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A Smart UAV-Based System for Industrial Chimney Inspection and Monitoring Using IoT.

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Abstract: *This paper presents a drone-based chimney monitoring system. The system uses a drone to perform inspection tasks efficiently. It has two parts.The first part is for real-time monitoring. The drone captures live video of the chimney. Sends it to a ground station using wireless communication. This allows operators to see the chimney conditions, record data and review past inspections. The second part involves processing and sensing on the drone. It continuously checks for defects like cracks smoke density variations and structural damage. If it detects any condition it immediately alerts the operator. The system also supports control and manual operation of the drone. This allows for inspection. Safety features are included to ensure operation and prevent system failure. The proposed system was. Showed reliable performance. It detected defects and monitored chimney conditions in real time. It provides a cost- safer alternative to traditional inspection methods. The system can be effectively used in industries, for routine chimney monitoring.*

Keywords: Drone Monitoring, UAV, Chimney Inspection, IoT, Raspberry Pi, MQTT, Node-REDrmance

I. INTRODUCTION

I. Chimney monitoring is an important task in places like power plants, factories and chemical units. If we do not monitor chimneys properly it can lead to problems like damage to the structure, too much smoke coming out and pollution in the environment.

If we do not find faults like cracks, blockages or abnormal smoke early it can cause damage to the infrastructure over time, increase the cost of maintenance and even create safety risks for the workers.

Current methods of inspecting chimneys are mostly done by hand. Are not fully automatic. These methods usually require workers to check the chimney using scaffolding or cranes which is dangerous and takes a lot of time. In cases there is no system to continuously monitor the chimney so problems are only found after a lot of damage has already happened. Some advanced systems that monitor chimneys depend heavily on internet connectivity, which can be a limitation. If the internet

connection fails the system may not be able to give us updates in time or find issues properly.

To overcome these limitations a system that uses drones to monitor chimneys is proposed. This system has two parts. The first part focuses on monitoring and control where live video and inspection data from the drone are sent to a station. This allows operators to see the condition of the chimney from a distance and keep track of inspection data over time.

The second part, known as the field unit, consists of the drone itself along with its camera and sensors. This unit is responsible for capturing real-time data finding defects like cracks or abnormal smoke patterns and giving immediate feedback to the operator. It also allows control for a detailed inspection when required.

The proposed system can find issues help with maintenance on time and reduce the need for manual inspections. It also gives us flexibility by allowing both monitoring and local control of the drone. The main goal of this system is to improve chimney inspection reduce risk and ensure safety for the environment and the structure.

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The proposed system helps us find chimney faults quickly and alerts the operator to take action. The monitoring setup works like a watchdog continuously checking the condition of the chimney and notifying us if any abnormality like cracks, excessive smoke or structural damage is found.

The part of the system that supervises allows real-time monitoring, data visualization and remote control of the drone. This makes it possible to inspect the chimney from a distance without needing to be physically present near hazardous areas. On the hand the field unit, which is the drone itself does the actual inspection by capturing live video and data. It can work independently. Give us continuous updates about the chimney condition.This combined approach makes the overall system more robust and reliable. By using the drone-based monitoring system faults in the chimney can be found at a stage, which helps in reducing maintenance costs and preventing serious damage. It also improves safety by minimizing the need for inspection.

The proposed architecture ensures operation and quick response to any issue that is found. The dual-level control system, which includes both monitoring and field-level inspection increases the flexibility and effectiveness of the system. It allows both observation and manual intervention when required.

Monitoring and maintaining chimneys is very important for safe and efficient plant operation. This system provides a solution for that purpose. It creates a framework for inspection using drones and modern monitoring techniques.

Compared to methods the proposed system offers better efficiency, faster response and improved safety. It helps us find and address chimney-related issues before they become problems. Overall the drone-based chimney monitoring system is a solution, for modern industrial inspection needs.

II. LITERATURE SURVEY

Chimney monitoring is a concern in industrial environ- ments. If chimneys are not maintained properly and faults are not detected it can lead to damage, pollution and high repair costs. Studies have shown that if industrial chimneys are not inspected properly it can result in cracks, corrosion and poor emission control which can affect safety and compliance with standards. Therefore it is necessary to monitor chimneys to ensure they are working properly.

IX. Detecting faults in chimneys at a stage is very important for maintaining industrial safety and reducing damage. Tradi- tional inspection methods are not always effective. May fail to identify small defects before they become big problems. This can lead to repairs and downtime.

Modern research is now focusing on using technologies such as drones, Internet of Things sensor networks and machine learning to improve inspection systems. In drone-based chim- ney monitoring, cameras and sensors are mounted on drones to capture real-time data. These may include cameras for crack detection thermal sensors for heat analysis and gas sensors for monitoring emissions.

XI. Recently there have been advancements in monitoring systems using Internet of Things technology. These systems allow data collection and remote access through cloud plat- forms. By integrating drones with Internet of Things-based monitoring it becomes possible to observe chimney conditions efficiently store inspection data and analyze it for better decision-making.

Sensors and monitoring devices can be integrated with the drone system to continuously observe the condition of chim- neys. The drone captures time visual data and if equipped with sensors can also measure parameters such as temperature, gas concentration and smoke density. This data is transmitted to monitoring platforms where it can be analyzed and visualized for understanding. Internet of Things-based frameworks play a role in this system by helping to identify patterns such as abnormal smoke levels, sudden changes in emission behavior or unusual thermal variations. These patterns may indicate faults like internal blockages, cracks or inefficient combustion processes inside the chimney.The collected data is sent to servers or monitoring dash- boards where it can be processed using basic algorithms or advanced techniques. These systems help in evaluating the performance of the chimney identifying defects and ensur- ing emission control. By combining drone technology with Internet of Things and data analysis the monitoring process becomes more efficient, reliable and suitable for industrial applications.

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Machine learning and artificial intelligence techniques are also being used to improve the accuracy of chimney inspection systems. Advanced models such as Convolutional Neural Networks and regression-based methods can analyze images and sensor data collected by the drone to identify defects like cracks, corrosion and abnormal emission patterns. These models are capable of detecting faults with accuracy making the inspection process more reliable compared to traditional methods.

By combining drone-based data collection with algorithms the system becomes more effective in monitoring chimney conditions. The integration of sensor data and AI-based anal- ysis helps in identifying issues at a stage, which is important for maintaining safety and reducing maintenance costs.

Another important area of research is the development of models and predictive maintenance systems for industrial infrastructure. In the context of chimney monitoring digital models can be created using sensor data, inspection records and simulation tools. These digital models act as a representa- tion of the actual chimney and are continuously updated with real-time data collected by the drone.

Such systems help in predicting failures before they occur and allow industries to plan maintenance activities in advance. This not improves operational efficiency but also reduces the chances of unexpected breakdowns. By using intelligence, Internet of Things and drone technology together chimney monitoring systems can become more intelligent, automated and suitable for modern industrial applications.

The collected data from the drone-based system can be continuously updated using sensor readings and visual in- spection results. This allows the system to monitor chimney conditions over time and even predict failures such as struc- tural cracks, excessive emissions or internal blockages. Such predictive analysis helps industries plan maintenance activities in advance. Reduce overall repair costs.

Some studies have also explored the use of SCADA-based monitoring systems in environments. In chimney monitoring SCADA systems can be used to supervise and control related equipment such as exhaust systems, emission controls and sensors. By combining real-time data from drones with control software operators can detect issues early. Take necessary actions, such as adjusting operations or initiating safety pro- cedures in case of abnormal conditions.

III. METHODOLOGY

The proposed system is designed to monitor industrial chimneys and detect potential hazards using drone technology integrated with the Internet of Things (IoT). The system combines sensing, data processing, communication, and control mechanisms to perform real-time inspection and analysis of chimney conditions. It continuously evaluates structural integrity and emission patterns, enabling early detection of faults and improving overall operational safety.

A. System Architecture

The overall system architecture consists of the following components:

- Drone (DM002HW)
- Camera and sensors
- Raspberry Pi (processing unit)
- MQTT communication protocol
- Node-RED dashboard

These components work together to capture, process, transmit, and visualize inspection data in real time.

B. Fault Detection Algorithm

The system performs fault detection by analyzing real-time data collected from the chimney and comparing it with predefined normal conditions. The drone captures images and sensor data from different sections of the chimney. This data is processed by the Raspberry Pi to identify anomalies.

Under normal conditions, parameters such as emission levels and temperature remain within a stable range. Any significant deviation, such as excessive smoke or abnormal temperature variation, is considered a potential fault. The system evaluates the magnitude of deviation to determine the severity of the issue. If the deviation exceeds a predefined threshold, an alert is generated and sent to the operator.

This continuous monitoring approach enables early fault detection, ensuring improved safety and reliability of chimney operations.

1. Camera and Sensor System

The system utilizes a camera mounted on the DM002HW drone to capture real-time video of the chimney. This visual data is used to detect structural defects such as cracks, corrosion, and surface damage.

In addition, optional sensors such as temperature and gas sensors are integrated to monitor environmental parameters. These sensors provide critical data related to heat levels and gas emissions. Any abnormal sensor readings indicate potential issues in chimney performance.

2. Processing Unit

The Raspberry Pi acts as the central processing unit of the system. It receives video and sensor data from the drone and performs real-time analysis. The processing unit is responsible for:

- Filtering and preprocessing data
- Executing fault detection algorithms
- Identifying abnormal patterns
- Transmitting processed data to the monitoring system

This ensures efficient analysis and timely detection of faults.

3. Control Mechanism (Drone-Based Control)

The system supports drone control through a mobile application or ground control interface. The operator can navigate the drone, focus on specific regions, and perform detailed inspections. In case of detected anomalies, the system alerts the operator, enabling immediate action and closer inspection.

3. Network Connectivity

The system uses Wi-Fi and 2.4 GHz communication for data transmission and drone control. The Raspberry Pi communicates with external systems using the MQTT protocol, which is lightweight and suitable for real-time IoT applications.

The communication workflow is as follows:

1. Inspection data is generated by the drone
2. Data is transmitted to the MQTT broker
3. The broker distributes data to connected clients
4. The monitoring dashboard displays the data in real time

This ensures reliable and efficient data transfer.

C. Data and IoT Integration

The proposed system utilizes the Message Queuing Telemetry Transport (MQTT) protocol for efficient data transmission. MQTT is a lightweight communication protocol specifically designed for IoT applications, offering low bandwidth consumption and reliable message delivery.

In this system, the Raspberry Pi acts as a data publisher, transmitting chimney inspection data, including video analysis results and sensor readings, to an MQTT broker. The broker functions as an intermediary that manages communication between different system components by distributing the received data to subscribed clients.

The data flow within the system operates as follows:

1. The Raspberry Pi collects and processes inspection data from the drone.
2. The processed data is published to the MQTT broker.

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3. The broker forwards the data to subscribed clients, such as the monitoring dashboard.
4. The Node-RED dashboard receives and displays the data in real time.

This architecture ensures efficient, scalable, and real-time data communication, enabling continuous monitoring and remote accessibility of chimney conditions.

D. Monitoring and Visualization

The proposed system employs Node-RED for real-time monitoring and data visualization. Node-RED is a flow-based development tool widely used in IoT applications due to its simplicity, flexibility, and ability to handle real-time data streams efficiently.

A dedicated dashboard is developed to display the operational status and condition of the chimney. The dashboard provides the following information:

- Live video feed captured by the drone
- Sensor readings, including temperature and gas levels
- Alerts for abnormal or fault conditions
- Drone operational status

The visualization interface uses graphs and charts to represent data in an intuitive and user-friendly manner, enabling quick understanding and decision-making by the operator. Additionally, the system stores historical data, which can be used for trend analysis, performance evaluation, and improvement of inspection strategies.

This integrated monitoring approach allows remote supervision of chimney conditions, enhances situational awareness, and supports timely intervention in case of detected faults.

F. System Operation Workflow

The chimney monitoring system operates in a structured sequence to ensure safe, efficient, and continuous inspection. The workflow of the system is illustrated in Fig. 2, which represents the interaction between system components and data flow during operation.

1. System Initialization:

When the system is activated, all hardware components, including the DM002HW drone, camera, sensors, Raspberry Pi, and communication modules, are initialized and prepared for operation.

TABLE I:

FEATURE	COMPARISION BETWEEN EXISTING SYSTEMS AND PROPOSED SYSTEM		
	TRADITIONAL	IoT	PROPOSED
Real-Time Monitoring	No	Yes	Yes
Appliance-Level Analysis	No	Limited	Yes
Cloud Data Storage	No	Yes	Yes
Predictive Bill Estimation	No	Limited	Yes
Cost Optimization Suggestion	No	Limited	Yes
Scalability	No	Moderate	High

The comparison clearly shows that the proposed system outperforms traditional and existing IoT systems in multiple aspects. Unlike traditional systems, which lack real-time monitoring and advanced features, the proposed system provides continuous real-time data tracking. It also enables detailed appliance-level analysis, which is either absent or limited in older systems. While IoT systems offer cloud storage and some predictive capabilities, they are still limited compared to the proposed model. The proposed system enhances efficiency through accurate predictive bill estimation and cost optimization suggestions. Additionally, it offers higher scalability, making it suitable for future expansion. Overall, the proposed system is more intelligent, efficient, and user-friendly than existing solutions.

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Fig. 3.DMOO2HW Drone Kit

2. Controller Setup:
The processing unit configures the system by establishing communication with the drone, setting threshold limits for fault detection, connecting to the MQTT broker, and initializing the Node-RED dashboard. This ensures that the system is fully operational before inspection begins.

3. Monitoring Process:
The drone is deployed to the chimney site, where it captures real-time video and sensor data. This data is transmitted to the processing unit for continuous analysis. The system monitors key parameters such as structural integrity, smoke emission patterns, and temperature variations.

4. Data Acquisition and Transmission:
The onboard camera captures visual data, while sensors measure environmental parameters such as temperature and gas emissions. This data is transmitted in real time to the Raspberry Pi or ground station for further processing.

5. Data Processing and Condition Analysis:
The processing unit analyzes incoming data by comparing it with predefined normal operating conditions. Variations in smoke patterns, temperature, or structural appearance are evaluated to identify potential abnormalities.

6. Fault Detection Decision:
The system determines whether the observed deviation exceeds acceptable limits.
• If parameters remain within limits, monitoring continues.
• If deviations exceed thresholds, the system identifies a fault and triggers an alert.

7. Emergency Response and Safety Mechanism:
Upon fault detection, the system immediately notifies the operator. Alerts are displayed on the dashboard, and the affected area is highlighted for quick identification. This enables timely intervention and prevents further damage.

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7. Safety Monitoring State:
After fault detection, the system continues monitoring the affected region. The drone can be repositioned to perform detailed inspection until the issue is resolved.

8. System Reset and Resume Operation:
Once the fault is addressed, the operator can reset the system through the dashboard. The system then resumes normal monitoring operations.

G. Sensors and Dashboard Integration

The integration of sensors and the monitoring dashboard is illustrated in Fig. 4. The drone-mounted camera and sensors continuously capture data related to chimney conditions, including structural integrity, temperature, and gas emissions.
The Node-RED dashboard acts as the primary user interface, allowing the operator to:

- Monitor real-time video and sensor data
- Control drone operations
- Receive and analyze alerts
- Reset or adjust system parameters

The Raspberry Pi processes all incoming data and identifies anomalies such as cracks, excessive emissions, or temperature fluctuations. Upon detecting a fault, the system generates alerts, highlights the affected region on the dashboard, and enables the operator to take corrective action.
All data is transmitted to the Node-RED dashboard using the MQTT protocol, ensuring reliable and real-time communication. This integration of sensing, processing, and visualization enables efficient decision-making and enhances the overall reliability of the system.

H. Drone Platform and Communication

The DM002HW drone serves as the primary inspection platform, equipped with a Wi-Fi FPV camera, a 6-axis gyroscope, approximately 7 minutes of flight time, and a range of up to 100 meters. The camera captures chimney visuals, while optional sensors detect temperature and gas levels.
The system utilizes Wi-Fi and MQTT-based communication for real-time data transmission. This ensures seamless connectivity between the drone, processing unit, and monitoring dashboard, enabling continuous and remote inspection.

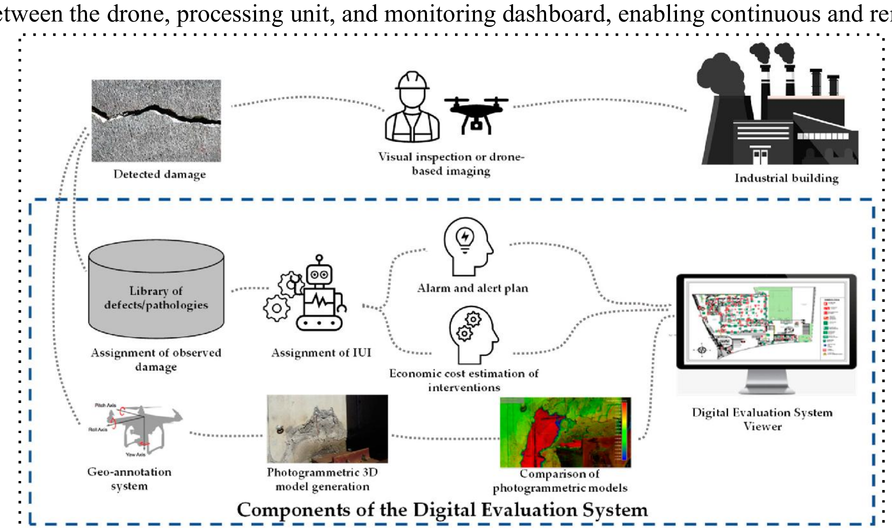

Fig. 2.Components of the Digital Evaluation System

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Fig. 3. Dashboard

IV. IOT INTEGRATION

The system incorporates the MQTT protocol to establish communication between different components in an efficient and reliable manner. MQTT follows a lightweight publish–subscribe model, making it suitable for real-time IoT applications with minimal bandwidth requirements.

In the proposed setup, the Raspberry Pi acts as the data publisher, sending processed information such as sensor readings and inspection results. This data is received by an MQTT broker, which manages the distribution of messages to all connected subscribers.

The monitoring dashboard, implemented using Node-RED, subscribes to the relevant topics and receives the transmitted data instantly. This allows real-time visualization of chimney conditions and system status.

The use of this communication framework ensures seamless data exchange, supports remote accessibility, and enhances the overall responsiveness of the monitoring system.

V. MONITORING AND VISUALIZATION

The proposed system utilizes a Node-RED dashboard for real-time monitoring and visualization of chimney conditions. The dashboard provides an intuitive and user-friendly interface that enables operators to observe and analyze system performance remotely.

The dashboard displays the following key information:

- Live video feed captured by the drone
- Sensor data, including temperature and gas readings
- Alerts for abnormal or fault conditions
- Overall system and drone operational status

The integration of real-time visualization with IoT-based communication enhances situational awareness and allows operators to take timely action in case of detected anomalies. This improves the efficiency, safety, and reliability of chimney inspection processes.

VI. SYSTEM WORKFLOW

The operation of the proposed chimney monitoring system follows a sequential process to ensure effective inspection and fault detection:

1. System Start
2. Initialization
3. Drone Monitoring
4. Data Processing
5. Fault Detection
6. Alert Generation

Once deployed, the drone continuously monitors the chimney by capturing real-time video through its onboard camera. Additional sensors measure parameters such as temperature and gas emissions. The collected data is transmitted in real time to the Raspberry Pi or ground station for analysis.

The system processes the incoming data to evaluate chimney conditions and detect any abnormalities. Continuous data transmission ensures that the system remains updated with the current state of the chimney, enabling timely identification of faults and prompt alert generation.

V. RESULTS AND DISCUSSION

The proposed chimney monitoring system was implemented using a DM002HW drone, a Raspberry Pi processing unit, an onboard camera, and additional sensors. The system was evaluated in a controlled environment to assess its capability in detecting faults and monitoring chimney conditions in real time.

During the experimental phase, various test scenarios were created, including simulated structural cracks, variations in smoke emission, and temperature fluctuations around the chimney. The drone captured real-time video and sensor data, which was transmitted to the Raspberry Pi for analysis.

Upon detection of abnormal conditions, the system demonstrated effective response mechanisms. The Raspberry Pi identified anomalies based on deviations from predefined thresholds and immediately generated alerts. These alerts were displayed on the monitoring interface, while real-time updates were transmitted to the Node-RED dashboard using the MQTT protocol, enabling remote monitoring.

The dashboard provided comprehensive visualization, including live video streaming, real-time sensor readings, and alert notifications for detected faults. This allowed operators to continuously monitor chimney conditions from a remote location without the need for direct physical inspection.

The experimental results indicate that the proposed system offers rapid response to abnormal events and ensures reliable real-time monitoring. It significantly reduces the dependency on manual inspection and enhances operational safety. The integration of drone-based inspection with IoT-based monitoring provides an efficient and scalable solution for industrial chimney evaluation.

Overall, the system demonstrated:

- Fast response to detected anomalies
- Reliable and continuous monitoring
- Reduction in manual inspection efforts

These results confirm that the proposed approach improves efficiency and safety in industrial chimney inspection processes.

VI. CONCLUSION

This study presented a drone-based chimney monitoring system designed to enhance the safety, efficiency, and reliability of industrial inspections. The system integrates a DM002HW quadcopter drone equipped with a camera and optional sensors to capture real-time data, which is processed using a Raspberry Pi to identify abnormalities such as cracks, excessive emissions, and temperature variations.

By incorporating Node-RED for visualization and the MQTT protocol for communication, the system enables real-time monitoring and remote access. The two-level architecture, consisting of field-level drone inspection and IoT-based monitoring and control, ensures effective fault detection and improved maintenance planning.

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Compared to traditional inspection methods, the proposed system demonstrates advantages in terms of cost-effectiveness, operator safety, and ease of deployment. Overall, the system provides a practical and scalable solution for modern industrial chimney inspection and monitoring.

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