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RESEARCH ARTICLE

ENHANCING FIRE AND SMOKE DETECTION THROUGH COMPUTER VISION AND OPENCV-BASED ANALYSIS IN HSV COLOR SPACE

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Abstract

Advances in computer vision, particularly with tools like OpenCV, are transforming fire and smoke detection by overcoming the limitations of traditional smoke detectors, which are often ineffective in large, open spaces with high ceilings or ventilation. Traditional detectors rely on particle or heat changes, leading to delayed alerts in ventilated areas. Computer vision-based systems, however, enable real-time analysis of video streams to identify early visual indicators of fire and smoke. Fire detection factors include analyzing unique flame characteristics such as color intensity in the RGB or HSV color space, shape irregularities using contour analysis, and flickering patterns through motion detection. Smoke detection involves techniques such as edge blurring, optical flow analysis, and texture variance to identify diffused, moving patterns indicative of smoke. By integrating OpenCV functions like color thresholding, contour detection, and background subtraction, these systems provide faster and more reliable alerts, enhancing safety in residential and commercial environments by mitigating risks associated with delayed responses.

Keywords: Computer vision, Smoke Detection, Fire Detection, Open CV.

1. INTRODUCTION

Advances in computer vision open up new ways to over- come the disadvantages of smoke detectors, such as diffusing smoke particles before they come into contact with sensor- based alarms in large, open areas. The traditional smoke de- tectors rely on either particle or heat change detection, which proves sluggish and inadequate under high ceiling or ventilated spaces. The computer vision can provide the possibility of early warning signs of smoke and fire by analyzing color, shape, and motion patterns in video sequences through visual analysis. For quick indication of probably fire/smoke areas, the proposed system utilizes real-time processing of images, such as color thresholding, contour analysis, and so on. By providing an early warning system that identifies not only fire dangers, this technology could enhance residential and commercial environments' ability to identify fires. Advances in computer vision are now able to design novel methods of fire detection that avoid the conventional drawbacks of smoke detectors, especially in large or open rooms where high ceilings or airflow may cause a delay or prevent smoke concentration. In conventional systems, smoke detectors are based on the sensing of changes in heat or smoke particles, which may take some time to be detected in ventilated rooms and result in possible hazardous delays. The restrictions may be lessened with computer vision allowing for rapid identification of visual signs of smoke and fire in video streams by unique color, shape, and motion patterns.

2. Literature Survey

Detection explores various methodologies and technologies in fire detection, emphasizing the significance of wireless sensor networks (WSN) for monitoring environmental factors like temperature and smoke, which are crucial for early fire detection. It highlights the integration of multiple sensors, including gas and flame sensors, to enhance detection accuracy and reduce false alarms. The paper also discusses the advantages of using ZigBee technology for its low power consumption [1] and ease of integration, making it a popular choice in fire detection systems. Furthermore, it addresses the challenges faced by current systems, such as the need for reliable solutions that minimize false alerts, and suggests that future research should focus on developing cost-effective and lightweight sensors to improve the overall effectiveness of fire detection technologies .Overall, the survey provides a comprehensive overview of existing fire detection methods and identifies areas for future advancements in the field.

Microcontrollers and GSM modules with smoke sensors and cameras to identify smokers, while later work by Panjang et al. (2018) [2] used IoT components like the MQ2 sensor and NodeMCU to send alerts when smoke was detected. Face recognition, particularly on low-cost platforms like the Rasp- berry Pi, has been applied widely in IoT security settings and serves here to identify smokers. Additionally, smoke sensors have seen varied use beyond cigarette detection, such as in smart homes, health monitoring, and environmental safety, providing a foundation for IoT-based monitoring. This study integrates GPS and a mobile notification system, following trends in real-time response systems, to create a location-aware solution for detecting and identifying smoking violations in non-smoking areas.

The advancements in automated fire detection systems, focusing on their necessity due to the increasing frequency of forest fires caused by climate change and human activity. Previous studies have shown that early detection can mitigate the devastating effects on ecosystems. Various technologies are employed in forest fire detection, including sensors, cameras, and image processing algorithms [3], which are integrated into IoT frameworks to detect fires at early stages and enable quick responses. Notably, this paper uses an Arduino as the central controller, processing data from smoke detectors, flame detectors, and cameras to determine fire presence accurately and minimize false positives. The literature emphasizes combining sensor data and AI to enhance detection accuracy, reduce response times, and protect biodiversity and local communities.

The literature surrounding the scheduling of Web Jobs within Azure App Service reveals several key themes and findings that contribute to understanding best practices and methodologies in this area: Efficient Resource Utilization: Research emphasizes the importance of optimizing resource [4] usage when scheduling tasks in Azure App Service. the advantages of leveraging serverless computing through Azure Functions and Logic Apps. This approach reduces operational overhead by allowing developers to focus on writing code. DevOps integration, and automation, all of which should be enhanced operational efficiency and reliability in cloud- based applications Traditional fire detection methods, such as satellite monitoring [5] and optical cameras, offer broad cover- age but struggle with limitations like high installation costs, signal interference, and false alarms due to environmental conditions. Recent developments in Wireless Sensor Networks (WSN) and IoT have improved fire detection systems by integrating temperature, smoke, and CO sensors with data analysis to enable real-time monitoring and rapid response. These networks, often supported by drones, GPS, and cloud- based analytics, enhance precision and reduce the time needed to detect and address fire incidents. Researchers are also investigating machine learning algorithms [6] to analyse visual data, enhancing accuracy by reducing false positives from non- fire-related elements. The study proposes an Arduino-based system integrating various sensors and alarm mechanisms to monitor forest conditions continually, offering an efficient and cost-effective solution to mitigate fire-related risks.

Importance of fire [7] and smoke detection in ensuring the security and well-being of students and staff, referencing previous works on IoT-enabled monitoring systems. Key studies include the use of IoT for identifying cigarette consumption in confined spaces and the detection of smoke and hazardous gases to prevent fires. The integration of technologies [8] such as Arduino microcontrollers, Wi-Fi modules, and smoke sensors is highlighted for real-time data transmission and notification. Previous research has demonstrated that smart systems can effectively detect and respond to smoke and fire threats, contributing to safer environments. These systems often in- corporate additional features such as mobile app notifications for authorized personnel, exemplified by platforms like Blynk and communication tools like Telegram.

The advancements in fire and smoke detection technologies emphasize the integration of IoT, Wireless Sensor Networks (WSN), and [9] AI for early and accurate detection. Studies high- light the use of microcontrollers like Arduino, sensors (smoke, flame, and gas), and ZigBee for low-power, real-time monitoring with reduced false alarms. IoT-enabled systems, supported by mobile notifications and GPS, enhance response times, making them suitable for smart homes, health monitoring, and environmental safety. Machine learning and image processing algorithms further improve accuracy by analyzing visual [10] data and reducing false positives. Applications extend to forest fire detection, smoking violation identification, and educational institutions, showcasing cost-effective, reliable solutions that prioritize safety and environmental protection

3. Proposed Work

To develop a fire and smoke detection system based on Open CV and Python which can monitor the video stream for fires or smoke and alert its users whenever fires or smoke are visible. Taking into account that lighting conditions may change, the system must employ changeable thresholds of the HSV values so that the correct identification can be made whilst cutting down on false alarms. This aspires to increase safety measures by preventing fire or smoke from being unnoticed during instances when it is critical to detect fire or smoke.

A. Objective

The main objectives of the project are:

- To detect smoke by identifying grayish hues with low saturation levels, typical of smoke.

- To detect fire in a video feed based on specific color characteristics associated with flames.
- To enable dynamic threshold adjustment for both fire and smoke detection using HSV color space filtering.
- To reduce false detections by requiring fire or smoke regions to be consistently detected over multiple frames before triggering an alert.

B. Novelty of Proposed work

The proposed fire and smoke detection system demonstrates novelty through its integration of fire and smoke detection in a unified framework, leveraging HSV color space for precise thresholding tailored to each phenomenon. It introduces real-time dynamic threshold adjustment using OpenCV trackbars, enabling adaptability to diverse environments and lighting conditions. By incorporating temporal consistency checks, the system significantly reduces false positives caused by transient noise. Additionally, contour-based area filtering refines detection by isolating meaningful regions while ignoring irrelevant noise. Its lightweight design, modular structure, and open-source implementation enhance its practicality and accessibility, making it a versatile, cost-effective solution for real-time hazard monitoring in various applications

4. Experimental Methodology

The Steps involved in Implementing and Evaluating a Fire and Smoke Detection System Using Python and Open CV are:

- Set Up the Open CV Development Environment.
- Capture and Preprocess Video Frames.
- Implement HSV-Based Fire Detection.
- Integrate Dynamic HSV Threshold Adjustment.
- Evaluate Performance Metrics.
- Analyze and Document Results.

C. HSV Color Space and Thresholding

HSV, in this case, is employed since it can distinguish be- tween hue and brightness, thus providing a better accuracy of detection associated with color and flames, and smoke. Unlike RGB, HSV allows for thresholding, which is adjustable. In this way, colors associated with flames and smoke are quite possible to segregate. For example, the color of flames are bright colors like red, yellow and orange; smoke usually ap- pears with low saturation, and with mixed brightness, looking mainly gray. The system could differentiate these two creating some HSV ranges. It detects areas with colors between 0 and 50; that is, colors like red and yellow, high saturation between 150 and 255, and high brightness through HSV filtering for fire recognition.

D. Contour Detection and Area Filtering

In the study, contours retrieved from the binary masks formulated from HSV thresholds are considered for evaluating the shape and size of regions detected. By removing tiny or very irregularly shaped areas-the majority of which are noise not actually fire or smoke it has been indicated that the contour analysis will enable focusing of the system on the meaningful places. Area thresholds applied on contours ensure meaningful areas only are highlighted. For example, it sets the contour area threshold for fire areas to at least 1000 pixels; therefore, the system can easily identify larger, more stable fire patches while excluding smaller changes or anomalies in the video stream. It would ensure that only significant and persistent regions are marked as potential fire or smoke regions, thus making this thresholding process increase the reliability of detection and reduce.

E. Real-time Threshold Adjustment

OpenCV track bars are able to be employed inside the project so that threshold can be changed dynamically, and HSV values can be customized in real time in case of testing. This flexibility is very important because it would permit hue and brightness thresholds to be set for different lighting conditions, settings, and sources of fire and smoke. Operators can fine- tune the detection settings by dynamically changing the HSV ranges for particular situations, such as artificial lighting, natural sunshine, or shadows that may otherwise interfere with accuracy. With this real-time adaptation ability, the change in the visual features of fire and smoke may vary with whether the situation is indoors or outdoors or daytime against night time, ensuring the system would be flexible and effective under any condition. In addition, dynamic threshold customisation also reduces false positives as threshold values.

F. Alert Mechanism

The fire or smoke alarm will be activated only when there is a probable fire or smoke region detected reliably for a number of consecutive frames. This method reduces the chance of false positives due to isolated noise, momentary illumination changes, or slight color shifts in the video stream. Transient visual artifacts, such as those that could be mistaken for fire or smoke, can be distinguished by the system from occurrence of real fire or smoke by requiring persistence in the detection. This way, this persistence check, acting like a filter, will make sure warnings are issued only in response to continuing, consistent visual patterns, coherent with smoke or fire and not necessarily in response to brief interruptions.

G. Tool used

Visual Studio Code is a streamlined code editor with support for development operations like debugging, task running, and version control. It aims to provide just the tools a developer needs for a quick code-build-debug cycle and leaves more complex workflows to fuller featured IDEs, such as Visual Studio IDE.

H. Flowchart

The flowchart illustrates the sequential process of a fire and smoke detection system using HSV color space. It includes initialization, frame capture, detection logic for fire and smoke, temporal consistency checks, alert generation and termination.

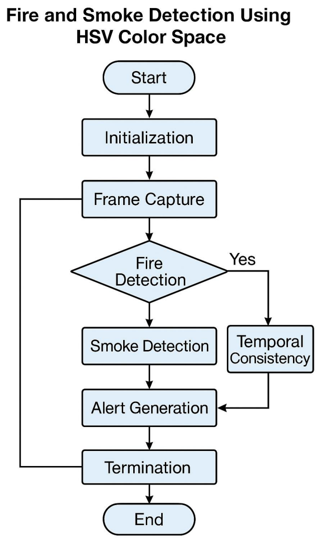

Figure 1: Process Flowchart

5. Result and Analysis

The proposed Fire and Smoke Detection System using HSV Color Space was successfully implemented and tested on video sequences captured under different lighting and environmental conditions. The system processes real-time frames and detects fire and smoke regions based on their color and motion characteristics.

A. Result

- ✓ The HSV color model effectively distinguished fire and smoke from the background due to its separation of chromatic content (hue and saturation) from intensity (value).
- ✓ Fire regions were identified using hue and saturation thresholds, while smoke detection relied on low-saturation and high-value pixel ranges.
- ✓ Temporal consistency checks reduced false positives caused by momentary color fluctuations or lighting variations.

Figure 2: Smoke Detection

Figure 3: Fire Detection

Figure 4: No smoke or Fire Detected

5. Conclusion

The HSV-based detection approach proved efficient for real-time fire and smoke monitoring. The fire and Smoke detection System offers a possible and reasonably proficient Python-and-OpenCV-based real-time hazard detection solution. It adapts to a variety of backgrounds and light situations through active thresh- old variations and color-space modifications using the Hue, Saturation, and Value (HSV) technique. The implementation minimizes false alarms and emphasizes an association with reliability through continual detection checks and noise- reduction strategies. The project creates a handy tool for fire and smoke detection in time to be put to good use in preventing possible disasters, strongly emphasizing the need for real-time monitoring for safety applications.

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