Auto-UIT: Automating UAV Inspection Trajectory by Recognizing Pylon Structure from 3D Point Cloud

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Abstract

UAV-assisted inspection is critical for modern power grid maintenance, enhancing efficiency and safety in remote areas. However, automatically designing UAV inspection trajectories is challenging due to the cluttered inspection environments, small inspection targets, and pervasive obstacles. We propose *Auto-UT*, a novel method for generating inspection trajectories in noisy, sparse, and complex 3D point cloud. *Auto-UT* has three core techniques: (1) *A local structure–enhanced pylon segmentation*, which accurately segments pylons, power lines, and surroundings in noisy point cloud for effective inspection target identification and trajectory planning. (2) *A 3D fingerprint–based pylon type recognition* that compensates for point cloud sparsity to complete missing inspection targets based on the pylon type. (3) *An adaptive trajectory generation* that samples positions in response to diverse pylon orientations and pervasive environmental obstacles, ensuring UAV operational safety. A four-month deployment in a power grid inspection system—covering a 270 km^2 primary mountainous area—yielded an expert first-review acceptance rate of 91.86% for the generated trajectories, and reduced design time by an average of 88.19% compared to manual methods, significantly improving inspection efficiency.

1 Introduction

With the advancement of Unmanned Aerial Vehicle (UAV) technology, UAV-assisted power grid inspection has been increasingly adopted to enhance the automation of power grid maintenance. During inspections, UAVs fly around transmission pylons to capture images of *inspection targets*, such as pylon heads, insulators, cross-arms, and conductors, ensuring early detection of structural defects and potential hazards [1, 2]. Due to their ability to cover remote areas and mitigate safety risks associated with manual inspections, UAV-assisted power grid inspections are gradually replacing human inspections and are widely used in the power grid industry [3–8].

The most critical step in UAV-assisted power grid inspection is the planning of the inspection trajectory to ensure that the UAV can successfully capture all inspection targets while maintaining a safe distance from surrounding objects.

Therefore, automating the trajectory design process has become a crucial requirement for UAV-assisted inspections. An ideal trajectory design process is illustrated in Figure 1.

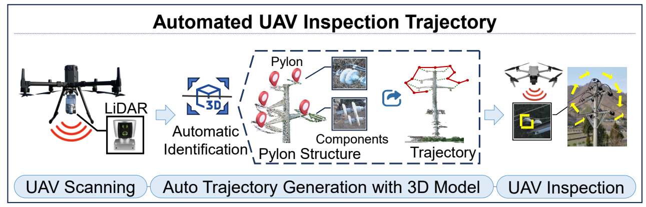


Figure 1: Automated design of UAV trajectories for power grid inspection.

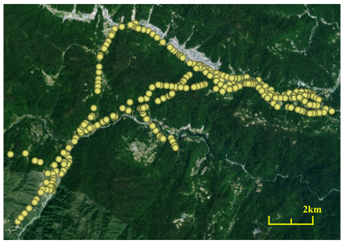
First, similar to existing methods, a large UAV scans the inspection area to generate a 3D model, which provides rich spatial and geometric information to facilitate the design of inspection trajectories. Then, unlike the current manual annotation approach, the ideal solution automatically identifies pylon structures and inspection targets and generates the UAV flight trajectory accordingly.

However, achieving an automated inspection trajectory design is highly challenging. This is due to the complex environment of power transmission networks in remote mountainous areas, where dense vegetation around pylons makes it difficult to distinguish structures, target equipment on pylons is small, and numerous obstacles (e.g., overlapping inspection lines) are present.

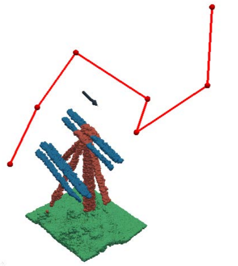
In this demo, we propose *Auto-UIT*, an automated system for UAV power grid inspection trajectory generation based on noisy, sparse, and complex 3D point cloud data. It incorporates three key technologies: local structure–enhanced pylon segmentation (*PySeg*), 3D fingerprint–based pylon type recognition (*PyRec*), and adaptive trajectory generation (*TrajGen*). *PySeg* leverages local geometric and distribution features of the point cloud to enhance edge information for precise segmentation of pylons, power lines, and surroundings. *PyRec* constructs 3D fingerprint features for different pylon types to recognize incomplete pylons in the point cloud and infer missing inspection targets. *TrajGen* first calibrates the positions of inspection targets based on the actual installation of pylons and then performs coarse-to-fine obstacle avoidance to generate trajectories.

2 System Overview

Auto-UIT is an automated trajectory generation system for UAV-based power pylon inspection. It processes a 3D point cloud of an inspection area ,typically complex mountainous terrain with dense vegetation, and outputs optimized flight trajectories targeting critical pylon components (see

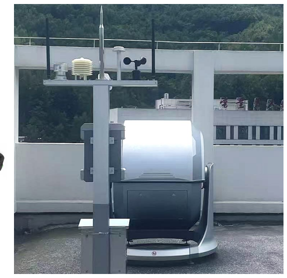


(a) Covered area

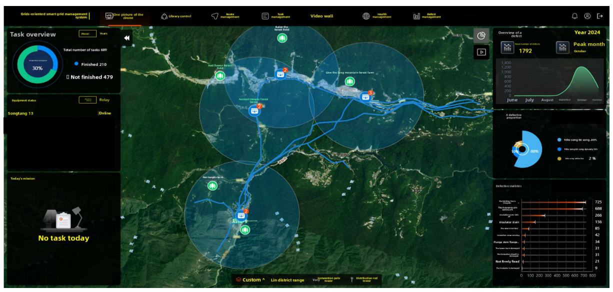


(b) Automated trajectory

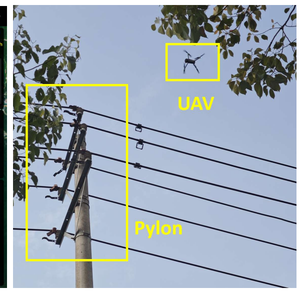
(c) UAV



(d) UAV nest



(e) Remote control platform



(f) Inspection execution

Figure 2: UAV inspection system.

Figures 2(b)). The system comprises three integrated modules:

- PySeg: Segments raw 3D point clouds around pylons into distinct structures (pylon, power lines, surroundings). The pylon segmentation enables precise localization of inspection targets, while other segments define obstacle constraints.
- PyRec: Identifies the pylon type from its segmented point cloud. To address inherent point cloud sparsity (which often omits small equipment), this module supplements missing inspection targets using type-specific models.
- TrajGen: Generates collision-free inspection trajectories using the segmented pylon point cloud , pylon type, and obstacle data. Its coarse-to-fine strategy dynamically refines waypoints to ensure safety and coverage.

Auto-UIT is embedded within an automated UAV inspection platform. It processes point clouds, stores trajectories in a backend database, and preloads them to UAVs housed in automated nests for charging/data transfer.

3 Demonstration

We demonstrate *Auto-UIT* deployed within a practical, automated UAV-based power inspection system operating in challenging environments-270 km^2 primary mountainous area (refer to Figure 2(a) for the operational environment). Each trajectory corresponds to a pylon, targets different components, and maintain a safe distance from the surrounding environment and obstacles. This section details the hardware setup, system integration, and overall workflow:

Inspection UAVs (Figure 2 (c)): Carry out the flight missions. They are equipped with cameras and navigation systems. They are stored in and launched from the UAV Nests.

Automated UAV Nests (Figure 2 (d)): House, charge, and protect the UAVs when not in operation (Figure 2 (d)). These nests facilitate data transmission between the UAVs and the Remote Control Platform. Before a mission, the precomputed inspection trajectory for the target pylon(s) is preloaded from the platform into the UAV's onboard computer via the nest connection.

Remote Control Platform (Figure 2 (e)): Hosts the *Auto-UIT* software. This platform receives raw or pre-processed point cloud data, runs the *Auto-UIT* modules (PySeg, PyRec, TrajGen) to generate optimized inspection trajectories, and manages the overall mission. Generated trajectories are stored in the platform's backend database.

UAV Network: Provides real-time communication during flight. This network connects the UAVs in the field back to the Remote Control Platform.

Defect Detection Module: Resides on the Remote Control Platform. It receives and analyzes the imagery captured by the UAVs.

During inspections, UAVs follow the predefined trajectories, capturing high-resolution images of critical components at each inspection point as shown in Figure 1 (f).

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