Autonomous Inspection Strategy for Insulator Strings Using a Drone

Munsu Jeon[1], Junhyeok Moon[1], Junsoo Kim[1], and Ki-Yong Oh[1,2,*]

[1]*Department of Mechanical Convergence Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul, 04763, Republic of Korea*

munsu3744@hanyang.ac.kr
moonjh1401@hanyang.ac.kr
tig05207@hanyang.ac.kr

[2]*School of Mechanical Engineering, Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul, 04763, Republic of Korea*

**Corresponding author: kiyongoh@hanyang.ac.kr*

ABSTRACT

This study proposes a novel autonomous inspection strategy for insulator strings using a drone. The proposed method not only optimizes the viewpoint of an optical camera for acquiring high-quality images of insulator strings but also detect anomalies of insulator strings from the acquired images. The proposed method features three key characteristics. First, an adaptive flight strategy is proposed based on the spatial configuration of transmission facilities. Specifically, the type of transmission tower is classified as either suspension or strain by analyzing the orientation of the insulator strings detected from optical images. Key structural features of transmission facilities are then extracted from point cloud data by addressing effective signal processing methods including random sample consensus, Euclidean distance clustering, and probabilistic downsampling. This feature enables the drone dynamically adjust the heading, altitude, and camera tilt to acquire optimal images of insulator strings. Second, a novel architecture of a deep neural network is proposed to detect defects in insulator strings based on the acquired images of insulator strings. Specifically, the architecture of the proposed network combines a multi-scale variational autoencoder and a lightweight classifier for anomaly detection. The variational autoencoder reconstructs normal insulator images at multiple scales to acquire hierarchical features, and the classifier distinguishes between normal and defective patterns by utilizing the extracted multi-scale features. Third, synthetic images of insulator strings are generated to mitigate a concern on the data imbalance between normal and abnormal images of insulator strings. Specifically, 3D models of insulator strings are constructed by using computer-aided design tools, and fault patterns are embedded to generate abnormal samples. 2D synthetic images are then rendered under varying viewpoints, lighting conditions, and backgrounds. Additionally, a generative adversarial network is addressed to produce realistic defect images to enhance the diversity of abnormal samples. These synthetic images contribute to improving the robustness of the proposed anomaly detection network. Systematic analyses conducted in both virtual and real-world environments show the effectiveness of the proposed method. The adaptive flight mission was successfully completed to acquire high-quality images of insulator strings without visual overlap between adjacent insulator strings. The proposed network achieves classification accuracy of 95.0% in distinguishing between normal and abnormal insulator strings for anomaly detection. The proposed strategy not only improves the performance of autonomous inspection but also enhances operational safety by reducing reliance on manual inspection in hazardous environments.

ACKNOWLEDGEMENT

This study was supported by the "Development of Drone System for Diagnosis of Porcelain Insulators in Overhead Transmission Lines (R22TA14)" project supported by 2022 Main R&D Projects performed by Korea Electric Power Corporation and "Developing digital safety measurement to enhance the availability of smart structural monitoring of facilities" funded by Korea Research Institute of Standards and Science (KRISS – 2025 – GP2025-0009).