BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

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Optoelectronics Laboratory

Final Project Report

Section: G1 Group: 03

Fire Detection System using Webcam-based Spectrometer

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Academic Honesty Statement:

"In signing this statement, We hereby certify that the work on this project is our own and that we have not copied the work of any other students (past or present), and cited all relevant sources while completing this project. We understand that if we fail to honor this agreement, We will each receive a score of ZERO for this project and be subject to failure of this course."

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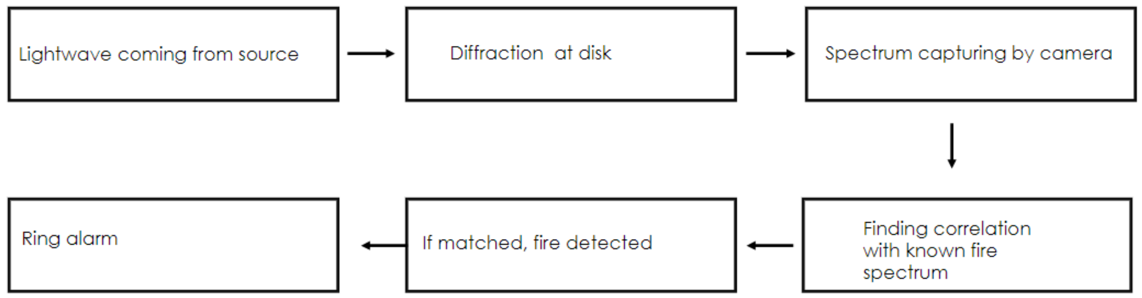
1 Introduction

Fire hazards pose significant risks, making early and accurate detection crucial. Traditional systems like smoke detectors often face delays or false alarms. To address these issues, our project introduces a **"Fire Detection System using Webcam-based Spectrometer"** that uses optical sensing to detect fire with precision.

The system analyzes the unique spectral properties of fire, such as light intensity and wavelength patterns, using a webcam and spectrometer. By processing this data in real-time, it effectively differentiates flames from other light sources, ensuring quick and reliable detection. This cost-effective and scalable solution demonstrates how accessible technologies can enhance fire prevention and safety.

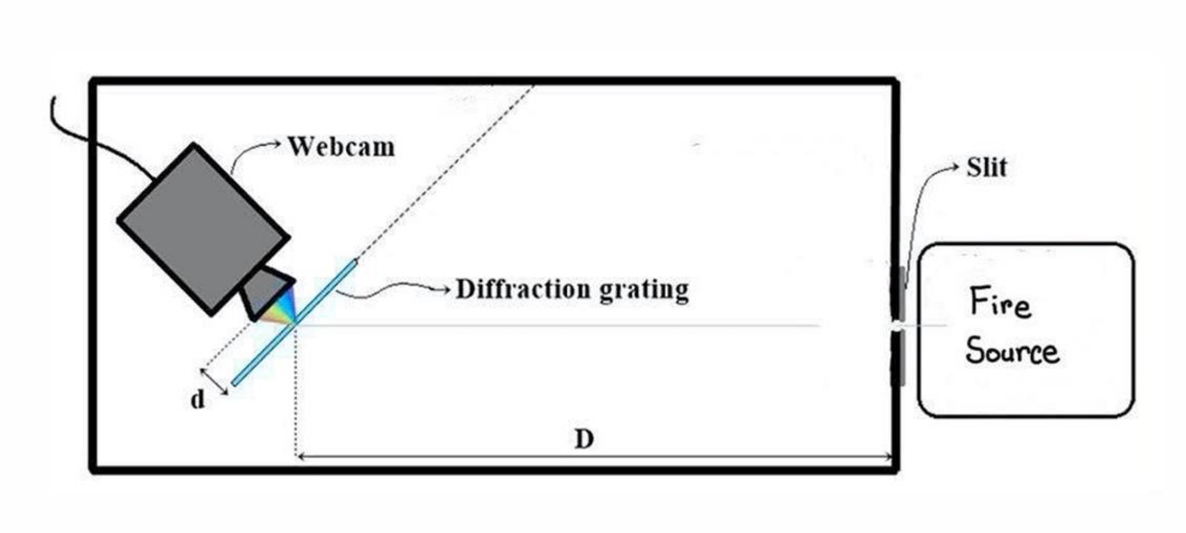
2 Design

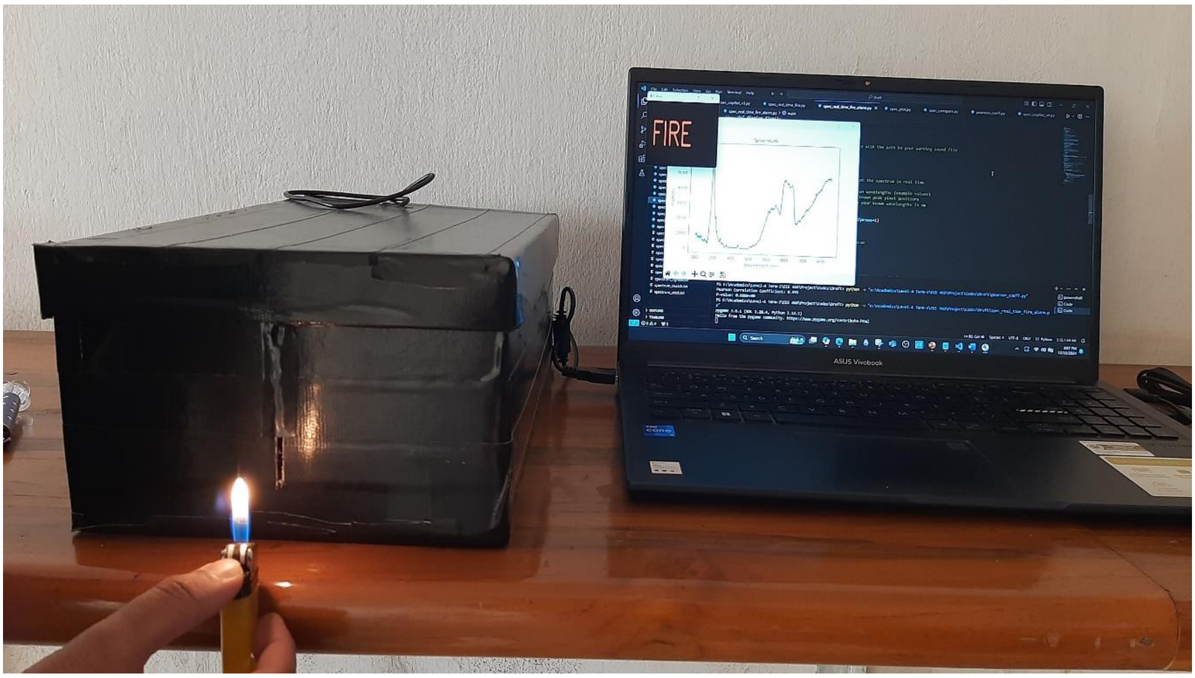
Workflow Diagram:



3 Experimental Setup

This is the experimental Stup of our Project





4 Working Methodology

4.1 Spectrum Extraction

In our project, the extraction of the spectrum is achieved using a combination of optical components and digital processing techniques. The process begins with a fire source, whose emitted light is first focused through a narrow slit to create a collimated beam. This beam then passes through a diffraction grating, which disperses the light into its constituent wavelengths, forming a spectrum.

The dispersed spectral light is captured using a **webcam** positioned at a specific angle to the diffraction grating. The webcam records the spectral image, which is then processed using image analysis techniques. The intensity and wavelength distribution of the spectrum are extracted from the captured image using software tools. By analyzing the pixel data, we map the light intensity to specific wavelengths, enabling the identification of the unique spectral characteristics of fire.

This method ensures a low-cost and efficient approach to spectrum extraction while maintaining high accuracy. The extracted spectral data is further used for analysis, including Correlated Color Temperature (CCT) calculations, to differentiate fire from other light sources.

4.2 Correlation Finding

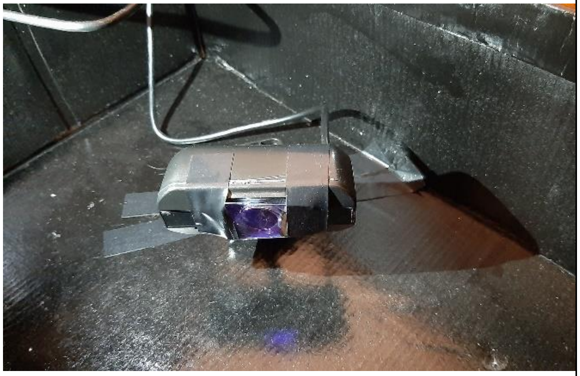
We have used the ‘Pearson Correlation Coefficient’ method in the need of our correlation finding between the ‘real time measured data’ & the ‘previously stored spectrum’.

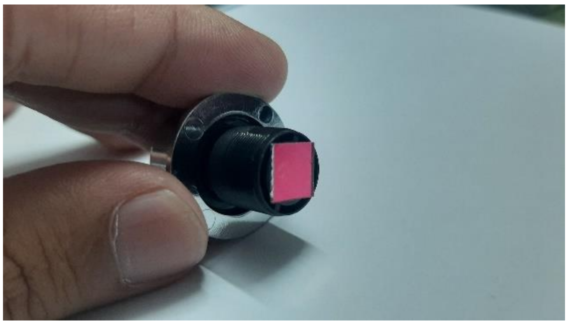
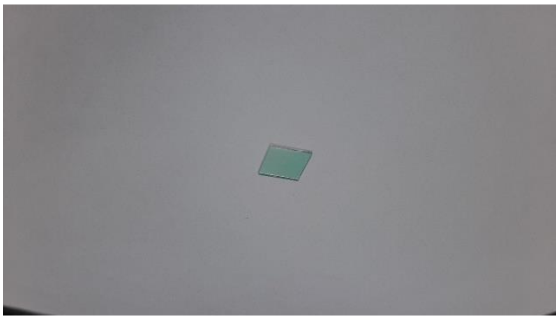
Pearson Correlation Coefficient:
The Pearson correlation coefficient measures the linear correlation between two datasets. It returns a value between -1 (perfect negative correlation) and +1 (perfect positive correlation).

This method is suitable for datasets with the same x-axis. Since we have used the method in the correlation finding.

5 Implementation

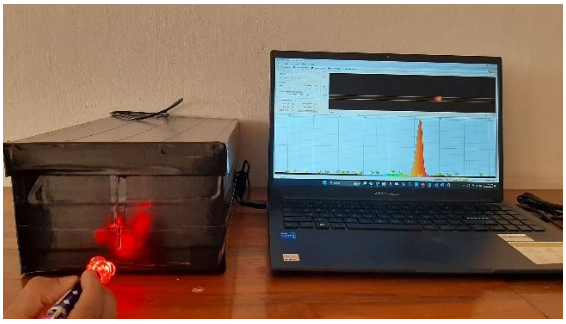
5.1 Setup

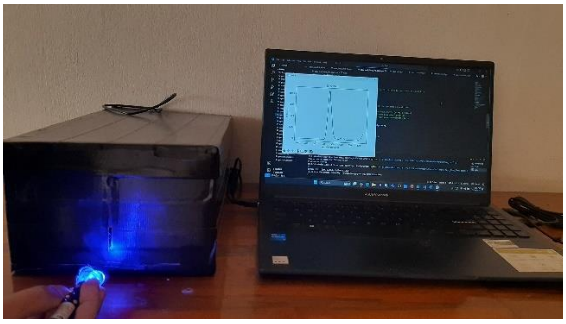
	

	
 Before Removing IR Filter from the lens	 After Removing IR Filter from the lens

5.2 Experimental Images

LED:





Fire:

5.3 Python Code

```
import cv2
import numpy as np
import matplotlib.pyplot as plt
from scipy.stats import pearsonr
import pygame

# Function to capture an image from the webcam
def capture_image(cap):
    ret, frame = cap.read()
    if not ret:
        print("Error: Could not read frame.")
        return None
    return frame
```

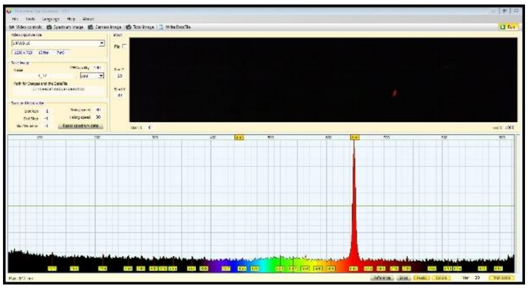
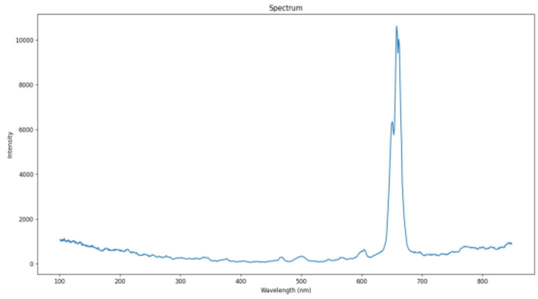
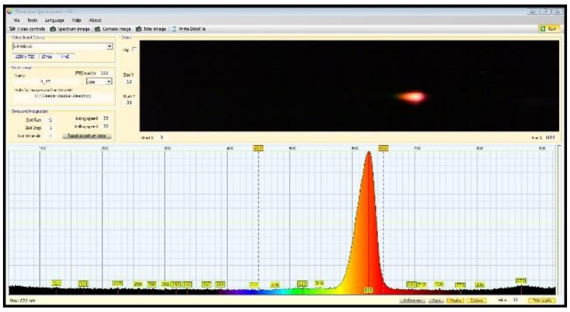
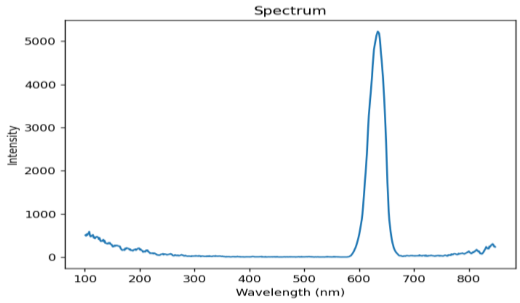
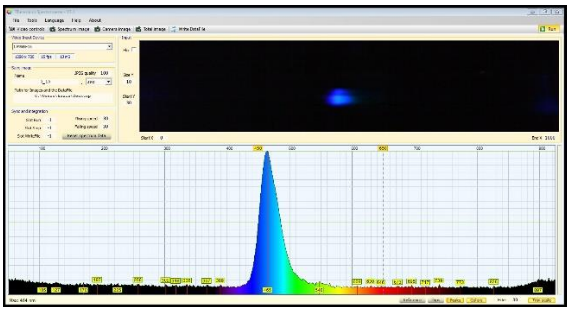
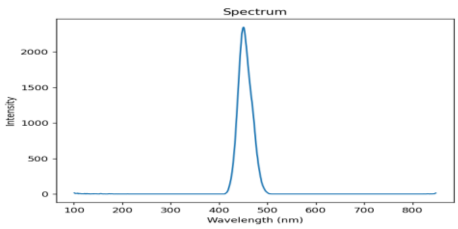
```
# Function to process the captured image to extract the spectrum
def process_image(image):
    # Convert the image to grayscale
    gray = cv2.cvtColor(image, cv2.COLOR_BGR2GRAY)

    # Sum the pixel values along the vertical axis to get the intensity distribution
    intensity = np.sum(gray, axis=0)

    return intensity

# Function to calibrate the spectrum using known sources
def calibrate_spectrum(intensity, known_peaks, known_wavelengths):
    # Fit a polynomial to the known peaks and wavelengths
    calibration_fit = np.polyfit(known_peaks, known_wavelengths, 1)

    return calibration_fit

# Function to plot the calibrated spectrum
def plot_spectrum(intensity, calibration_fit):
    # Convert pixel positions to wavelengths using the calibration fit
    pixel_positions = np.arange(len(intensity))
    wavelengths = np.polyval(calibration_fit, pixel_positions)

    plt.clf()  # Clear the current figure
    plt.plot(wavelengths, intensity)
    plt.xlabel('Wavelength (nm)')
    plt.ylabel('Intensity')
    plt.title('Spectrum')
    plt.pause(0.1)  # Pause to update the plot

    return wavelengths, intensity

# Function to compare real-time spectrum with stored spectrum
def compare_spectra(real_time_intensity, stored_intensity):
    # Calculate Pearson correlation coefficient
    correlation, _ = pearsonr(real_time_intensity, stored_intensity)

    # Display 'fire' if the coefficient is greater than 0.8
    if correlation > 0.8:
        display_fire()
        return True
    return False

# Function to display 'fire' in a new window and play warning sound
def display_fire():
    cv2.namedWindow("Alert", cv2.WINDOW_NORMAL)
    img = np.zeros((300, 600, 3), dtype=np.uint8)
    cv2.putText(img, 'FIRE', (50, 200), cv2.FONT_HERSHEY_SIMPLEX, 5, (0, 0, 255),
10, cv2.LINE_AA)
    cv2.imshow('Alert', img)
```

```
    # Play warning sound
    pygame.mixer.init()
    pygame.mixer.music.load('fire_alarm.mp3')  # Update with the path to your warning
sound file
    pygame.mixer.music.play()

    cv2.waitKey(0)
    cv2.destroyAllWindows()

# Main function to capture, process, calibrate, and plot the spectrum in real time
def main():
    # Known peak pixel positions and corresponding known wavelengths (example values)
    known_peaks = [290, 452, 470]  # Update with your known peak pixel positions
    known_wavelengths = [440, 630, 650]  # Update with your known wavelengths in nm

    # Load stored spectrum from text file
    stored_data = np.loadtxt('spectrum_candle.txt', skiprows=1)
    stored_wavelengths = stored_data[:, 0]
    stored_intensity = stored_data[:, 1]

    cap = cv2.VideoCapture(0)  # Use 0 for default webcam
    if not cap.isOpened():
        print("Error: Could not open webcam.")
        return

    # Set resolution
    cap.set(cv2.CAP_PROP_FRAME_WIDTH, 640)  # Set the width to 640 pixels
    cap.set(cv2.CAP_PROP_FRAME_HEIGHT, 480)  # Set the height to 480 pixels

    plt.ion()  # Turn on interactive mode for real-time plotting

    try:
        while True:
            image = capture_image(cap)
            if image is not None:
                intensity = process_image(image)
                calibration_fit = calibrate_spectrum(intensity, known_peaks,
known_wavelengths)
                wavelengths, real_time_intensity = plot_spectrum(intensity, calibration_fit)

                # Compare the real-time spectrum with the stored spectrum
                if compare_spectra(real_time_intensity, stored_intensity):
                    break

            if cv2.waitKey(1) & 0xFF == ord('q'):
                break

        print("Real-time monitoring stopped.")
    finally:
        cap.release()
        cv2.destroyAllWindows()
```

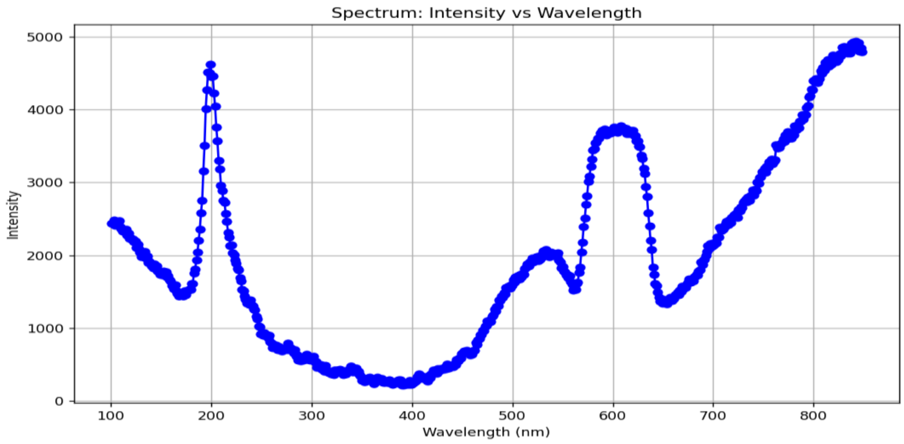
```
        plt.ioff()  # Turn off interactive mode
        plt.close()  # Close the plot window

if __name__ == "__main__":
    main()
```

5.4 Python Spectrum & Final Outcome

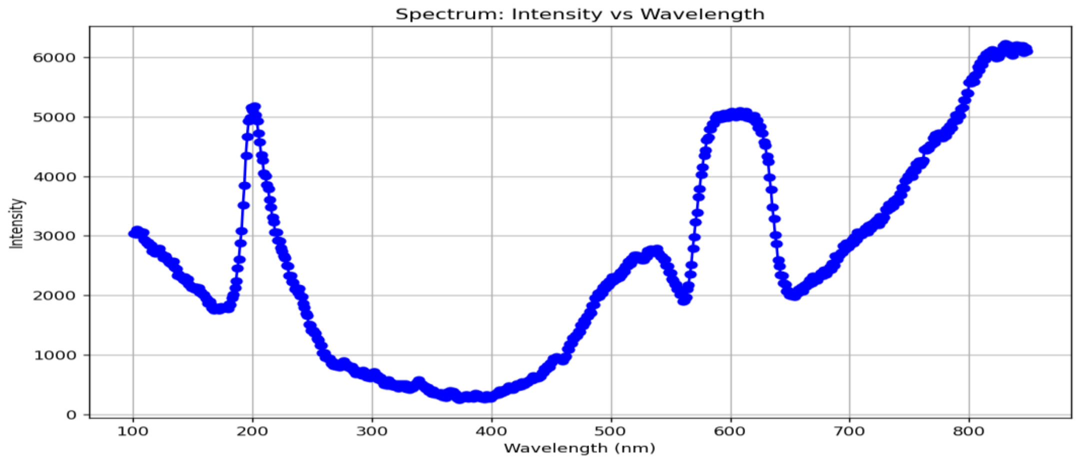
5.4.1 Spectrum of LED's & LASER:

 Laser	 Laser
 Red LED	 Red LED
 Blue LED	 Blue LED

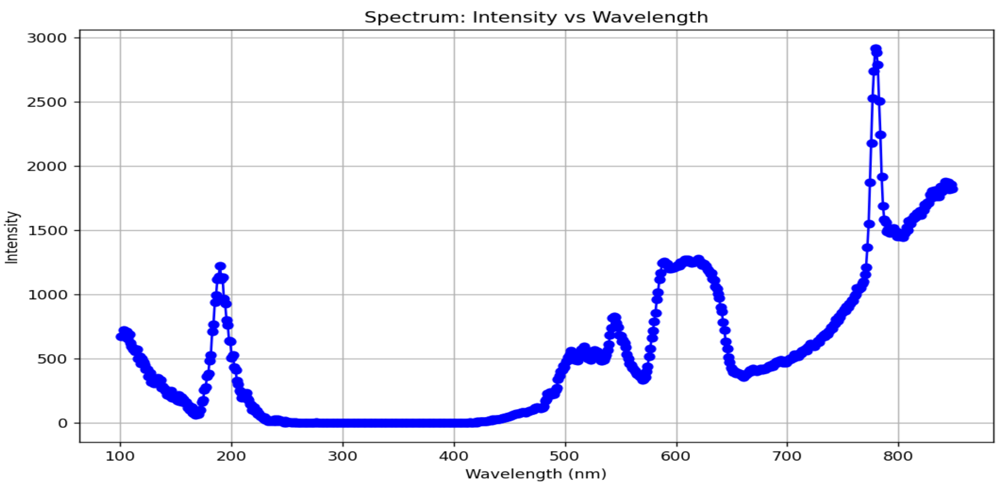
5.4.2 Python Spectrum of Fire Sources:



Candle

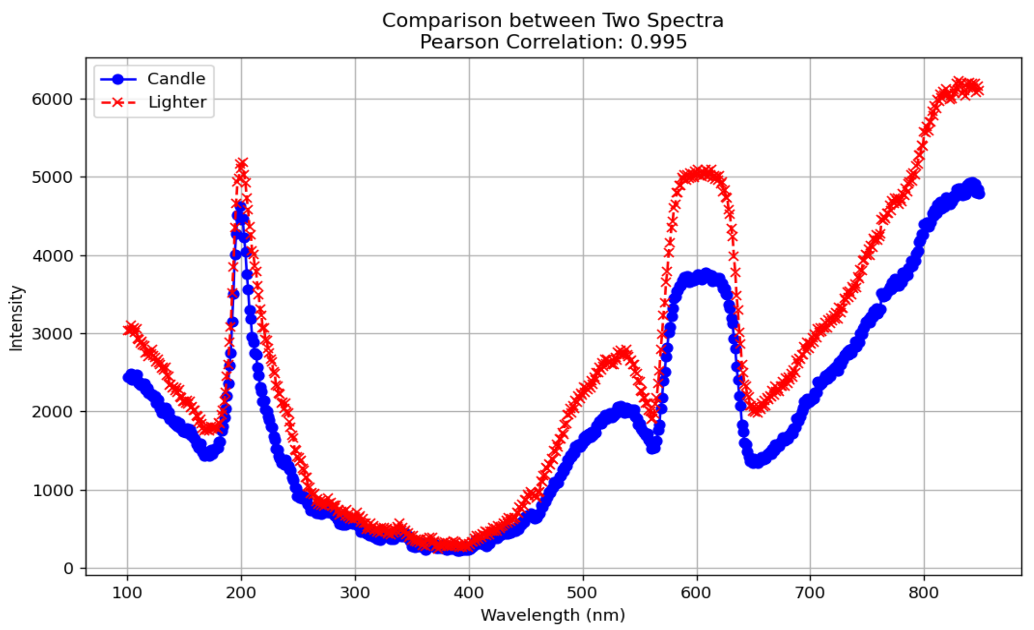


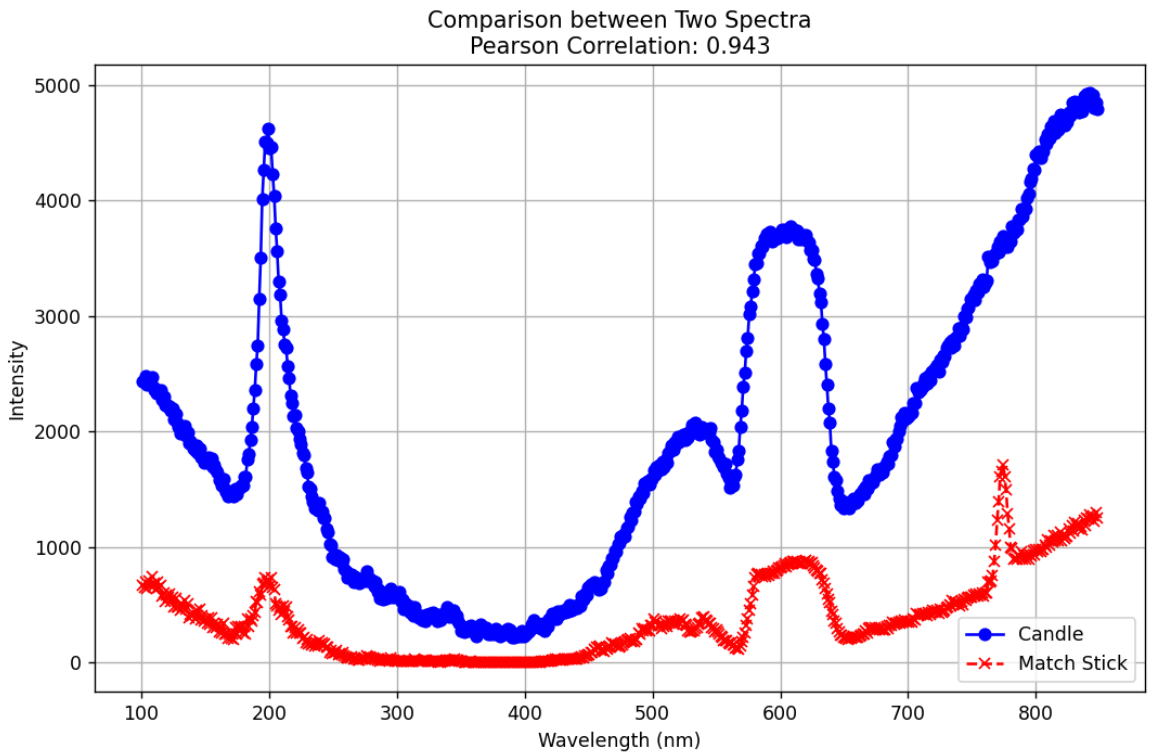
Lighter

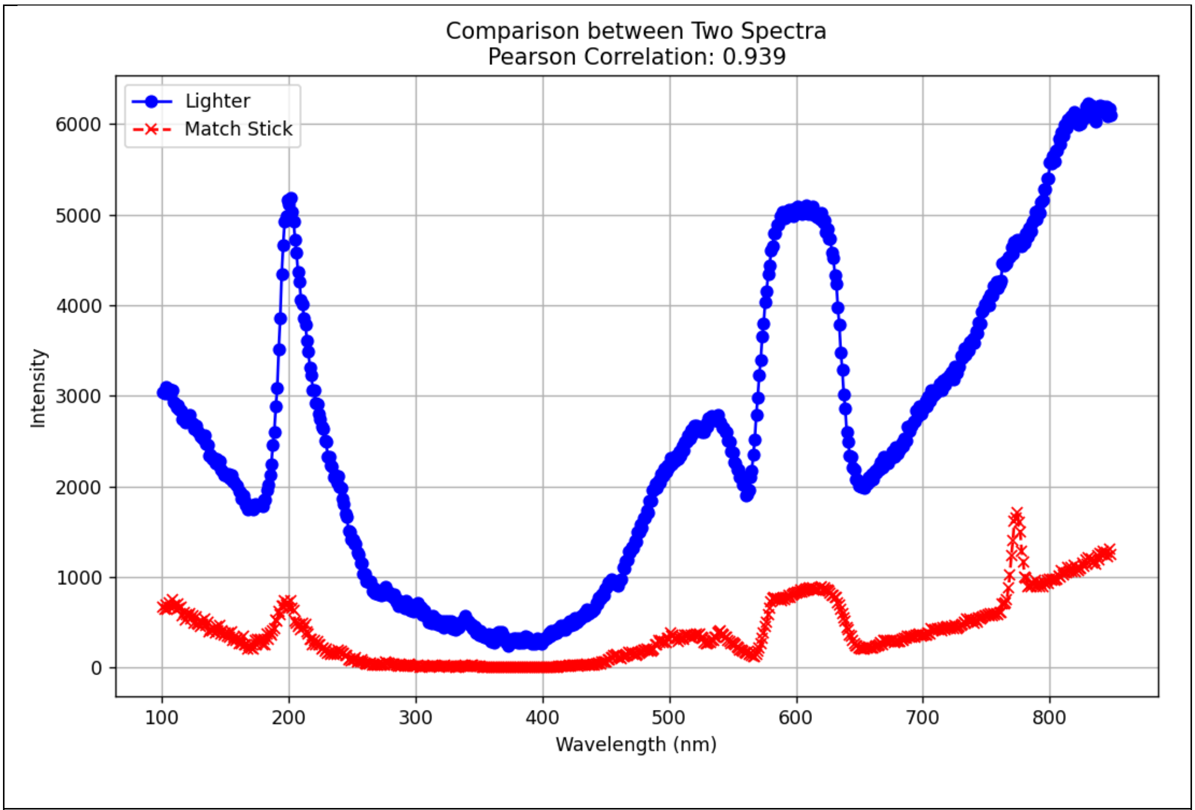


Match Stick

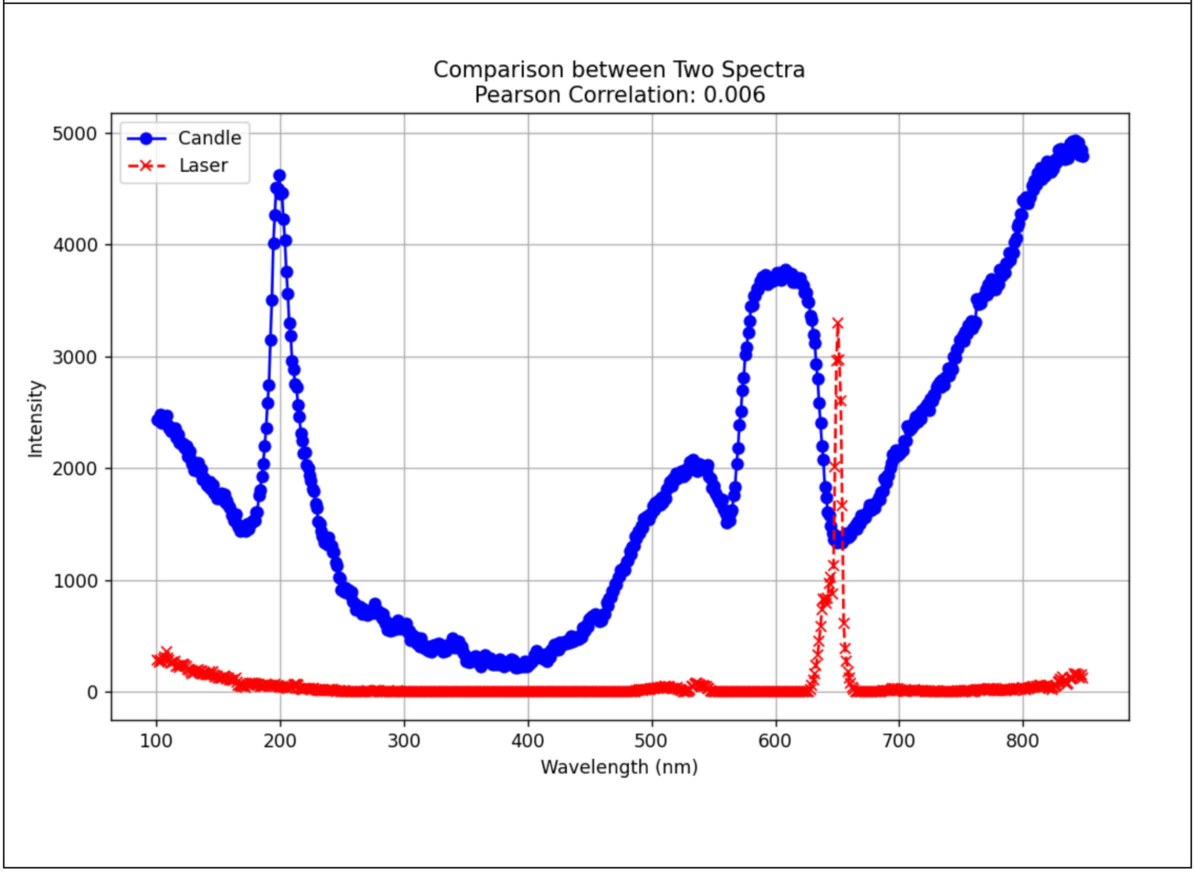
5.4.3 Comparison:







Comparison between Two Spectra
Pearson Correlation: 0.939
Lighter
Match Stick
Intensity
Wavelength (nm)



Comparison between Two Spectra
Pearson Correlation: 0.006
Candle
Laser
Intensity
Wavelength (nm)

5.5 Differentiation among the Sources:

We were unable to distinguish between the different sources of fire in our project due to several factors. The fire sources we tested, such as candles, gas lighters, matchsticks, wood, and paper, are all hydrocarbon-based fuels. As a result, these sources produce similar spectral characteristics in the visible range, making it difficult to identify unique patterns for each. Additionally, the resolution and sensitivity of our current setup, which uses a webcam-based spectrometer, were not sufficient to capture subtle variations in the spectra. With the available resources, it was not feasible to achieve accurate differentiation between fire sources. Future improvements, such as higher-resolution spectrometers or advanced detection techniques, could help overcome these limitations.

5.6 Solutions to the Problem

To address the challenge of distinguishing between different sources of fire, the following improvements can be considered:

1. **Higher-Resolution Spectrometer**: Using a spectrometer with higher spectral resolution would allow us to capture finer details in the emission spectra. This could help identify subtle differences in wavelength intensities that are not visible with low-resolution systems.
2. **Expanded Spectral Range**: Extending the analysis to include ultraviolet (UV) and infrared (IR) regions, in addition to the visible spectrum, could reveal unique spectral characteristics for different fire sources. Many fire sources emit distinct signatures outside the visible range that could aid in classification.
3. **Machine Learning Algorithms**: Implementing machine learning models to analyze spectral data can improve the system's ability to identify subtle variations and patterns in fire emissions. By training the model on a large dataset of spectra for different fire sources, the system could learn to classify them more accurately.
4. **Calibration with Standardized Sources**: Using standardized and well-characterized fire sources during calibration could help establish baseline spectral patterns for each type of fuel, improving the differentiation process.

By combining these enhancements, such as higher spectral resolution, multi-sensor data fusion, and advanced data processing techniques, the system can achieve more precise fire source classification while maintaining its cost-effectiveness.

6 Analysis & Evaluation

6.1 Novelty

Our project offers a novel approach to fire detection by combining low-cost hardware with advanced data-driven techniques. Unlike conventional systems, our solution utilizes a webcam and spectrometer to analyze the spectral properties of fire, enabling precise and real-time detection. A key innovation of this system is its ability to perform Correlated Color Temperature (CCT) calculations, which enhances accuracy in identifying fire sources while minimizing false alarms. Additionally, the system's broad range of applications—from residential and industrial settings to remote areas—makes it versatile and practical. By offering a cost-effective, scalable, and data-driven fire detection mechanism, our project presents a significant advancement in fire safety technology.

6.2 Project Management & Cost Analysis

We offer a low-cost solution to the fire detection and here is the cost analysis of our experimental setup.

Component	Cost
Webcam	1300
Spray Paint	150
Black Tape	80
Glue	20
DVD Disk	80
Card-Board Box	100
Laser	60
Lighter	15
Candle	10
Match box	2
Total	**1817**

6.3 Practical Consideration of the design

6.3.1 Public Health and Safety

The project prioritizes public health and safety by enabling early and accurate fire detection. This helps in minimizing fire-related injuries, fatalities, and property damage by allowing timely intervention. Its real-time data-driven approach ensures reliable performance, enhancing overall safety in residential, industrial, and remote settings.

6.3.2 Environmental Impact

Fires contribute significantly to environmental degradation through smoke, greenhouse gas emissions, and destruction of natural resources. Our system supports quicker fire detection and response, thereby reducing the scale of environmental damage. By helping to control fires early, it aids in minimizing air pollution and preserving ecosystems.

6.3.3 Societal and Cultural Needs

The system addresses societal and cultural needs by offering a low-cost, scalable solution that can be deployed in diverse environments. In rural and underserved communities, where access to advanced fire safety systems may be limited, this technology provides an affordable alternative. Additionally, it helps protect cultural and historical assets from fire-related risks, safeguarding community heritage.

6.4 Assessment of the impact of the project

Societal Issue:
The project promotes STEM education through an affordable and accessible setup, benefiting underfunded institutions. It inspires innovation and addresses societal needs by fostering equitable access to scientific tools.

Health and Safety Issues:
The design ensures safety through the use of non-toxic materials, light diffusion to prevent harm, and robust construction.

Legal Issues:
The project complies with safety and quality standards, uses ethically sourced materials, and avoids intellectual property infringement. Any future dissemination will respect copyright and licensing requirements.

Cultural Issues:
The universal and resource-conscious design makes it relevant across diverse cultural settings. It supports applications in culturally significant areas like art restoration and heritage conservation, ensuring inclusivity and respect for global contexts.

6.5 Evaluation of the sustainability

The project is designed with sustainability in mind, addressing environmental, economic, and social factors. Environmentally, the system promotes early fire detection, reducing large-scale fires that lead to deforestation, air pollution, and greenhouse gas emissions. Economically, the use of low-cost components such as webcams and spectrometers makes the system accessible and affordable, ensuring widespread adoption without excessive resource consumption. Socially, the system enhances community safety and resilience by providing a reliable solution for fire prevention, particularly in underserved or high-risk areas. Its scalability and energy-efficient operation further support long-term sustainability, aligning with global efforts to create safer and more environmentally conscious technologies.

7 Conclusion

Our Project successfully combines innovation, affordability, and practicality to address the critical challenge of fire detection. By leveraging low-cost hardware and advanced spectral analysis techniques, the system offers accurate and real-time detection while minimizing false alarms. Its ability to perform data-driven Correlated Color Temperature (CCT) calculations enhances precision, setting it apart from traditional fire detection methods.

The project's broad range of applications from residential and industrial settings to remote and underserved areas demonstrate its versatility and societal relevance. Furthermore, its contribution to public safety**,** environmental preservation, and sustainability highlights the system's potential to make a meaningful impact on communities and ecosystems.

In conclusion, this project not only provides a reliable and scalable fire detection solution but also aligns with modern technological and societal needs. It serves as a stepping stone toward smarter and safer fire prevention strategies, offering a sustainable approach to safeguarding lives, property, and the environment.

8 References

Reference-1: https://youtu.be/MgogwcXUIoc?si=CvJGfnisLE7M1NSS
Reference-2: DIY Spectrometer
Reference-3: Ismail, O. S., & Chukwuemeka, C. I. (2017). Development of a model fire detection algorithm. *DOAJ (DOAJ: Directory of Open Access Journals)*.