Real-Time Drone Inspection for Irrigation Pipeline Leaks

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ABSTRACT

Water loss from irrigation pipeline leaks is a major challenge in agricultural regions such as Al-Ahsa. This project presents a MATLAB-based simulation for real-time leak detection using UAV thermal imaging. The system performs pipeline mapping, thermal simulation, anomaly detection, and autonomous return-to-base logic. Results demonstrate high detection accuracy and strong coverage performance.

INTRODUCTION

Efficient water management is a critical challenge in arid agricultural regions such as Al-Ahsa, where irrigation systems play a central role in sustaining crop production. Underground and surface irrigation pipelines are prone to leaks caused by aging infrastructure, soil movement, pressure fluctuations, and environmental conditions. These leaks often remain undetected for long periods, leading to significant water loss, reduced irrigation efficiency, increased operational costs, and potential crop damage.

Traditional inspection methods rely on manual field surveys, which are time-consuming, labor-intensive, and limited in their ability to detect early-stage or subsurface leaks. With the growing demand for smart agriculture solutions, unmanned aerial vehicles (UAVs) equipped with thermal sensors have emerged as a promising alternative. Thermal imaging enables the detection of temperature anomalies on the ground surface that correlate with hidden water leaks.

This project aims to develop a simulation-based framework that models a real-time UAV inspection system for detecting irrigation pipeline leaks. The system integrates pipeline mapping, thermal environment simulation, autonomous UAV navigation, anomaly detection, and return-to-base logic. The goal is to validate the feasibility and performance of thermal-based leak detection before transitioning to real-world deployment.

METHODS AND MATERIALS

1. Pipeline Mapping
- A sinusoidal pipeline model is generated to simulate realistic irrigation layouts.
- Figure1: Pipeline Buffer Map

2. Thermal Environment Simulation
- A thermal map is generated with baseline temperature, noise, and artificial leak hotspots.
- Figure2: Thermal Map with UAV Path

3. UAV Path Planning
- A grid-based waypoint strategy ensures systematic coverage of the inspection area.
- Figure3: Coverage Map

4. Leak Detection Logic
- A statistical threshold (mean + k·std) is used to detect temperature anomalies in real time.
- Figure4: Visualization Legend

RESULTS

- The system achieved **high leak detection accuracy**, with detected leak points closely matching the true leak locations.
- The UAV achieved **96.2% coverage**, demonstrating the effectiveness of the grid-based waypoint strategy.
- **Alert delay remained low**, indicating that the anomaly detection algorithm can operate in near real-time.
- The UAV successfully completed the mission with an **autonomous return-to-base path**, confirming the reliability of the navigation logic.

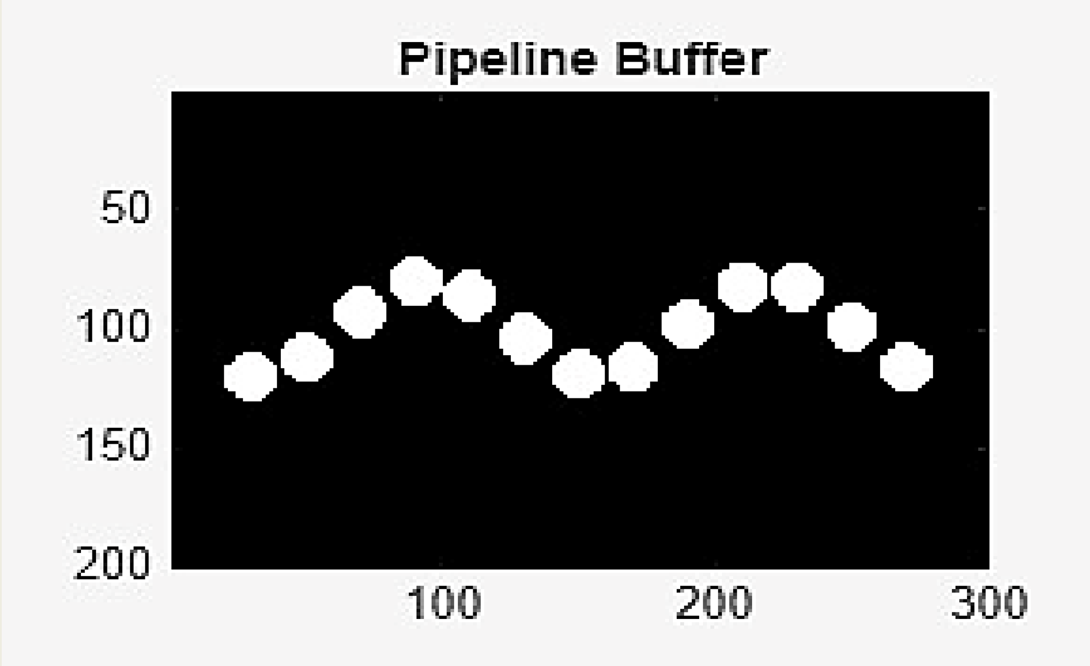


Figure1: Pipeline Buffer Map

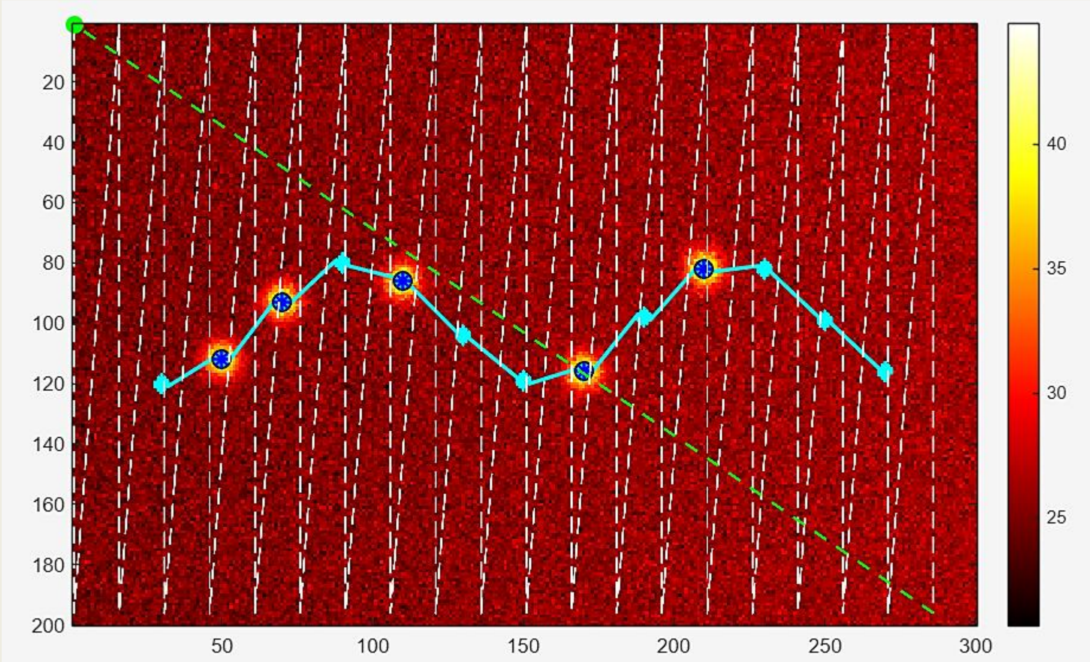


Figure2: Thermal Map with UAV Path

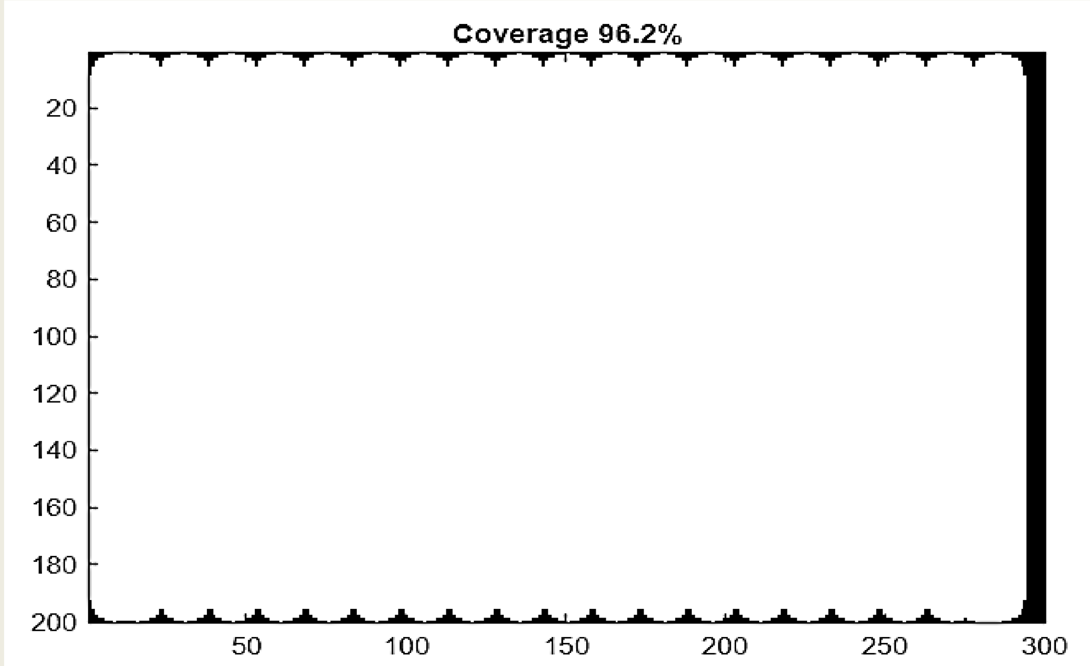
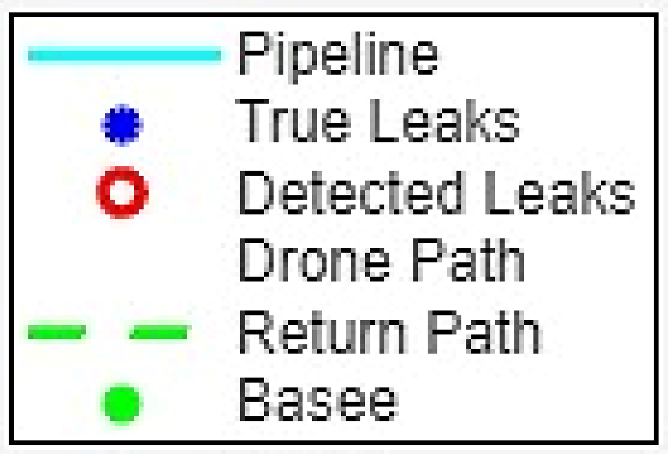


Figure3: Coverage Map

Figure4: Visualization Legend



DISCUSSION

The simulation results demonstrate that the proposed UAV-based thermal inspection system is capable of detecting irrigation pipeline leaks with high reliability. The strong alignment between true leak locations and detected anomalies indicates that the threshold-based detection method is effective even under noisy thermal conditions. The high coverage percentage confirms that the grid-based waypoint strategy ensures systematic scanning of the entire field, minimizing the chance of missing leaks.

The low alert delay shows that the system can operate in near real-time, which is essential for practical deployment in agricultural environments where rapid response is required. The successful autonomous return-to-base behavior highlights the robustness of the navigation logic and its suitability for real-world UAV missions. Overall, the results validate the feasibility of using thermal imaging and UAV automation as a practical solution for improving water management in large-scale irrigation systems.

CONCLUSIONS

The simulation results demonstrate that thermal imaging is a reliable method for detecting irrigation pipeline leaks in agricultural environments. The grid-based UAV scanning strategy provided high coverage and consistent detection performance. The threshold-based anomaly detection method proved simple yet effective for real-time leak identification. Additionally, the autonomous return-to-base logic improved mission safety and operational efficiency. Overall, the system shows strong potential for real-world deployment in smart agriculture applications.

Future Work

- Integrating the system with the Simulink UAV Toolbox to simulate more realistic flight behavior.
- Enhancing the path-planning algorithm to improve coverage efficiency and reduce mission time.
- Applying machine learning techniques to classify leak severity and reduce false detections.
- Conducting field experiments in Al-Ahsa farms to validate the simulation results and refine system performance.

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