A Smart Forest Fire Detection and Notification System using IOT and Machine Learning

Bharati Masram
Department of Electronics &
Telecommunication Engineering
Yeshwantrao College of Engineering
Nagpur,India
bharatimasram@gmail.com

Anish Mendhe
Department of Electronics &
Telecommunication Engineering
Yeshwantrao College of Engineering
Nagpur, India
ankymendhe12@gmail.com

Ayush Mishra
Department of Electronics &
Telecommunication Engineering
Yeshwantrao College of Engineering
Nagpur, India
ayushmin1234@gmail.com

Aniket Pathade
Research Consultant
Jawaharlal Nehru Medical College,
Datta Meghe Institute of Higher
Education and Research,
Sawangi (M), Wardha.
aniketpathade@gmail.com

Nakshatra Shindekar
Department of Electronics &
Telecommunication Engineering
Yeshwantrao College of Engineering
Nagpur, India
nakshatrashindekar44@gmail.com

Yash Kangale
Department of Electronics &
Telecommunication Engineering
Yeshwantrao College of Engineering
Nagpur, India
yashkangale248@gmail.com

***Abstract*— In this paper, the proposed system presents a two-stage forest fire detection system that first uses a wireless sensor network of MQ sensors and a Node MCU and then a YOLOv8 forest fire detection model to reduce false alarms. The entire process is seamlessly integrated with the Raspberry Pi, which immediately triggers an email notification for quick action upon receiving confirmation of a fire. As the frequency and severity of wildfires continue to escalate, it is imperative that we take swift action to address their devastating impact. The YOLO model was able to achieve an accuracy of 92% with low power and memory consumption on the MCU. The method serves as a demonstration of the potential of combining innovative technologies to solve environmental problems and contributes to the development of effective and proactive fire detection systems using IOT and Machine learning.**

Keywords— Forest Fire Detection System, Node MCU, ESP8266, MQ sensor, highly flammable gas, YOLOv8 technology, Raspberry-Pi, Email notification.

I. Introduction

Forest fires pose a significant global challenge, particularly during the summer months. According to the Forest Survey of India,[1] an alarming number of over 300,000 forest fires were detected between November 2020 and June 2021 alone. Moreover, the Indian State of Forest Report (ISFR) for 2019 highlights that approximately 36% of the country's forest cover is susceptible to wildfires, with around 54.4% of forests in India being exposed to occasional fires. This escalating trend in forest fires has devastating consequences, including the destruction of vegetation, habitats for wildlife, and soil quality degradation. Additionally, the emission of toxic gases and CO2 exacerbates health risks and contributes to global warming. Despite the awareness of these issues, effectively combating forest fires remains a challenge. Previous literature has identified several key challenges, including limitations in early detection methods and the delayed response of fire departments due to reliance on manual monitoring systems. Traditional approaches often fail to promptly detect fires in their initial stages, leading to heightened damage and difficulty in containment. Motivated by the urgent need for improved forest fire detection and response systems,[2] this paper presents a novel two-stage approach utilizing advanced sensor and camera technologies. The objective of this research is to enhance the efficiency and rapidity of fire detection, thereby reducing the extent of damage caused by wildfires. By integrating cutting-edge technologies such as the Wireless Sensor Network of MQ135 sensor using ESP modules and YOLOv8-equipped camera with the Raspberry Pi platform, this system aims to revolutionize forest fire detection. This work contributes to the development of proactive solutions for addressing the escalating threat of forest fires. By leveraging innovative technologies, the proposed system offers a more efficient and timely approach to fire detection, potentially mitigating the destructive impact of wildfires. Furthermore, the seamless integration of sensors, cameras, and computing platforms demonstrates the potential of technological advancements in solving environmental challenges.

II. Realted Work

Traditionally watchtowers, patrol, aerial patrols, etc. were used to monitor the forest and prevent or detect wildfires. However, these techniques use constant human monitoring and hence can be tedious and exhausting, leaving room for error. Remote sensing is also popular method for detecting forest fire that does not require constant human monitoring but Satellite imagery can be very expensive and satellites have limited resolution, hence the data recorded is not accurate instead an average of the area. Also, satellites require processing time for each image; hence they are not the best for wildfire detection. Recent advancements in technology such as IoT, artificial intelligence and 5G Networks have made possible to accurately detect forest fire with almost no need for human exposure [3]. Technologies such as IOT have enabled the development of several solutions for early fire detection and management [4].. The Wireless Sensor Network is one of the best examples of a IOT based fire detection system; it enables the monitoring of a sizable forest utilizing several

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sensors that are capable of communicating with one another and effectively and precisely detecting forest fires [5]. To establish wireless communication links with many devices, a variety of approaches like Bluetooth, WIFI, RF, and LoRa wan can be employed. Many microcontrollers with these characteristics pre-installed are available on the market, such as the ESP32 and NodeMCU. At mounting heights of 2.5 to 3 meters and spacings of up to 5 to 10 meters, a WSN prototype utilizing ESP32 was able to detect fire within 30 seconds and gas within 10 seconds [6][7]. A simple IOT based forest fire detection system using sensors is described by K. Mehta, S. Sharma and D. Mishra .Sensor network with LoRa wan can be used to cover a wider region [10] .It can be challenging, though, to supply power to these sensors in the forest. Because forests receive a lot of sunlight, employing solar energy to power the sensors offers a sustainable and environmentally responsible alternative. In order to contain the fire before it spreads, we can further enhance these systems to incorporate a fire extinguisher feature that uses a pressured water flushing tap [11].

The creation of different Artificial Neural Network models and detection algorithms to identify forest fires using meteorological parameters [11] or images taken with a regular camera [8][13] have been made possible by advances in machine learning. Yolo, one of the newest algorithms for detecting forest fires, shows to be incredibly effective at quickly and accurately identifying flames, even in large-scale photos with low resolution [7]. Nevertheless, these techniques run the risk of setting off false alarms, which can waste money and inconvenience the fire service.

III. PROPOSED SYSTEM

In this paper, the proposed system has used the power of both IOT and Machine Learning to detect forest fire with a higher accuracy and power efficiency. It detects the gases and smoke generated during forest fire using WSN of MQ sensors and then use Raspberry pi to perform on-board image processing on the camera feed using YOLOv8 Object Detection Model [9] that uses a single pass through its ANN to detect fires in image. Thus, this 2-step verification effectively reduces the accuracy and reduces the memory and power consumption of raspberry pi by only triggering camera after smoke detection.[12][13] Also, the Real-time Processing using YOLOv8 allows the MCU to quickly send alert signal to the Fire department to act on the wildlife in its initial stage [14][15]. The raspberry pi will form the Centre and main base station for the wireless sensor network. The use of Raspberry pi as the MCU due to its computing power, storage facility and connectivity [16] is as shown in Fig.1.

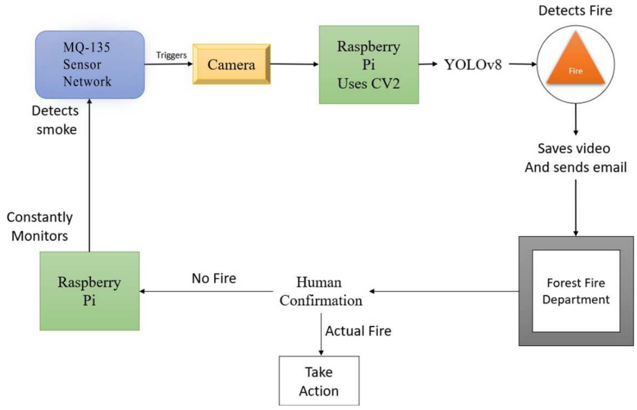

Fig. 1. Block Diagram of Proposed Sytem

The primary objective of this research is to study and present a comprehensive methodology for the development of a Forest Fire Detection System [17] [18] using Flow chart as shown in Fig.2. Our approach involves an applied research design, focusing on the practical implementation and analysis of performance, usability, and impact on users.

In the following sections, we will delve into the intricacies of the methodology, providing detailed insights into the prototype's design and development. Paper has also elucidated the selection of components, the rationale behind their integration, and the challenges encountered during the process.

A. Major Componenets used in the system

Hardware Components: Raspberry Pi 4 - Model B:

Description: A microcomputer that functions as a central processing unit.

Functions: Monitoring system performance, receiving and processing data from sensors and cameras

Node MCU:

Description: A low power microcontroller that runs on ESP8266 WIFI SoC.

Function: Creates a wireless mesh network that transmit sensor data to raspberry pi.

Sensor MQ-135:

Description: Gas sensor that detects NH3, NOx, alcohol, benzene, smoke, CO2.

Function: Continuously monitors gas leaks and activates the camera when detected.

YOLOv8 Camera:

Description: A YOLOv8 is applied on the live camera feed to detect flame present in the environment.

Function: Retrieves images for analysis based on the YOLOv8 model.

32GB SD Card:

Description: Storage device with Raspbian OS.

Function: Stores system data, application configurations, and operating system files.

USB Camera:

Description: HP w300 webcam.

Function: capture real-time video images for fire detection.

HDMI Cable:

Description: Used to display the Raspberry Pi interface on the monitor.

Functionality: Provides visual feedback and interface access.

USB Type C Cable:

Description: Provides the Raspberry Pi 4 with a high wattage power supply.

Features: Powers the Raspberry Pi for continuous operation.

5V Power Supply and Ground Voltage:

Description: Powers up the MQ-135 sensor.

Function: Ensure continuous operation of the gas sensor.

B. MQ-135 Wireless Sensor Network

The MQ-135 sensor is widely used to detect smoke particles and gases present in the air such as carbon monoxide, carbon dioxide, nitrogen oxides, etc. It is particularly effective at detecting harmful gases like CO and NOx, making it essential for air quality monitoring and environmental devices. The sensor works by measuring gas conductivity using a tin dioxide semiconductor sensing element. When the target gas is present, the sensor's conductivity increases, causing a change in its resistance, which is converted into an electrical signal.

- Node MCU

Node MCU is an open-source development board and firmware that has been specifically created with Lua scripting for IOT applications. It consists of code running on the ESP8266 Wi-Fi SoC from Espress if Systems and hardware based on the ESP-12 module. An inexpensive, compact, and potent open-source IoT platform is Node MCU. Initially, it came with hardware based on the ESP-12 module and firmware that uses Espress if Systems' ESP8266 Wi-Fi SoC. Prototyping is accelerated by its compatibility with the Arduino IDE and Micro Python.

- ESP-NOW

The ESP-NOW library is a feature provided by Espressif Systems for their ESP microcontrollers. It allows for efficient communication between ESP8266/ESP32 devices without relying on Wi-Fi networking infrastructure or TCP/IP. With ESP-NOW, devices can communicate directly over a local wireless connection, without needing a router. Operating in the 2.4 GHz band, it supports data rates of up to 250 kbps. Devices must be paired before communication, requiring the exchange of unique mac address and cryptographic keys.

C. YOLO v8 detection

YOLOv8 (You Look Only Once Version 8) is a real-time object recognition model known for its speed, accuracy, and efficiency. This model belongs to the family of YOLO object detection models and can feed images to a neural network in one step.

- YOLOv8 Architecture

Backbone (CSPDarknet53):

The backbone functions as the feature extractor. It consists of a modified CSPDarknet53, a convolutional neural network with repeated Cross-Stage Partial (CSP) modules.

CSP modules enhance gradient flow, allowing for deeper and more efficient networks while reducing computation.

The backbone extracts meaningful features from the input images at varying scales.

Neck (SPP, PAN): The neck aggregates the features extracted from the backbone. In YOLOv8, it incorporates:

SPP (Spatial Pyramid Pooling): Enhances receptive field and enriches feature representations by applying pooling operations with varying kernel sizes on the feature maps.

PAN (Path Aggregation Network): Improves feature propagation and fusion, particularly between lower and higher layers of the network, boosting the model's ability to localize objects accurately.

Head (Decoupled Head): The head generates the final predictions from the processed features. YOLOv8 utilizes a decoupled head featuring two parallel branches:

Classification Branch: Determines the class (e.g., 'fire')

Regression Branch: Determines the bounding box coordinates and object-ness score (confidence that an object is present).

Key Improvements in YOLOv8:

Efficiency: Advancements in network design and the introduction of techniques like SPPF (instead of SPP) lead to faster processing times.

Decoupled Head: Separating the object classification and regression tasks enhances accuracy in object detection.

Stronger Backbone: The modified CSPDarknet53 architecture provides a powerful foundation for feature extraction.

D. Working of the system

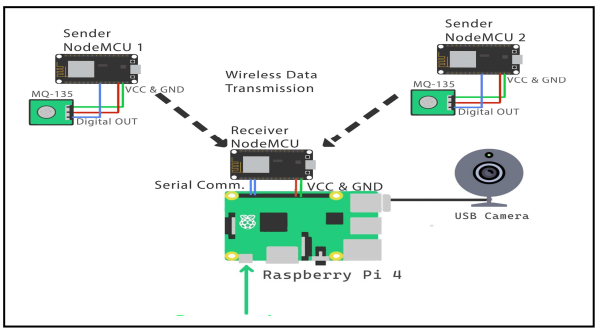

Fig. 2. Hardware Interconnections

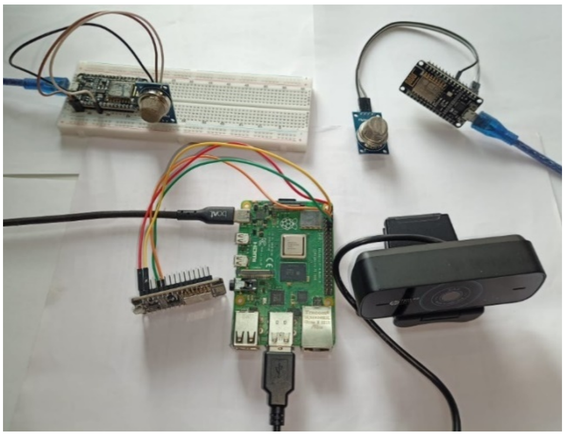

Fig. 3. View of the Proposed system

a. Initialization and Sensor Monitoring

1. Start the Raspberry Pi and Receiver NodeMCU.

The Receiver NodeMCU is powered using the 5V (or 3.3V) GPIO pins of the Raspberry pi. Once the Raspberry pi is powered, the Receiver NodeMCU will also get switched on and it will create a new WIFI network for the sensor network.

The SSID and password of this WIFI network is available to every node in the system.

2. Power up the Sender NodeMCUs.

Once powered up, every node will connect to the WIFI network with the given SSID and password. The mac-address of all nodes will be paired up to their respective Node ID.

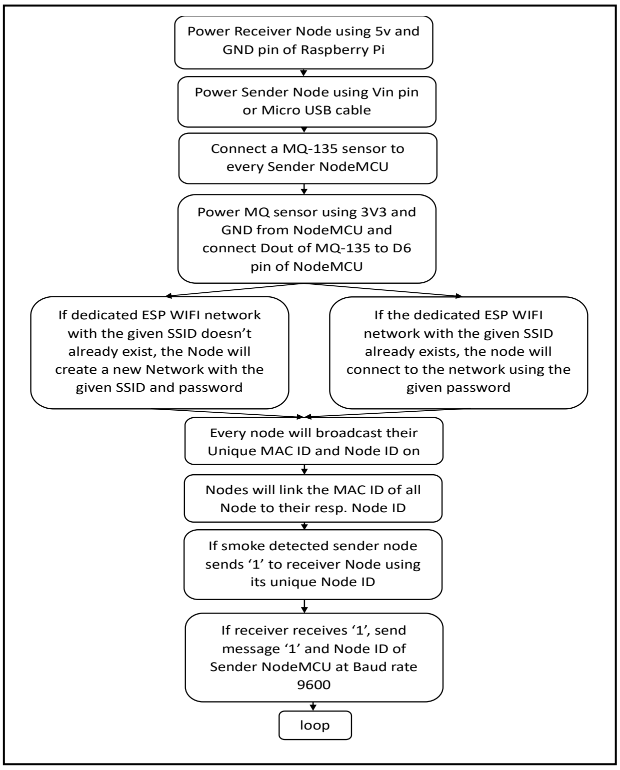

Fig. 4. Flow Chart of the Wireless Sensor Network

3. Smoke detection using MQ-135 sensor:

The MQ-135 sensors connected to every sender node, are active Low and hence output 0V at the Data pin of the NodeMCU upon smoke detection. When the Sender NodeMCU detects this change in input, it send the detection message to the receiver NodeMCU.

4. Reception by Raspberry pi.

The receiver NodeMCU, upon receiving the detection message from the Sender Node, sends a detection message along with the Node ID to the Raspberry pi serially. When the Raspberry pi receives this message, it initiates the YOLO application.

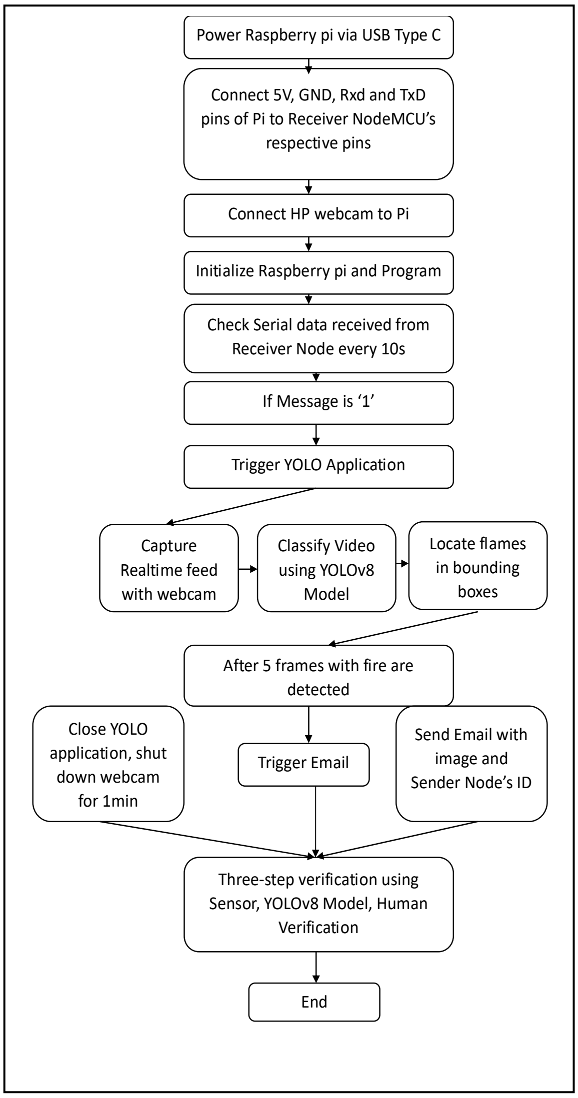

Fig. 5. Flow chart of Main system

a. Fire detection using YOLOv8

1) Activation: Once the YOLO program is activated, it performs object detection on the live feed from the connected camera.

2) Image capture and processing: The camera uses the Open CV library (cv2) to capture video frames. The YOLOv8 model processes these images and places a

bounding box around each target/flame in the image along with a confidence value.3. Image Accumulation: The system continuously accumulates detection results across multiple images to ensure flame identification.

3) Confirmation: Flame detection is confirmed when the system detects the presence of flame for five consecutive frames.

b. Notification

1. Close the YOLO app and turn off your camera: After the flame detection is confirmed, the YOLO app closes to save memory and reduce power consumption. To reduce memory consumption, the camera will turn off for 1 minute.

2. Email Notification: The system launches an email program that uses Simple Mail Transfer Protocol (SMTP). An email notification with the ID of the NodeMCU that detected the smoke and the annotated image from YOLO detection is sent to the user for human verification.

c. Three-step verification:

The fire detection model uses a three-step validation process to reduce false alarms.

1. Sensor Verification: Initial detection by MQ-135 sensor.

2. Validation of YOLOv8: Analysis using a specially trained YOLOv8 fire detection model.

3. Human validation: Annotated images are sent to the user or fire department for human validation, thereby improving the accuracy of the detection system.

This working model ensures an efficient and reliable fire detection system that uses IoT-based Wireless Sensor Network technology and advanced machine learning techniques to minimize false alarms and improve overall system accuracy.

IV. Results and Discussion

The WSN of NodeMCU was able to transmit the MQ sensor detection data to the Raspberry Pi within 15 seconds of detection every time. The nodes were able to transmit data very accurately and without any noise interference. Since the Nodes create their own local WIFI network, the absence of internet facility does not create any hindrance in the performance of the system.

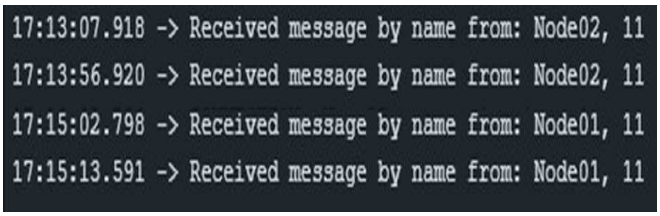
17:13:07.918 -> Received message by name from: Node02, 11
17:13:56.920 -> Received message by name from: Node02, 11
17:15:02.798 -> Received message by name from: Node01, 11
17:15:13.591 -> Received message by name from: Node01, 11

Fig. 6. Received message by Receiver

Here, the YOLO model was used to detect fire in a low resolution video as shown in Fig.4 colour accurate stock video and it showed promising results. It was able to enclose all flame object in the video with very less inaccurate detection and false positives.

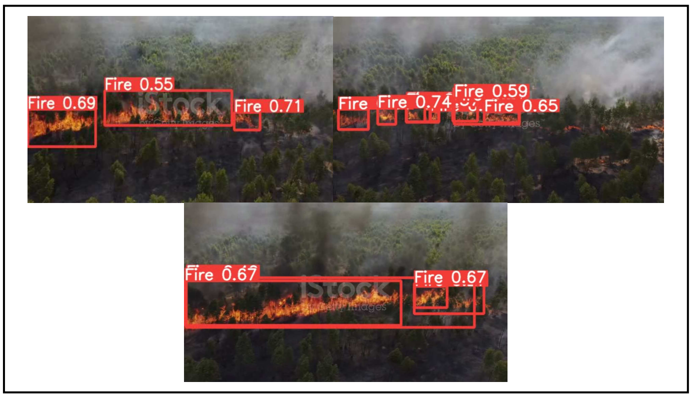

Fig. 7. Low Resolution stock video with different resolution value

Here, the model was used to detect fire in a high-resolution video as shown in Fig. 5 and it was able to accurately detect fire with high confidence value. Image above shows that model detected fire with a confidence value of 0.73 even when the fire was largely covered with smoke.

Fig. 8. High Resolution stock video with different resolution value

TABLE I. Resolution Based Analysis.

Comparative analysis		
Dataset / Camera used	***Avg. Confidence value***	***Accuracy (%)***
Smartphone Camera	0.7-0.8	81
Webcam	0.6	63
Low-Resolution Video	0.7-0.8	86
High-Resolution Video	0.8-0.85	92

This suggests that by increasing the quality of the camera we can make our proposed system significantly more accurate.

Ensure compatibility and version requirements for all dependencies

Advantages of the system.

1. Swift detection for timely intervention and mitigation.

2. Accurate identification of fire locations for targeted response.
3. Proactive measures to prevent extensive environmental harm.
4. Minimizes response time by automating the detection process, crucial for preventing the escalation of fires.
5. Timely alerts for community safety and evacuation.
6. Suited for deployment in diverse forest landscapes.
7. Requires minimal maintenance, making it a cost-effective and sustainable solution for long-term deployment.
8. Provides insights for informed decision-making.
9. Minimizes losses associated with forest fires by enabling timely response and containment strategies.
10. Efficient allocation of fire fighting resources.

V. Conclusion

The Raspberry Pi system in the conclusion successfully integrates cutting-edge technologies to enhance safety and monitoring capabilities. By combining the power of a Raspberry Pi, Wireless Sensor Network of Node MCU and MQ135 gas sensor, YOLOv5 object detection model, and a camera module, we've created a versatile system capable of detecting flames and gas in real-time. Moving forward, opportunities for improvement include refining machine learning models for even more accurate detection, exploring additional sensors for a comprehensive environmental assessment, and enhancing the user interface for greater user interaction. This Raspberry Pi system represents a successful convergence of hardware and software technologies, showcasing the potential for innovation in safety and environmental monitoring applications. Its modular design and adaptability lay the foundation for future enhancements, emphasizing the system significance in contributing to the growing landscape of IoT and intelligent systems.

VI. Future Scope

The fire detection system based on YOLOv8, Raspberry Pi, and the MQ-135 Wireless Sensor Network exhibits promising capabilities, and its future scope could be extended in various ways to enhance its functionality, usability, and applicability. Some potential areas for future development and expansion include:

- Enhanced Machine Learning Models:
- Integration of Additional Sensors.
- User Interface Improvements:
- Integration with Smart Home Systems:

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