Digital Twin-Based Condition Assessment and Predictive Maintenance of Oil and Gas Pipelines Using Smart PIG Inspection Videos

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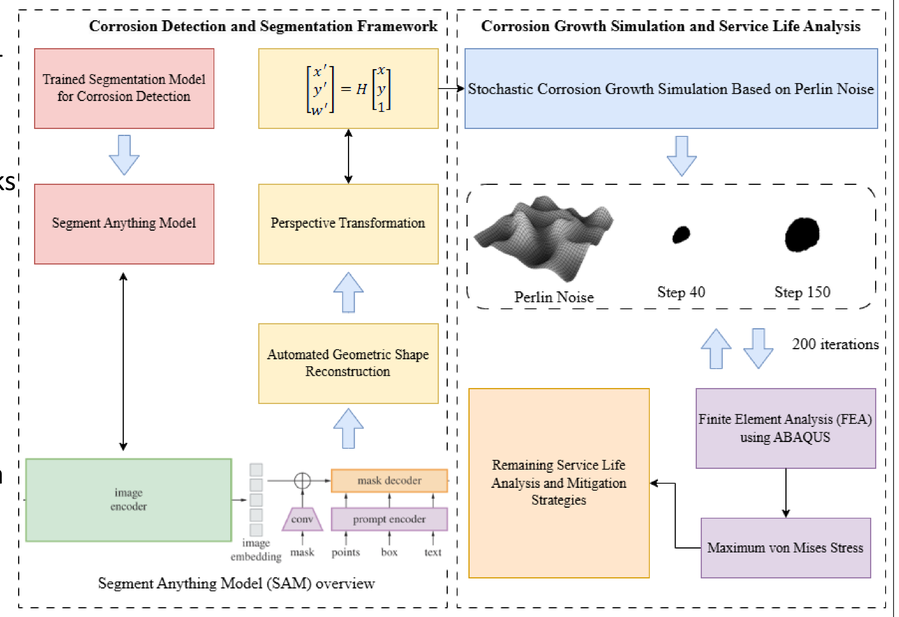
Objectives

- Developing a digital twin framework for oil and gas pipelines, integrating interconnected key modules for condition assessment and predictive maintenance of pipelines
- Improving the quality of in-pipe videos using generative artificial intelligence (AI) techniques
- Detecting, locating, quantifying, and visualizing pipeline anomalies from PIG inspection videos using deep learning models
- Predicting the time-dependent development of pipeline anomalies over time
- Analyzing the degradation of the mechanical performance of the pipeline with anomalies
- Optimizing the operation and management (O&M) management of pipelines

Methodology

- **Generative AI techniques for enhancing video quality**
  - ➢ Videos of interior surfaces have low quality (e.g., blurry, low brightness, over-exposure)
- **Deep learning-based anomaly detection**
  - ➢ Train deep learning models for semantic segmentation tasks, automating tasks of processing and analyzing inspection videos for detecting anomalies (e.g., corrosion, crack, and dent)
- **Computer vision techniques for geometric restoration of anomalies**
  - ➢ Apply homograph transformation to correct non-planar corrosion distortions and restore structured geometries
- **Digital twin for condition assessment and predictions**
  - ➢ Develop a BIM-based digital twin in Revit, integrating anomaly detection data
  - ➢ Construct a finite element model in ABAQUS for mechanical analysis
  - ➢ Assess pipeline condition in terms of safety and remaining life
- **Operation and maintenance management**
  - ➢ Optimize O&M management strategies for minimization of O&M costs

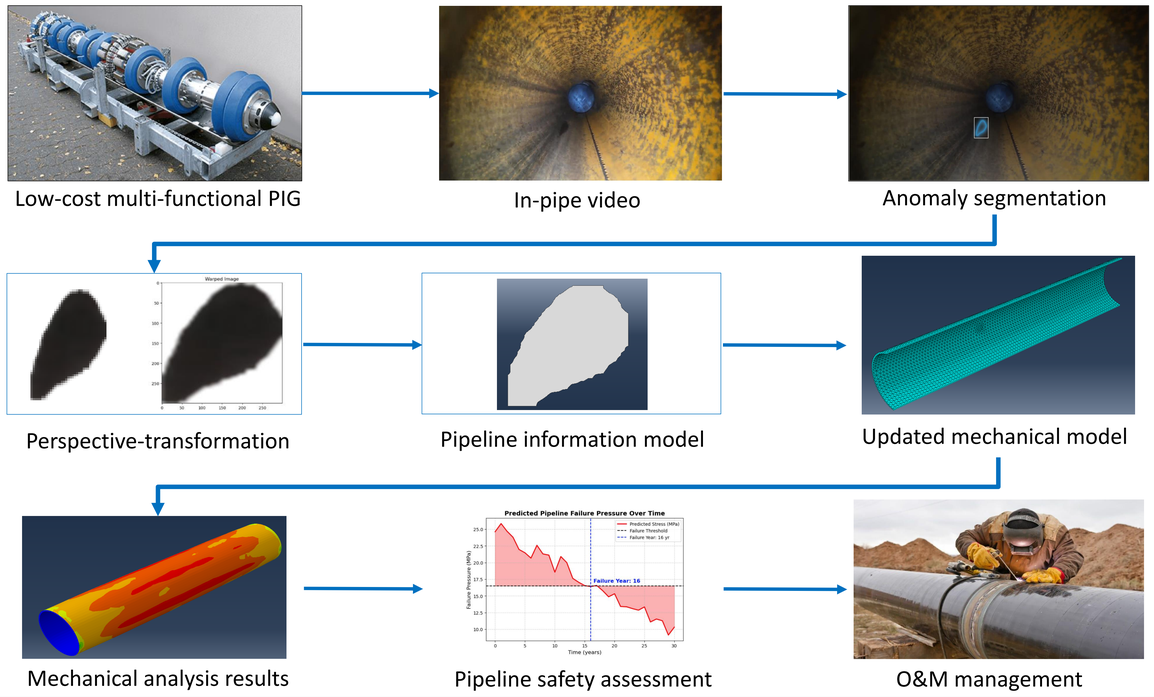


Corrosion Detection and Service Life Analysis Workflow

Potential Impacts

- Improving the safety of oil and gas pipelines by detecting anomalies such as leaks at an early stage
- Improving the O&M management efficiency by predictive conditions from machine learning models
- Reducing pipeline inspection costs by low-cost PIGs (low-cost sensors, continuous operation of pipelines)
- Reducing O&M costs by identifying anomalies before severe development
- Enhancing the durability of pipelines by enabling the optimization of O&M management
- Enhancing the reliability and resilience of critical pipelines by enabling risk-based management

Results & Discussion



Conclusions

- The proposed digital twin framework is effective in assessing and predicting the condition of oil and gas pipeline
- The deep learning model can detect and locate multiple anomalies, and the computer vision technique can quantify and visualize anomalies
- The digital twin model incorporating pipeline information model and finite element model can evaluate the mechanical performance of the pipeline with anomalies
- The optimization of O&M management largely improves safety and reduces costs

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