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IoT Based Autonomous Drainage Inspection and Blockage Removal Robot with Live Monitoring

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Abstract: *The IoT Based Autonomous Drainage Inspection and Blockage Removal Robot with Live Monitoring is an intelligent robotic system developed to improve the safety, efficiency, and reliability of underground drainage maintenance. Conventional drainage inspection and cleaning methods rely heavily on manual labor, exposing workers to hazardous gases, contaminated water, and confined spaces while increasing maintenance time and operational risks. The proposed system employs an ESP32 microcontroller integrated with an ESP32-CAM, MQ-series gas sensor, DHT11 temperature and humidity sensor, L298N motor driver, and a high-torque drilling mechanism to perform real-time drainage inspection and blockage removal. The robot navigates through drainage pipelines, continuously monitors environmental conditions, streams live video over a Wi-Fi-enabled web interface, and detects hazardous gases to generate instant alerts. The drilling mechanism efficiently removes soft blockages, reducing the need for human intervention and minimizing maintenance delays. By combining IoT technology, embedded systems, sensors, wireless communication, and robotic automation, the proposed system provides a cost-effective, safe, and efficient solution for smart drainage management. The project contributes to the development of smart city infrastructure by enhancing worker safety, reducing operational costs, improving maintenance accuracy, and enabling continuous real-time monitoring of underground drainage networks.*

Keywords: : Internet of Things (IoT), Autonomous Robot, Drainage Inspection, Blockage Removal, ESP32, ESP32- CAM, Live Monitoring, Gas Sensor, Smart Drainage System, Robotics.

I. INTRODUCTION

Drainage systems play a crucial role in maintaining urban sanitation, preventing waterlogging, and ensuring the safe disposal of wastewater. As urban populations continue to grow, drainage networks are increasingly affected by the accumulation of plastic waste, sludge, sediments, and other solid materials that obstruct the normal flow of wastewater **[1]**. These blockages often lead to flooding, environmental pollution, unpleasant odors, and the spread of waterborne diseases, causing significant economic and public health concerns **[2]**. Conventional drainage inspection and cleaning methods primarily rely on manual labor, requiring sanitation workers to enter confined underground spaces where they are exposed to toxic gases, contaminated water, and harmful microorganisms **[3]**. Such hazardous working conditions increase the risk of serious accidents, respiratory illnesses, and even fatalities, highlighting the urgent need for safer and more efficient drainage maintenance technologies **[4]**.

Recent advancements in the Internet of Things (IoT), embedded systems, robotics, wireless communication, and sensor technologies have enabled the development of intelligent solutions for infrastructure inspection and maintenance **[5]**. IoT-based robotic systems can continuously monitor drainage conditions using multiple sensors while transmitting real-time information to remote operators through wireless communication networks [6]. The integration of environmental sensors, cameras, and cloud-based monitoring platforms allows authorities to inspect underground drainage pipelines without direct human intervention [7]. These intelligent monitoring systems improve operational efficiency, reduce

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maintenance delays, minimize inspection errors, and significantly enhance worker safety by providing early warnings about hazardous environmental conditions [8].

The proposed IoT Based Autonomous Drainage Inspection and Blockage Removal Robot with Live Monitoring is designed to address the limitations of conventional drainage maintenance methods by integrating intelligent robotics with IoT technology [9]. The system utilizes an ESP32 microcontroller as the central processing unit, an ESP32-CAM module for live video streaming, MQ-series gas sensors for detecting hazardous gases, a DHT11 sensor for monitoring temperature and humidity, and an L298N motor driver for controlling the robot's movement [10]. A high-torque drilling mechanism mounted at the front of the robot efficiently removes accumulated waste and soft blockages inside drainage pipelines [11]. The collected sensor data and live video are transmitted through a Wi-Fi-enabled web interface, allowing operators to remotely monitor drainage conditions and control the robot in real time [12].

The autonomous robotic platform provides several advantages over traditional inspection techniques by reducing human intervention and improving inspection accuracy [13]. Live video streaming enables maintenance personnel to identify blockages, structural defects, and hazardous gas accumulation at an early stage, allowing timely maintenance before major failures occur [14]. The integrated environmental monitoring system continuously measures gas concentration, temperature, and humidity, ensuring safer working conditions and better decision-making [15]. Furthermore, the automated blockage removal mechanism reduces maintenance time, lowers operational costs, and improves the overall reliability of drainage management systems [16].

The implementation of this intelligent robotic system represents a significant advancement toward smart and sustainable urban infrastructure [17]. By integrating IoT technology, robotics, embedded systems, wireless communication, environmental sensing, and live monitoring, the proposed solution provides a safe, reliable, and cost-effective approach for drainage inspection and blockage removal [18]. The system minimizes human exposure to hazardous environments while improving maintenance efficiency and supporting smart city initiatives [19]. Moreover, the proposed platform can be further enhanced by incorporating artificial intelligence, autonomous navigation, cloud computing, computer vision, and predictive maintenance algorithms, making it suitable for future intelligent drainage management applications [20].

II. PROBLEM STATEMENT

Modern drainage systems are frequently affected by the accumulation of plastic waste, sludge, leaves, sediments, and other solid materials, resulting in severe blockages, wastewater overflow, environmental pollution, and urban flooding **[1]**. Conventional drainage inspection and cleaning methods depend heavily on manual labor, requiring sanitation workers to enter confined underground drainage pipelines where they are exposed to toxic gases, contaminated water, biological hazards, and oxygen-deficient environments **[2]**. These hazardous working conditions significantly increase the risk of respiratory diseases, infections, accidents, and fatalities while making the inspection process slow, labor-intensive, and inefficient **[3]**. Existing drainage maintenance systems generally lack real-time monitoring, live visual inspection, automated blockage removal, and remote accessibility, leading to delayed fault detection and higher maintenance costs [4]. Therefore, there is a critical need for an intelligent IoT-based autonomous drainage inspection and blockage removal robot capable of continuously monitoring drainage conditions, detecting hazardous gases, providing live video surveillance, and removing blockages without direct human intervention [5]. Such a system can improve worker safety, reduce maintenance time and operational costs, enhance inspection accuracy, support predictive maintenance, and contribute to the development of smart, sustainable, and technologically advanced urban drainage infrastructure **[6]**.

III. OBJECTIVES

1. To design and develop an IoT-based autonomous robot for efficient inspection of underground drainage pipelines.

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2. To continuously monitor hazardous gas concentration, temperature, and humidity inside drainage systems using environmental sensors.
3. To provide real-time live video streaming of drainage conditions through an ESP32-CAM module for remote visual inspection.
4. To detect and remove drainage blockages using a high-torque motor-driven drilling mechanism, thereby reducing manual cleaning efforts.
5. To enable wireless remote monitoring and control of the robot through a Wi-Fi-enabled web interface for safe and efficient operation.

IV. LITERATURE SURVEY

Paper 1: Jain and S. Das (2021) developed an **IoT-based inspection robotic system** integrated with an anti-clogging mechanism for drainage pipeline maintenance. The proposed robot utilized IoT communication, environmental sensors, and a mechanical cleaning unit to inspect drainage pipelines remotely while reducing human exposure to hazardous environments. Experimental results demonstrated effective detection and removal of minor blockages with improved operational safety and maintenance efficiency. However, the system exhibited limited autonomy during navigation in complex drainage networks. This work provides a strong foundation for developing intelligent IoT-enabled drainage inspection robots with live monitoring capabilities.

Paper 2: Nguyen and H. Ryu (2022) presented an autonomous mobile robot for sewer pipeline inspection using intelligent navigation and obstacle avoidance algorithms. The proposed system successfully navigated curved and narrow underground pipelines while maintaining stable movement and reliable inspection performance. Autonomous control significantly improved inspection accuracy and reduced operator intervention. Nevertheless, the robot lacked an integrated blockage removal mechanism, limiting its application in complete drainage maintenance operations.

Paper 3: Jung et al. (2024) proposed a deep learning-based sewer damage inspection framework that combines computer vision with robotic inspection systems. The developed approach automatically detects cracks, joint displacements, corrosion, and structural defects from sewer inspection images using artificial intelligence. Experimental evaluation demonstrated higher defect detection accuracy and reduced inspection time compared to manual analysis. However, the study primarily focused on defect identification and did not include automated cleaning or blockage removal capabilities.

Paper 4: B. Xiong and H. Zhang (2025) introduced a **visually assisted sewer cleaning robot** equipped with a camera-guided inspection system, YOLO-based defect detection, and an automated cleaning mechanism. The robot successfully detected, localized, and removed obstacles inside sewer pipelines under simulated operating conditions. Experimental results confirmed improved cleaning accuracy, reliable navigation, and enhanced worker safety. The proposed system demonstrated the effectiveness of integrating computer vision with robotic cleaning for intelligent sewer maintenance.

Paper 5: Georg Villinger and Alexander Reiterer (2025) presented a comprehensive review of robotic systems for sewer inspection and monitoring. The study analyzed various locomotion mechanisms, laser scanners, cameras, LiDAR, and intelligent sensing technologies used in modern inspection robots. The authors proposed an advanced robotic platform capable of autonomous navigation, high-resolution imaging, and digital twin generation for predictive sewer maintenance. The work highlighted future opportunities for integrating artificial intelligence and autonomous robotics into smart drainage management systems.

Paper 6: Sachin V. Gaikwad et al. (2026) proposed an **IoT-Based Autonomous Drainage Inspection and Blockage Removal Robot with Live Monitoring** using an ESP32 controller, ESP32-CAM, gas sensors, environmental sensors, Wi-Fi communication, and a high-torque drilling mechanism. The system provided real-time live video streaming, hazardous gas detection, remote monitoring, and automated blockage removal while significantly reducing manual intervention. The proposed solution improved worker safety, maintenance efficiency, and operational reliability, making it highly suitable for smart city drainage management applications.

V. WORKING OF SYSTEM

A. ESP32 Microcontroller and Power Management

The **ESP32 microcontroller** acts as the central controller and processing unit of the entire drainage inspection robot. It receives regulated power from the battery supply and coordinates the operation of all connected hardware modules. The ESP32 continuously collects data from the DHT11 and MQ6 sensors, processes sensor readings, controls the motor driver, operates the relay module, and manages communication with the ESP32-CAM. Through its built-in Wi-Fi capability, the controller transmits real-time sensor information and receives user commands from the web-based monitoring interface. Thus, the ESP32 synchronizes sensing, movement, monitoring, and blockage removal operations to ensure smooth and autonomous system performance.

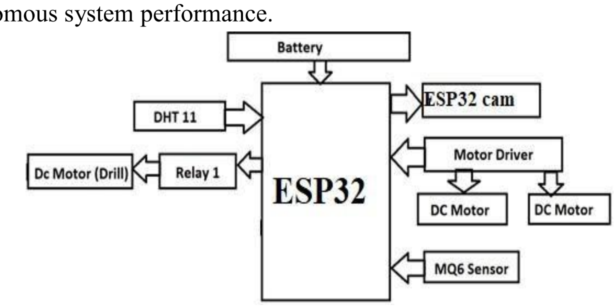

Fig 1: System architecture

B. Environmental Monitoring using DHT11 and MQ6 Sensor

The robot continuously monitors the internal drainage environment using the **DHT11** and **MQ6 gas sensor**. The DHT11 measures the surrounding temperature and humidity inside the drainage pipeline, providing information about environmental conditions that may affect the robot's operation. Simultaneously, the MQ6 sensor detects hazardous gases such as methane, LPG, and other combustible gases that commonly accumulate inside underground drainage systems. The sensor values are periodically transmitted to the ESP32, where they are compared with predefined safety thresholds. Whenever abnormal gas concentration or environmental conditions are detected, the controller immediately generates warning notifications on the monitoring interface, allowing authorities to take preventive action before dangerous situations arise.

C. Live Video Monitoring using ESP32-CAM

The **ESP32-CAM** module is mounted at the front of the robot to provide continuous visual inspection of the drainage pipeline. As the robot moves through the drainage channel, the camera captures real-time video of blockages, cracks, sludge accumulation, water flow conditions, and other structural defects. The ESP32 processes and transmits the live video stream over Wi-Fi to a remote web interface, enabling operators to inspect inaccessible underground areas without physically entering the drainage system. The live video significantly improves inspection accuracy, supports remote navigation, and assists operators in identifying blockage locations and hazardous conditions during maintenance operations.

D. Robot Navigation using Motor Driver and DC Motors

Robot movement is achieved using two **DC geared motors** controlled through the **L298N motor driver module**. The motor driver receives control signals from the ESP32 and regulates the direction and speed of each motor independently. Based on operator commands received through the wireless interface, the robot can move forward, backward, turn left, or turn right while maintaining stable navigation inside narrow drainage pipelines. The motor driver also provides sufficient driving current to the motors while protecting the ESP32 from excessive electrical load. This controlled locomotion enables the robot to efficiently inspect long drainage sections and accurately position itself near detected blockages.

E. Blockage Removal Mechanism

Once a blockage is identified through live video monitoring, the ESP32 activates the **relay module**, which supplies power to the high-torque **DC drill motor** mounted at the front of the robot. The rotating drill mechanism breaks soft sludge, plastic waste, organic deposits, and other accumulated materials obstructing the drainage pipeline. The drilling operation continues until the blockage is sufficiently cleared, restoring the normal flow of wastewater. Since the drilling motor operates independently through the relay circuit, the robot can simultaneously perform inspection and cleaning without interrupting other monitoring functions, thereby improving maintenance efficiency and reducing manual intervention.

F. Wireless Monitoring and Integrated System Operation

The entire system operates as an integrated **IoT-enabled drainage monitoring platform**. Sensor readings, robot status, and live camera footage are continuously transmitted to a web-based monitoring interface through the ESP32's Wi-Fi connectivity. Operators can remotely observe environmental conditions, inspect drainage pipelines, navigate the robot, and activate the blockage removal mechanism from a safe location. The integration of real-time sensing, live video streaming, wireless communication, autonomous navigation, and mechanical cleaning enables efficient drainage inspection while minimizing human exposure to hazardous underground environments. This intelligent system significantly improves worker safety, inspection accuracy, operational reliability, and maintenance efficiency, making it suitable for smart city drainage management applications.

VI. SYSTEM DESIGN

The system design of the AI-Based IoT-Enabled Autonomous Drainage Inspection and Blockage Removal Robot is divided into different functional sections. Each component performs a specific task to ensure smooth inspection, blockage detection, cleaning, and real-time monitoring operations.

A. Power Supply Section

The power supply section provides electrical energy to the complete robotic system. A rechargeable battery is used as the main source of power for controllers, sensors, motors, camera, and relay modules. Voltage regulation circuits ensure stable output and protect components from fluctuations.

B. ESP32 Controller Section

The ESP32 microcontroller acts as the primary control unit of the robot. It manages sensor readings, motor movement, relay switching, and wireless communication. Its built-in Wi-Fi module enables IoT connectivity for remote monitoring and control.

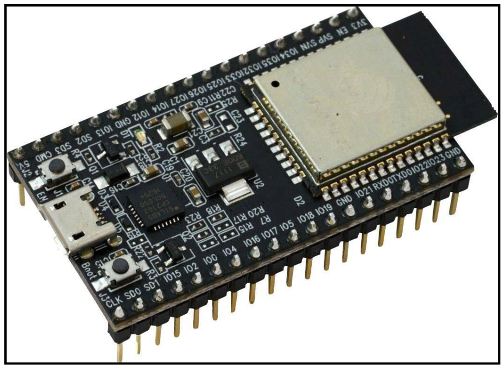

Fig 2: ESP32 microcontroller

D. Sensor Section

The sensor section includes DHT11 and MQ6 sensors. The DHT11 measures temperature and humidity inside drainage channels. The MQ6 sensor detects toxic or flammable gases, helping to maintain safety during operation.

E. Camera Monitoring Section

Fig 3: USB camera

A USB camera is mounted on the robot for real-time visual inspection. It captures live video of drainage pipelines, cracks, waste materials, and obstacles. The camera feed is processed by Raspberry Pi and can be viewed remotely.

F. Motor Driver Section

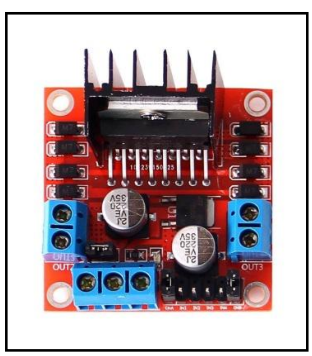

Fig 4: Motor driver

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The motor driver section interfaces between the controller and DC motors. It controls motor speed and direction based on commands from ESP32. This section ensures proper robotic movement inside narrow drainage areas.

G. Mobility Section

The mobility section consists of wheels and DC geared motors. It allows the robot to move forward, backward, and turn inside drainage channels. Strong wheels help the robot travel on wet and uneven surfaces.

H. Cleaning Mechanism Section

The cleaning section includes a drill, cutter, or rotating blade connected through a relay module. It removes sludge, plastic waste, and solid blockages when activated. This section reduces manual cleaning effort.

I. Communication Section

The communication section uses Wi-Fi technology for IoT-based data transfer. Sensor readings, robot status, and live video are sent to a remote dashboard or mobile application. It enables real-time supervision and control.

J. Monitoring and Alert Section

This section provides instant alerts when harmful gas levels, abnormal temperature, or blockage conditions are detected. Notifications help operators take quick action and improve safety.

K. Integrated Operation Section

All sections work together as a smart robotic system. Sensors collect environmental data, the camera performs inspection, controllers manage movement, and the cleaning mechanism removes blockages. The integrated design ensures efficient and autonomous drainage maintenance.

VI. RESULTS

The developed IoT-Based Autonomous Drainage Inspection and Blockage Removal Robot with Live Monitoring was successfully fabricated and tested under laboratory conditions. The prototype integrates an ESP32 microcontroller, ESP32-CAM module, MQ6 gas sensor, DHT11 temperature and humidity sensor, relay module, motor driver, DC geared motors, and a high-torque drilling mechanism on a compact mobile platform. The robot demonstrated stable movement over flat surfaces and effectively transmitted live video and environmental data through a Wi-Fi-based monitoring interface. The integrated drilling mechanism successfully removed soft drainage blockages while the environmental sensors continuously monitored gas concentration, temperature, and humidity. The experimental results confirm that the proposed system provides an efficient, reliable, and safe solution for drainage inspection and maintenance while significantly reducing the need for manual intervention.

A. Prototype Development

The hardware prototype was successfully assembled using lightweight chassis material with all electronic components securely mounted on the platform. The ESP32 controller coordinated the operation of sensors, camera, motor driver, and drilling mechanism without communication delays. The compact design allowed the robot to move smoothly while maintaining structural stability, making it suitable for drainage inspection applications.

B. Functional Performance Evaluation

The robot successfully performed all major functions including wireless navigation, live video transmission, environmental monitoring, hazardous gas detection, and blockage removal. The ESP32-CAM provided continuous live video for remote inspection, while the DHT11 and MQ6 sensors accurately monitored environmental conditions.

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C. Performance Analysis

The experimental evaluation indicates that the proposed robotic system significantly improves drainage inspection efficiency compared to conventional manual methods. Live monitoring enables operators to identify blockages and hazardous conditions in real time, while autonomous navigation reduces inspection time and improves operational safety. The integration of IoT communication, environmental sensing, and mechanical blockage removal provides a cost-effective and reliable solution for smart drainage management. The prototype demonstrates excellent potential for deployment in municipal drainage systems and can be further enhanced using artificial intelligence, autonomous navigation, and cloud-based monitoring technologies.

Table 1 Performance Evaluation of the Proposed System

Sr. No.	Performance Parameter	Observation	Status
1	Robot Movement	Smooth forward, backward and turning motion	Successful
2	Live Video Monitoring	Continuous real-time video streaming	Successful
3	Gas Detection	MQ6 sensor detected hazardous gases accurately	Successful
4	Temperature & Humidity Monitoring	Stable environmental data acquisition	Successful
5	Wireless Communication	Reliable Wi-Fi communication with ESP32	Successful
6	Blockage Removal	Drill mechanism removed soft drainage blockage effectively	Successful
7	System Integration	All hardware modules operated simultaneously	Successful
8	Overall Performance	Reliable operation during laboratory testing	Successful

Model prototype

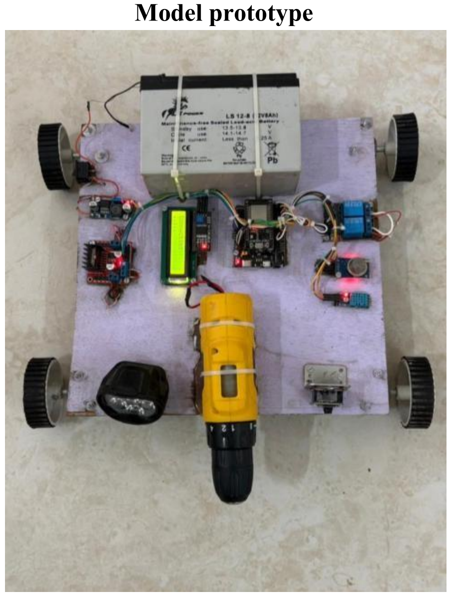

Fig 7: Model view 1

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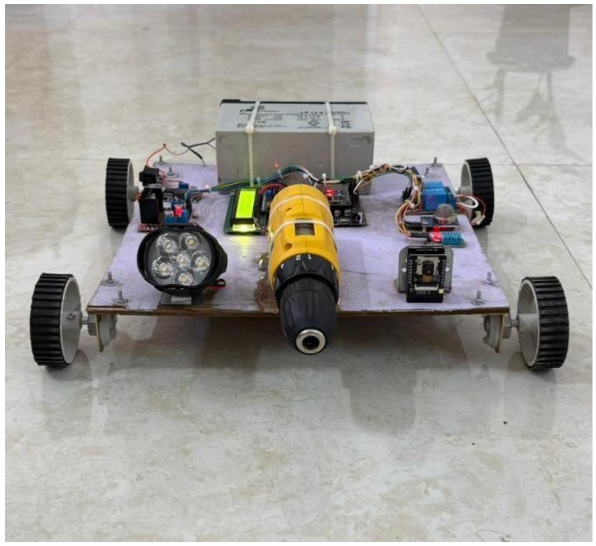

Fig 8: Model view 2

VII. CONCLUSION

The IoT-Based Autonomous Drainage Inspection and Blockage Removal Robot with Live Monitoring successfully demonstrates an intelligent and efficient solution for modern drainage maintenance. The developed prototype integrates an ESP32 microcontroller, ESP32-CAM, MQ6 gas sensor, DHT11 sensor, motor driver, and a high-torque drilling mechanism to perform real-time drainage inspection, environmental monitoring, live video streaming, and automated blockage removal. The system effectively reduces the need for manual intervention, thereby minimizing human exposure to hazardous gases, contaminated water, and confined underground environments. Experimental testing confirmed reliable robot navigation, continuous wireless communication, accurate environmental sensing, and efficient removal of soft drainage blockages. The live monitoring feature enables operators to remotely inspect drainage conditions and make timely maintenance decisions. Overall, the proposed system provides a cost-effective, safe, and reliable approach for smart drainage management while improving maintenance efficiency, worker safety, and environmental sustainability. The project also demonstrates the practical application of IoT and robotics in supporting smart city infrastructure and intelligent sanitation systems.

VIII. FUTURE SCOPE

The proposed drainage inspection robot can be further enhanced by incorporating advanced technologies to improve its intelligence, efficiency, and operational capabilities. Artificial Intelligence (AI) and Computer Vision algorithms can be integrated for automatic detection of blockages, cracks, corrosion, and structural defects without human supervision. Autonomous navigation using LiDAR, ultrasonic sensors, and SLAM (Simultaneous Localization and Mapping) techniques can enable the robot to navigate complex drainage networks independently. The system can be connected to cloud platforms for real-time data storage, remote analytics, and predictive maintenance of drainage infrastructure. Future versions may also include robotic manipulators or advanced cutting mechanisms capable of removing hard blockages and larger debris. The integration of GPS, 5G communication, and edge computing can further improve monitoring speed and operational reliability. Additionally, renewable energy sources such as solar-assisted charging and high-capacity lithium-ion batteries can increase operational duration. These improvements will transform the proposed system into a fully autonomous smart drainage management solution suitable for large-scale municipal, industrial, and smart city applications.

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