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Proactive Asset Health Monitoring in Power & Utility: Leveraging AI, Robotics, and Advanced Surveillance for Predictive Maintenance and Failure Prevention

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Abstract

The power and utility sector relies heavily on maintaining infrastructure reliability and operational safety. This study explores an advanced digital transformation strategy by Saudi Electricity Company (SEC) to improve asset health monitoring and predictive maintenance using artificial intelligence (AI), robotics, and surveillance technologies. This approach includes pilot implementations of CCTV and robotic monitoring for fuel tanks to detect leaks, as well as drones and AI-enhanced computer vision for the inspection of transmission lines. These pilot technologies are being evaluated for their ability to detect potential issues in real-time, with initial results indicating promising improvements in maintenance response, safety, and environmental compliance.

Keywords: Asset Health Monitoring, Leak Detection, Predictive Maintenance, Safety Enhancement, Surveillance Technologies, Transmission Line Inspection.

Introduction

In the power and utility sector, uninterrupted service and operational safety are paramount, making effective asset health monitoring and early fault detection essential. This paper introduces a digital transformation strategy at Saudi Electricity Company (SEC) that leverages AI, robotics, and Knowledge Mining to enhance infrastructure reliability. Traditional inspection methods often fail to detect early-stage issues, but SEC's use of CCTV, robotic surveillance, UAVs, and AI-driven computer vision for monitoring fuel tanks and transmission lines is setting new standards for proactive maintenance and safety [1].

Beyond operational reliability, these technologies significantly improve environmental monitoring and workforce safety. Real-time sensors and IoT facilitate emission and leak detection, advancing sustainability objectives while reducing manual inspections in hazardous areas and boosting workforce safety. By addressing industry-specific challenges, like inspection disruptions and regulatory compliance, these solutions reinforce SEC's commitment to operational excellence. This paper explores SEC's technical implementations, operational benefits, and a scalable model for other power and utility companies pursuing Industry 4.0/5.0 advancements.

Methodology

System Architecture

Fuel Tank Oil Leakage Detection : The Smart Video Surveillance System (SVSS) was tested as a pilot project at PP10, with distributed IP Dome and PTZ cameras strategically placed to cover critical points within the oil tank area. Each camera is connected to an AI inference server via the Video Management System (VMS). The AI algorithms analyze video feeds in real time, detecting oil leaks and flagging them for operators. An AI training platform enables iterative improvement of the algorithms based on sample data from previous leak incidents.

Transmission Lines Inspection: The UAV- based inspection system is in the proof-of-concept phase and includes drones equipped with visual, thermal, and specialized sensors, deployed strategically along transmission lines and key structural points. Each drone captures high-resolution images and transmits them to an AI processing server for real-time analysis. Advanced AI algorithms identify structural and environmental defects, flagging issues for maintenance teams and enabling continuous refinement of detection accuracy through an AI training platform that leverages sample data from previous inspections [2].

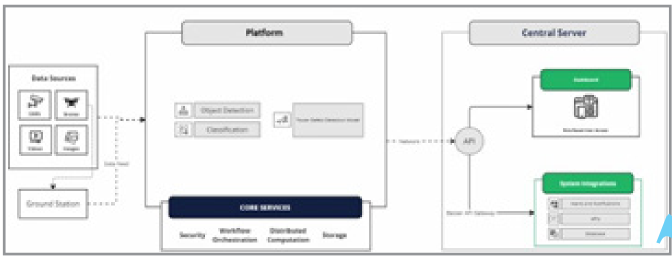

Figure 1: Solution Architecture of Electric Power Model

AI Algorithm and Deployment

Fuel Tank Oil Leakage Detection: The core of the SVSS is an optimized AI model designed to detect irregularities, such as oil leaks, in video feeds. The detection algorithm was trained on simulated leak data (using water to mimic oil) and tested in controlled and uncontrolled environments within the facility. The model is capable of identifying leaks of different shapes and sizes, marking them within the video feed. The real-time results are displayed on a unified management platform for quick response [3].

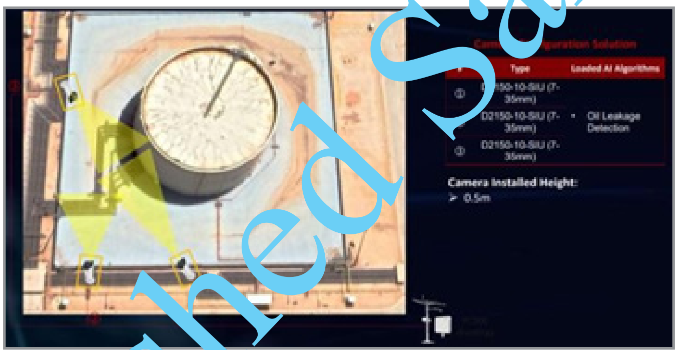

Figure 2: PP10 Camera Deployment in Oil Tank Area

Transmission Lines Inspection: The UAV inspection system leverages an advanced AI model designed to spot issues in transmission line components like insulators, grounding devices, and structural fittings. The AI has been trained with extensive data to recognize defects such as rust, misalignment, and missing bolts, ensuring accuracy across different environments. It detects anomalies in real-time and highlights them within the inspection imagery. These insights are then presented on a centralized management platform to support quick and efficient maintenance decisions.

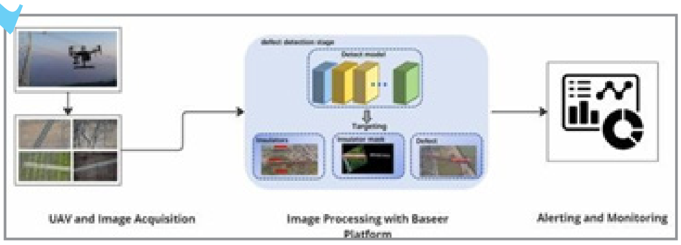

Figure 3: Process for Transmission Lines Inspection

Results and Discussion

Fuel Tank Oil Leakage Detection: The pilot implementation at SEC PP10's oil tank area demonstrated promising results in detecting various oil leak scenarios. The system successfully marked detected leaks with red bounding boxes, alerting operators through the VMS interface. Testing results indicated that the AI model maintained robust accuracy across different lighting conditions and leak sizes. Additionally, the unified platform enables centralized monitoring, enhancing situational awareness for facility operators and reducing response times.

Figure 4: Oil Leakage Detection Testing Result

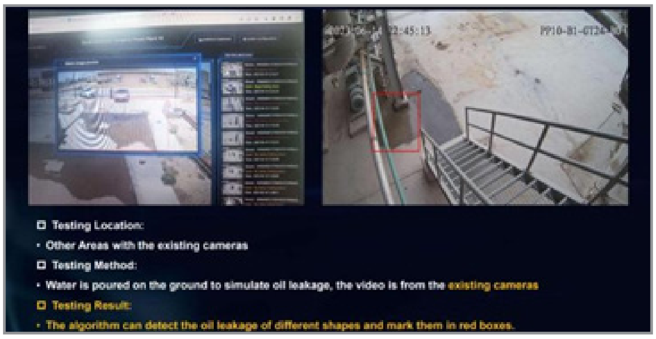

Figure 5: Oil Leakage Detection Testing Result

Transmission Lines Inspection: The proof-of- concept testing of the UAV-based AI inspection solution indicated potential effectiveness in identifying various structural and environmental issues across transmission lines.. The system accurately flagged detected anomalies, such as rust and misalignment, displaying these findings on the management interface for operator review. Testing showed that the AI model maintained high accuracy in diverse weather and lighting conditions, ensuring reliable, on-demand assessments of asset health. Additionally, the centralized platform supports enhanced monitoring, improving situational awareness for maintenance teams and will reduce both response times and operational downtime [3].

Figure 7: Defective Detection (1/2)

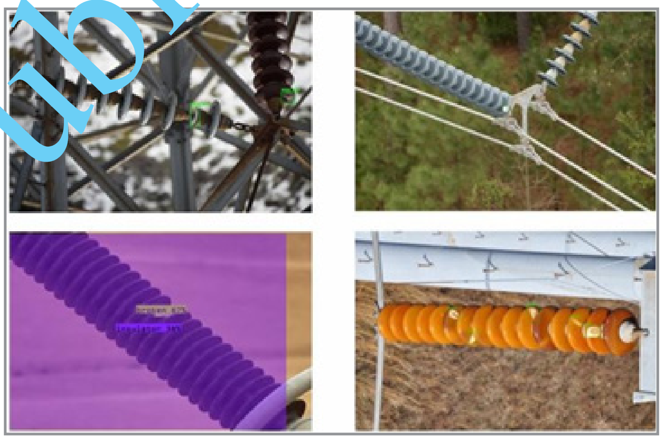

Figure 8: Defective Detection (2/2)

Environmental and Safety Impact

These autonomous inspection systems significantly enhance safety by reducing the need for personnel to inspect hazardous or hard-to-reach areas [4]. Additionally, real-time monitoring reduces the likelihood of environmental incidents, as issues such as leaks can be detected and resolved promptly.

Future Enhancements

Future enhancements to the SVSS and UAV-based Transmission Lines Inspection aim to leverage advanced robotics and autonomous technologies to improve monitoring and inspection capabilities in both power plants and transmission infrastructure. These enhancements are designed to minimize human intervention, enhance data accuracy, and optimize detection and maintenance of critical assets such as fuel oil tanks and transmission lines. Key areas include:

Autonomous Inspection Technologies: Unmanned Ground Vehicles (UGVs) and Drones: Deploy UGVs, drones, and other robotics to conduct inspections in hard-to-reach or hazardous areas, significantly reducing personnel risk. Equipped with AI-based video analytics, these robots can autonomously navigate, inspect, and collect data on both tank and transmission line conditions, identifying issues like leaks, corrosion, structural integrity, and line anomalies [4].

Simultaneous Localization and Mapping (SLAM): SLAM technology will enable robots to create detailed 3D maps of tank and tower environments, supporting precise inspection planning and real-time localization within the power plant and across transmission line corridors.

Advanced Data Collection and Analysis

Non-Destructive Testing (NDT) Sensors: Integrate NDT techniques, such as ultrasonic probes and acoustic emission sensors, to gather real-time data on corrosion, metal thickness, and structural integrity for both tanks and transmission line components. These sensors will offer early warnings on degradation and potential failure points.

Corrosion, Leak, and Structural Defect Detection: Utilize AI-driven image recognition and analytics to monitor indicators of corrosion, leaks, and structural defects in both power plant equipment and transmission line structures. This data will be linked to predictive maintenance systems, automating early intervention strategies to prevent costly downtime and ensure continuous asset health.

Enhanced Data Automation and Integration: Process Automation and Instrumentation

Platforms: Seamless integration with operational technology (OT) platforms will facilitate real-time data capture and transmission from both SVSS and UAV inspection activities, enhancing each system's role within broader industrial automation frameworks.

These improvements reflect Industry 5.0's vision of intelligent, human-centered, and sustainable industrial operations, combining advanced technology with a focus on safety, efficiency, and human collaboration. By integrating autonomous inspection and advanced analytics, these systems support a resilient energy sector that can proactively manage and maintain vital infrastructure [5].

Conclusion

The AI-driven surveillance and UAV inspection solutions have shown promising potential in enhancing SEC's predictive maintenance and asset health monitoring strategies during pilot and proof-of- concept phases. The integration of AI, robotics, and Knowledge Mining in asset management demonstrates a scalable and efficient approach that aligns with Industry 4.0/5.0 advancements. Initial results indicate notable improvements in reliability, safety, and operational efficiency, highlighting the possibilities for broader application in the power and utility sector.

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