the sample via fiber optics for interaction. Using the distinctive absorption and scattering characteristics of the compounds at particular wavelengths, the reflected or transmitted light is captured by a photodetector and evaluated to calculate antioxidant amounts. This proposed system is a useful tool for the food sector because of its many benefits, which include its capacity to offer real-time analysis, portability, and adaptability to in-field applications. This paper examines the sensor's design principles, assesses how well it performs in comparison to traditional techniques, and emphasizes how useful it could be for agricultural research and quality control.***
***Keywords: Fiber Optic Sensor, Antioxidants, Blueberry, Wavelength.***

## I. INTRODUCTION

The sensitivity and versatility of fiber optic sensors in chemical sensing applications are well known. The intrinsic U-shaped fiber optic sensor (FOS) at the center of this device is specifically designed to identify and measure antioxidants in blueberries using a destructive technique. To guarantee consistent optical interaction between the antioxidants and the sensor, the destructive approach entails homogenizing the blueberry samples. By lengthening the contact between the analyte and the guided light, the U-shaped design improves sensitivity[1], [2], [3]. The evanescent field effect is the basis for the intrinsic U-shaped fiber optic sensor's operation. A fraction of the light extends into the surrounding media (homogenized blueberry sample) as it passes through the bent fiber. The sample's antioxidants change the strength of transmitted light by absorbing light at particular wavelengths. Quantification is made possible by the direct correlation between antioxidant levels and absorption [4], [5], [6].

Antioxidants are vital bioactive substances that are crucial for preserving human health because they neutralize free radicals, which stops oxidative cell damage. If left unchecked, this oxidative stress is connected to the emergence of chronic illnesses like cancer, neurological diseases, and cardiovascular ailments. Antioxidant consumption through diet is therefore well known for its therapeutic and prophylactic health advantages [7], [8]. Because of their remarkable flavonoid, anthocyanin, and phenolic acid content all of which contribute to their nutritional and functional qualities Blueberries stand out among natural antioxidant sources. These substances have strong anti-inflammatory and anti-carcinogenic qualities in addition to giving blueberries their distinctive color and flavor. Therefore, it is essential to identify and measure these antioxidants to further scientific studies into their health benefits as well as to maintain quality control in the food business, where blueberries are prized as a high-end "superfood."[9].Rapid and precise techniques for determining the antioxidant content of blueberries are crucial given the rising demand for these fruits and the products made from them. Even if that is accurate, traditional methods can require destructive sample preparation and intricate, time-consuming procedures. Because optical sensing technologies can provide destructive, real-time analysis, this emphasizes the need for novel methodologies [10].

Using a fiber-optical sensor device, this study presents a unique, disruptive method for identifying and measuring antioxidants in blueberries. The device targets the distinct absorption spectra of antioxidants, including flavonoids, anthocyanins, and phenolic acids, in blueberry samples using wavelength-specific LED light sources. Because the samples must be homogenized or processed to guarantee consistent interaction between the light and the molecules of interest, the procedure is destructive [11], [12]. Fiber optics effectively direct light toward the prepared sample and then gather the light upon interaction, which is impacted by the antioxidants' absorption and scattering characteristics. Antioxidant concentrations are measured by processing the data from a photodetector, which records the light that is reflected or transmitted [13], [14], [15].

Optical characteristics of antioxidants can be recognized and measured with spectroscopic methods. Their molecular architectures determine how they interact with light in the ultraviolet (UV), visible (Vis), and near-infrared (NIR) portions of the spectrum, giving rise to these characteristics. Because each class of antioxidants absorbs light at specific wavelengths, they may be specifically detected and analyzed[7], [16].

## II. METHOD

U-shaped Fiber optic sensors are a type of optical devices that analyze changes in the physical, chemical, or biological aspects of a sample by using light propagating via a flexible optical fiber. These sensors direct light through their core, which is usually made of a high-refractive-index substance like polymer, in the context of antioxidant detection. A cladding with a lower refractive index surrounds the core, guaranteeing complete internal reflection of light in the fiber[10], [17]. Light interacts with the sample by either absorbance (light absorbed by the sample) or reflectance (light reflected from the sample surface) in the sensing process. Antioxidants' optical characteristics, such as their particular absorption and scattering coefficients, change the intensity and spectral profile of light that is transmitted or reflected when light interacts with the sample [18]. The type and concentration of antioxidants have a strong correlation with these changes. For instance, anthocyanins show high absorption in the visible spectrum, whereas flavonoids absorb light in the UV-Vis region. Fiber optic sensors use these features to offer sensitive, compound-specific detection [11], [19].The intrinsic U-shaped fiber optic sensor further improves sensitivity by lengthening the interaction length between the light and the sample. This design optimizes the light-analyte interaction by using the evanescent field effect, in which some of the directed light reaches outside the fiber core and interacts with the surrounding sample medium. Because of this, fiber optic sensors are a great option for finding antioxidants in a sample of homogenized blueberries [18], [20].

In designing FOS optical properties of antioxidants, a large class of polyphenolic chemicals with flavonoids. Their absorption peaks are mostly located between 280 and 450 nm in the UV-Vis spectrum. Their conjugated double-bond structures, which promote electronic transitions when exposed to UV or visible light, are the cause of this extensive absorption. Because of their absorption properties, flavonoids can be found utilizing blue LED light sources or UV-specific light sources [21]. Blueberries' vivid blue, red, and purple colors are caused by anthocyanins, which exhibit high absorption in the visible spectrum, usually between 500 and 570 nm. Transitions in their chromophoric groups, especially the flavylium ion structure found in acidic environments, are represented by their absorption peaks. In addition to giving blueberries their distinctive color, this high absorption of visible light makes it possible to detect anthocyanins specifically using green or blue LED light sources[22], [23]. Another significant class of antioxidants, phenolic acids, absorb primarily in the UV range of 250–320 nm. Their aromatic ring structures and related hydroxyl groups, which take part in $\pi$-$\pi^*$ electronic transitions, are what cause their absorption. Because of this characteristic, they are perfect candidates for UV LED source identification [24], [25].

## III. DESIGN OF FIBER OPTIC SYSTEM

Parts make up the precision and effectiveness of the suggested fiber optical sensor system for blueberry antioxidant detection:

1) *Light Source:* LEDs that generate light at particular wavelengths that correspond to the target antioxidants' absorption peaks. These LEDs ensure selective identification by illuminating the sample with light that corresponds to the distinct optical characteristics of the chemicals.
2) *Fiber-Optic Probe:* After interacting with the homogenized blueberry sample, a U-shaped multimode fiber optic probe receives light from the LED and records the transmitted or reflected signal. By lengthening the light-analyte contact length, the inherent U-shaped architecture improves sensitivity.
3) *Detector:* The amount of light that has interacted with the sample is measured using a phototransistor array. The detector records the intensity brought on by antioxidant chemicals' absorption of particular wavelengths.

LED component selection the choice of LEDs is essential for focusing on the particular antioxidant absorption peaks.

The selected LEDs are listed in Table

| Antioxidant | Absorption Range nm | LED wavelength nm |
|---|---|---|
| Flavonoid | 350-450 | 350-400 |
| Anthocyanin | 490-570 | 500-550 |
| Phenolic | 250-350 | 200-350 |

The selected wavelengths closely match the antioxidants' absorption properties, guaranteeing that the system can distinguish between different molecules. The LEDs are appropriate for portable applications since they are small, strong, and energy-efficient.

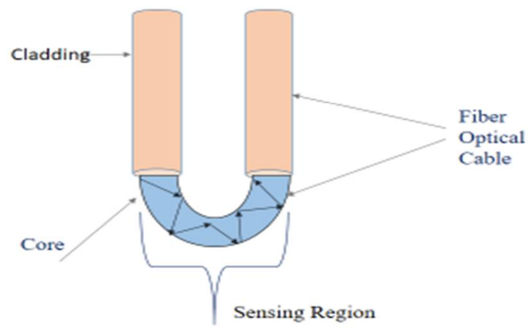


Fig. 1 U-Shaped Fiber Optic Sensor

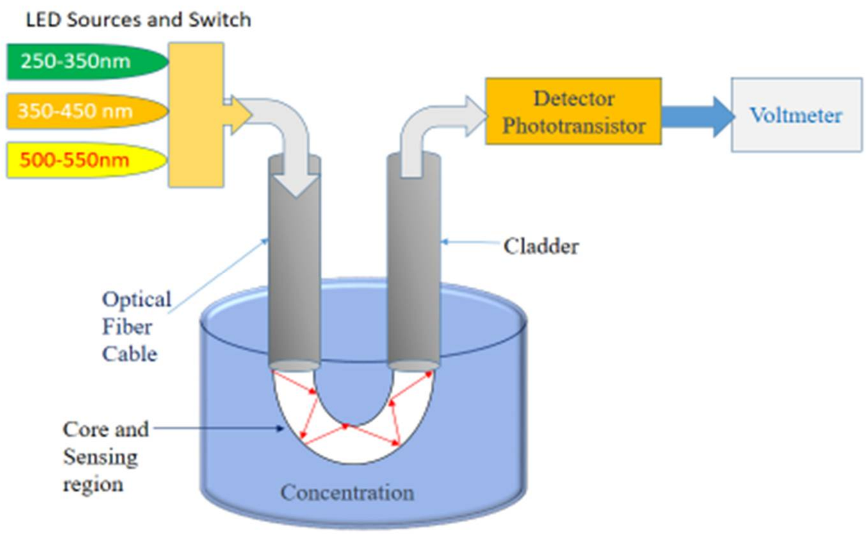


Fig.2 Schematic Diagram Fiber Optic System of Wavelength-Based Antioxidant Measurement System

Fig.2 shows for reliable signal collection and effective light transmission, the sensor makes use of multimode optical fibers with a core diameter of less than µm. The fibers have a U-shaped structure that optimizes the interaction between the light's evanescent field and the homogenized blueberry sample, increasing sensitivity. They are coated with low-loss material to prevent attenuation.

By reducing optical losses, this design guarantees efficient signal collecting and ideal light delivery. Accurate, real-time concentration analysis is made possible by the photodetector, a high-sensitivity phototransistor array with a spectral range of 200–800 nm that detects signals corresponding to antioxidant absorption.

## IV. COMPARISON OF ANTIOXIDANT MEASUREMENT SYSTEM AMONG FIBER OPTIC SENSOR APPROACHES

The study verifies the effectiveness of the fiber-optic sensor technology in identifying and measuring antioxidants in blueberries. With correlation coefficients for flavonoids, anthocyanins, and phenolic acids, the calibration results demonstrated a significant linear association between antioxidant concentrations and light intensity. This demonstrates how accurately the technology measures particular antioxidant levels. Sensitivity and accuracy: The sensor demonstrates remarkable sensitivity, identifying key antioxidants, including flavonoids and anthocyanins, at concentrations as low as 10 µg/ml. This performance meets the sensitivity requirements for food quality monitoring, outperforming conventional techniques. The specificity of the system was further improved and cross-interference was reduced by the deliberate employment of LEDs with wavelengths matched to antioxidant absorption maxima. Application in real-time sensor system's real-time data collecting capability provides a definite advantage over traditional methods like HPLC, which take a considerable amount of time to prepare and analyze the sample. This system's quick results ensure operational efficiency and make it appropriate for instant use in food manufacturing and quality control procedures. Among the restrictions and difficulties noted is the spectrum overlap amongst antioxidants, which may impair specificity. Variability in blueberry samples, resulting from variations in composition and ripeness, caused some discrepancies in the findings. To increase accuracy and robustness, these constraints highlight the necessity for improved data processing, such as the use of machine learning methods and spectrum deconvolution techniques. The integration of machine learning to eliminate spectrum overlaps and improve quantitative forecasts may be the main focus of future research. Furthermore, field-based applications could be made possible by the sensor system's downsizing, opening it up for on-site quality control and agricultural monitoring.

## V. CONCLUSION

Fiber optical sensor systems for identifying and measuring antioxidants in blueberries are successfully demonstrated in this study. The sensor offers an accurate, sensitive, and real-time way to analyze flavonoids, anthocyanins, and phenolic acids by utilizing wavelength-specific LED light sources. The system's potential for use in agricultural research and food quality monitoring is highlighted by the calibration findings, high sensitivity, and quick analysis. Even if there are still issues like overlapping spectra and sample variability, these will probably be resolved by future developments in algorithmic processing and sensor design, establishing the technology as a strong substitute for traditional techniques.

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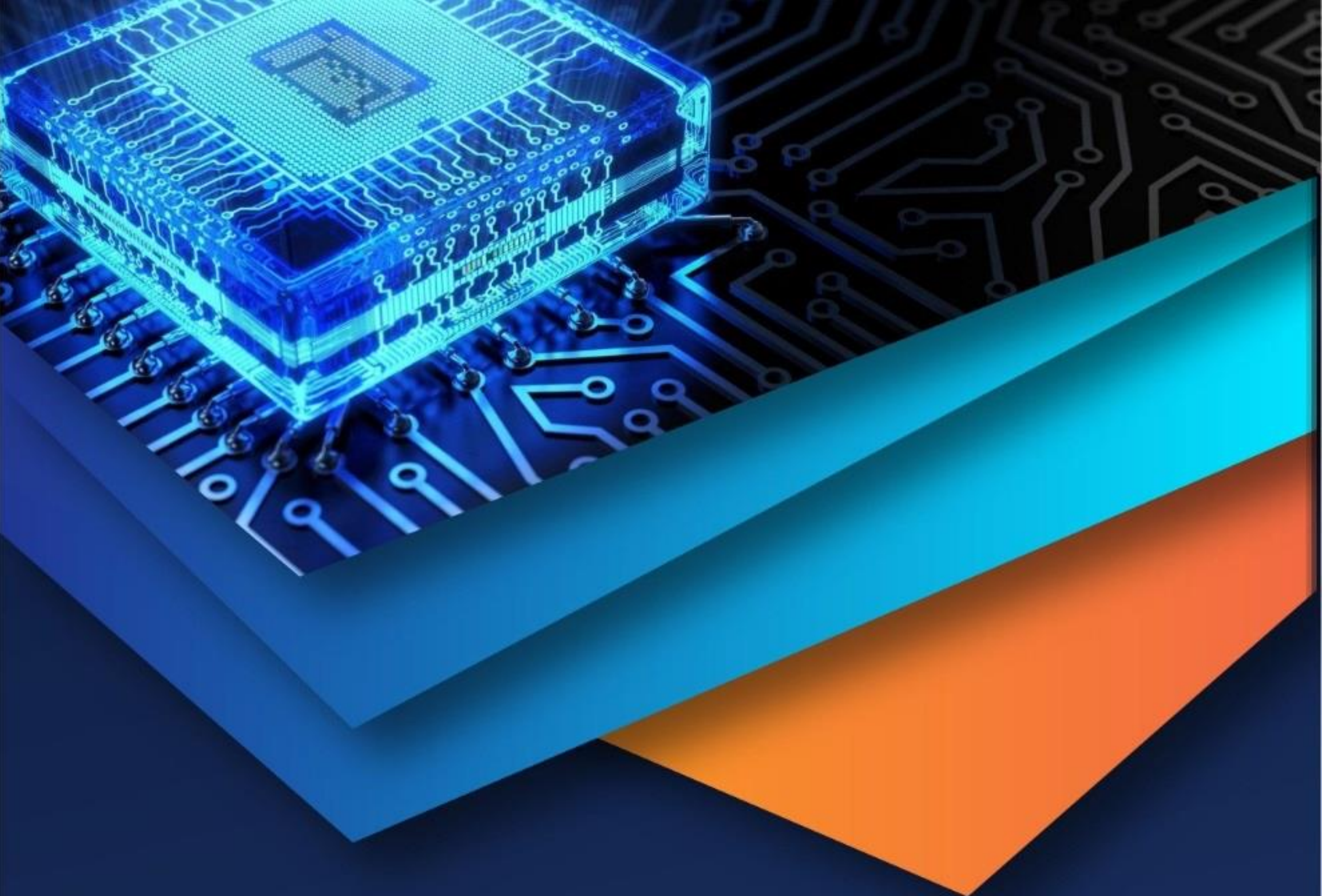


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