CHAPTER 47

An Automated GIS and Image-based Inspection System for Pre commissioning Assessment of High-tension Transmission Tower

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ABSTRACT

Transmission towers are an essential component in the power transmission setup, which needs comprehensive inspection before being used. Traditional inspection processes tend to be physically intensive, time-consuming, and pose serious risk to the lives of personnel conducting the inspection, especially in terrains that are difficult to traverse. This paper aims to provide an automated inspection system for pre commissioning tasks involving high tension transmission towers, combining the usage of GIS and image analysis techniques. High resolution images captured through Unmanned Aerial Vehicles and satellite imagery would be used for analyzing and identifying transmission towers and their structural integrity through missing object detection techniques. All inspection results are georeferenced and managed within the GIS environment for exact spatial visualization, efficient data management, and systematic analysis. The study introduces innovative system that reduces the time of inspection in contrast with conventional approaches while improving the accuracy and consistency of observation. The framework improves safety operation by minimizing direct human involvement in hazardous inspection activities and provides a sound, data-driven basis for inspection documentation, quality verification, and maintenance planning before the handover of the project.

Keywords: Automated tower inspection, Pre-commissioning evaluation, GIS-based assessment.

1.0 Introduction

High tension transmission towers are a very important part of power transmission network which is responsible for transferring electricity over long distances. With a very rapid expansion in power infrastructure factors such as increasing energy demand, number, height and structural complexity of the transmission towers have increased significantly.

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Ensuring the structural integrity, proper assembly and assembly of these towers before commissioning is therefore critical. Factors such as operational safety, system reliability, and life span of the towers may not be as promised. Even minor construction defects such as missing members, improper bolt connections or misalignments can lead to very serious operational failures, increased maintenance costs and safety hazards after commissioning.

Pre commissioning inspection is a very major step in the transmission projects to ensure proper quality assurance. Traditionally this process relies mainly on manual inspection which is carried out by trained personnel who must climb the full length of the towers to carry out the inspection process which involves measurement checks and other major checks. These inspections are effective to some extent, but they are very much time consuming, labour intensive, and are subjected to human errors. Other than this the inspectors are exposed to high level of safety risks due to working at heights, harsh weather conditions. These disadvantages make the conventional method of inspection inefficient and very unsuitable for large-scale transmission projects.

Recent usage of unmanned ariel vehicle (UAV) technology and remote sensing have opened new possibilities for safer and faster inspection. These unmanned ariel vehicles are equipped with high resolution cameras which capture detailed visual photographs of the tower components from multiple angles. This feature of UAVs allows inspection of inaccessible and hazardous areas while reducing the inspection time and safety hazards. This has also gained attention as an alternative to manual climbing, especially for large transmission towers. Many UAVs still depend on manual inspection of captured images which limit their effectiveness.

Developments in computer vision and image processing have enabled automated detection, classification and assessment of structural elements by digital images. Some techniques such as auto detection, feature extraction and anomaly identification can be used to identify errors. This can have an improved consistency over human visual judgement. When the UAVs are used in the acquired image, the raw data can be transformed into actionable inspection data. The absence in combination between automated image analysis and structured spatial management systems narrows the practical usability of these methods in large infrastructure projects.

Geographical information system (GIS) provides a platform for managing, visualizing and analyzing spatial referenced data. GIS enables precise mapping of locations of the tower, storage of inspection attributes and visualization of defects along transmission corridors. When this information is combined with the UAV images and automated image analysis output, GIS will be serving as a centralized inspection system that supports systematic documentation, verification of quality and helps in decision making. Most

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existing studies focus mainly on post commissioning maintenance monitoring but ignore construction stage quality assessment.

This study proposes an integrated UAV and GIS based automated inspection framework for pre commissioning assessment of high-tension transmission towers. This study combines high resolution UAV imaging and GIS based spatial data to improve inspection accuracy, enhance safety and reduce inspection time. This ensures data driven quality assurance in power transmission construction projects

2.0 Literature Review

Inspection of high-tension transmission tower is a critical activity for ensuring the safety, reliability longevity of power transmission infrastructure. Conventional inspection methods rely hyper on manual visual assessment, tower climbing and helicopter aided surveys add time consuming costly and associated with significant safety risk. These limitations have driven extensive research into automated inspection techniques based on unmanned aerial vehicles (UAVs), computer vision deep learning geographic information system (GIS).

2.1 UAV-based inspection of transmission towers and power line

Current studies clearly illustrate a change in interest from traditional manual inspection towards inspection assisted by UAV technology for power transmission inspection. The experimental study verifies that safe access of UAV platform to tower structure and power transmission corridors which could be difficult and dangerous for manual inspection. Visual based system using images taken by UAVs have been broadly used in locating transmission towers, power lines, as well as their structural components.

Computer vision-based approaches to tower identification have proven effective in separating lattice structure from their environment based on principle of features extraction and machine learning classification algorithms. Computer vision-assisted inspection system makes it possible to automate the identification of geometric shapes and structural elements of towers with minimal manual visual inspections.(Chen et al., 2024; Jiang & Jiang, 2019; Li et al., 2023)

2.2 Damage and defect detection in structural automatically using UAVs

Various works and detect the structural damage of transmission towers automatically by using UAV acquired images. Deep learning based methods specifically convolution neural networks, has been conducted in detecting damaged or missing components such as bolts, joins and steel members. These ways provide an enhanced level

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of detection accuracy and consistency over those obtained using conventional image processing techniques on images with both wearing illumination and backgrounds

They have been used in steel transmission towers for the detection of surface defects like corrosion and cracking among others. This method is based on enhancing images, finding boundaries and recognising patterns in images collected by high-resolution UAV camera to perform defect feature extraction. Such kinds of automated defect detection system are gaining attention due to their reliability and repeatability of inspection results in comparison with subjective results from manual inspections.(Chen et al., 2024; Santos et al., 2022)

2.3 GIS-based visualization and inspection data asset management

Applications of geographic information system is a common means of managing and visualising inspection data of power transmission infrastructures. For GIS-based inspection system enables a spatial organisation of transmission assets, integration of inspection results, and visualisation of structural conditions at the network scale. Further enhancements in inspection analysis are possible using three-dimensional GIS environment to enable spatial visualisation of towers, corridors and defect locations.

This system-based access management framework locates the effectiveness of combining inspection attributes with spatial database to enable planning and maintenance activity and also monitoring infrastructures. The case studies on power utilities reveal that the traceability documentation and long-term asset management have been involved advanced by GIS platforms as the inspection records and spatial analytics are given under one platform. Such system provides an important building block to combine the result stemming from automated inspection into operational workflows.(Jiang & Jiang, 2019; Li et al., 2023)

2.4 3D modelling and photogrammetric reconstructions of transmission towers

3D reconstruction techniques of UAV photogrammetry have been considered for the detailed structure condition assessment of transmission towers. Photogrammetric modelling can accurately reconstruct the geometry of any tower, as there are no limitations to the evaluation of alignment deformation and completeness integrity of all the constituent parts without physical contact. Ground reality documentation and visualisation where possible using UAV based 3D reconstruction methods. It has produced high quality models suitable for offsite inspection and engineering studies.

Oblique photogrammetry and multi-view imaging techniques further enhance the accuracy of construction by capturing tower components for multiple viewpoints these approaches provide comprehensive spatial information that supports accurate measurement

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and structural verification, which is particularly valuable during pre-commissioning assessment stages.(Jiang & Jiang, 2019)

2.5 Remote sensing and GIS for transmission corridor monitoring

Various remote sensing methods along with the use of GIS has been adopted on a last scale for monitoring transmission corridors. Satellite images and analysis done using GIS are helpful for identifying environment related risk and infrastructure conditions over large geographic areas. The reviews and the lined that while applications of GIS and remote sensing tools are fruitful for monitoring on large scale, they do not have the necessary spatial resolution required for the structural analysis of individual towers.

Satellite monitoring system works best when coupled with high resolution UAV images which help in creating multi-scale inspection system. GIS is essentially the platform which integrates satellite monitoring system, UAV images and inspection results together in a common spatial database for carrying out infrastructure monitoring.(Jiang & Jiang, 2019; Li et al., 2023)

2.6 UAV based visual inspection of transmission infrastructure

UAV based inspection has been more of a practical alternative to traditional inspection approaches due to its ability to capture high resolution imagery of transmission towers and power line corridors while minimising human exposure to hazardous environments. Studies on UAV based inspection consistently highlight advantages such as improved accessibility, reduced operational cost and enhanced inspection frequency. And automated power line inspection using UAV imagery has proved that aerial platforms are particularly effective for monitoring surprisingly distributed infrastructure over large geographic areas.(Zhang et al., 2017)

Early UV inspection research focused on detecting power lines and surrounding obstacles using photogrammetric and stereo vision techniques automated extraction of power line geometry and spatial position from UAV images has been shown to achieve accuracy comparable to manual stereo measurements enabling obstacles detection within transmission corridors. (Zhang et al., 2017) However, these approaches primarily address corridor monitoring and vegetation clearance rather than structural assessment of towers.

2.7 Automated damage and defect detection using UAV images

With advance access in computer vision and planning research has increasingly focused on automated detection of structural damage in transmission towers using UAV imagery. Deep learning-based methods have been applied to identify corrosion, missing paint, surface degradation on steel tower components. These studies emphasises that

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automation significantly reduces the effort needed for manual imagery inspection while improving consistency and repeatability of damaged assessment.

A key challenge identified in UAV based damage detection is the scarcity of labelled training data as damaged components are relatively rare and difficult to capture. Researchers have addressed this issue through data argumentation technique and Taylor neural network architectures to improve robustness under limited data conditions. Experimental evaluation demonstrate that deep neural networks can successfully localised and segment damage regions on tower surface even under wearing illumination and background complexity.(Barreiro et al., 2021)

In addition to surface damage automated inspection system have been developed to identify quality or missing components such as insulators, bolts and vibration dampers. Real time come onboard detection system using deep learning models have shown the feasibility of performing component and fault detection directly on UAV platforms enabling near real time inspection results and reducing post processing requirements.

2.8 Transmission tower recognition and image-based identification

Accurate identification of transmission towers within large UAV image data set is prerequisite for automated inspection workflows. Machine learning and deep learning techniques have been employed to rapidly recognise transmission towers from aerial imagery, even in complex backgrounds. Fast image recognition models based on Convolutional neural networks and big data frameworks have demonstrated significant improvement in processing efficiency enabling large scale inspection of transmission networks.(Hu et al., 2018)

This recognition systems are particularly important for reducing manual intervention in inspection pipelines. By automatically distinguishing towers from background features such system allows inspection algorithms to focus on relevant regions of interest, improving overall efficiency and scalability.

2.9 GS based visualisation and spatial management of inspection data

While UAV and vision-based techniques provide detailed inspection data, Effective management and interpretation of inspection results requires spatial integration. GIS-based system has been widely used to manage, visualise, and analyse transmission infrastructure data. GIS enables georeferencing of inspection findings spatial querying of tower attributes and visualisation of inspection outcomes at network scale.

GIS based approaches have been shown to improve inspection demonstration and asset management by providing a structured spatial database or transmission network. Spatial analysis techniques allow inspectors and Decision makers to identify locations

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specific issues and prioritise maintenance activities more effectively. Studies unified decision support environment. (Zipf et al., 2019)

However, many GIS applications focus on planning and routing of transmission lines rather than integrating automated inspection intelligence. This highlights the need for tighter integration between image-based inspection outputs and GIS based asset management system.

2.10 Integration of UV inspection and GR system

Recent reviews studies emphasises that the full potential of UAV based inspection can only be realised through integration with advanced data management and analysis platforms. Combining UAVs imagery b learning based inspection, and its GIS visualisation enables comprehensive monitoring for transmission infrastructure. Review literature highlights that you a v equipped with optical thermal and LIDAR sensors provide complementary information for structural assessment, but also notes Challenges related to data processing sensor integration and regulatory constraints.(İnce, 2024)

Despite technology advancement most existing studies focus on operational monitoring and maintenance rather than pre commissioning inspection period furthermore, inspection system is often developed as standalone solutions, either emphasising image analysis or spatial visualisation without end-to-end integration.

2.11 Limitations of existing approaches

While UAV imaging computer vision analysis, geographic information system analysis and 3D modelling have each contributed individually to the advancement of transmission infrastructure analysis, nearly all these previous works have been related to operation and maintenance analysis. Most of these are designed as standalone application that do not have linkage from analysis to management of geographic infection process.

Moreover, the new techniques for defect point detection and tower identification remain well developed in literature relatively few papers deal with verification of construction completeness and documentation of systematic inspection results prior to handover project. The attention given to integrating automated image analysis results for inspection in GIS-based quality assurance system clearly identifies a gap in the field of literature.(Chen et al., 2024; Jiang & Jiang, 2019; Li et al., 2023)

2.12 Research gap identification

Based on literature reviewed, it is evident that significant advancement has been achieved in the individual domains of UAV based image acquisition automated analysis GIS based spatial management for power transmission infrastructure inspection. UAV

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platforms equipped with high resolution censors have been widely adopted to reduce human exposure 2 hazardous inspection and environments computer inspections and deep learning techniques have demonstrated strong capabilities in detecting defects and Differences in transmission towers. Similarly, GIS based systems have been effectively used for spatial visualization asset inventory management and large-scale infrastructure monitoring despite these advancements existing inspection solutions largely operate in isolation focusing either on UAV based image analysis or GIS based spatial management Kumar rather than offering a unified framework that integrates automated structural assessment With spatial you driven inspection management. Most studies emphasis operational maintenance task such as damage detection, vegetation monitoring or transmission corridor safety with limited attention to specific requirement of pre commissioning stage.

Pre commissioning inspection demands a distinct inspection objective the primary focus is on verifying construction completeness structural conformity and the correct installation of critical tower components prior to energisation or project handover. Existing UAV based inspection frameworks rarely address these requirements, as they are predominantly designed for fault detection in commissioned systems. As a result, systematic verification of missing or improperly elected members, which is crucial for pre commissioning quality assurance, remains insufficiently addressed in current research.

Furthermore, while automated image-based inspection techniques generate valuable analytical outputs these results are often stored as stand-alone image level findings or textual reports. The lack of direct integration of automated inspection outputs into GIS environments restricts Patel dress ability, tower wise inspection tracking, and comprehensive documents. GIS platforms, in turn, or commonly used as passive repositories rather than active systems that incorporate automated inspection intelligence.

Therefore, a clear research gap exists in development of an integrated inspection framework that combines UAV based automated image analysis with GIS based spatial visualisation and data management specifically tailored for pre commissioning inspection of high-tension transmission towers. Addressing this gap is essential to enhance the efficiency, accuracy and reliability of inspection process prior to commissioning, and forms the central motivation of the present study.

3.0 Research Methodology

The proposed paper uses a combined image identification technique that uses UAVs and GIS based inspection method for pre commissioning inspection of high tensioned transmission towers. The high-resolution images are captured using Unmanned Aerial Vehicles (UAVs), which guarantee a very minimal risk of exposure to people in

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dangerous site conditions during inspection. The flight of UAVs is planned such that there is a very accurate coverage of important areas like cross arms, bracing and tower legs.

These captured images are then processed for the detection of any flaws in transmission tower and evaluation of the presence and completeness of the critical structure features with the help of computer vision algorithms. This approach focuses on the identification of missing or improperly erected members as well as structural purity, which are important in for pre-commissioning assessment.

All inspection results are geo referenced and all results are merged in Geographic Information System (GIS) environment. This helps to spatially organize the location of transmission towers, display inspection results, and organize inspection results. Finally, geo referenced inspection maps and detailed inspection records are produced.

4.0 Analysis of Data

Using UAV-acquired imagery and spatial data obtained during the pre-commissioning phase of high-tension transmission towers, the data analysis process, the efficacy of the suggested automated GIS and image-based inspection framework. Automated computer vision techniques are used to analyse image data obtained from UAV platforms in order to identify transmission towers and evaluate the presence, alignment and completeness of critical structures. In order to verify construction quality before commissioning, the analysis focus on finding missing members, incorrect installation, and obvious surface irregularities

The accuracy of spatial data, consistency of the geo-referenced process, and completeness of the records of the GIS analysis environment. Tower-to-tower comparison of the inspection, spatial distribution of problems found an organisational structuring of the inspection data can be achieved as a result of analysis by the GIS environment. Regarding the length of inspection, consistency of the observation, level of human interaction and quality of documentation, the qualitative assessment of the automated inspection outputs and the conventional manual inspection is accomplished. The assessment is aimed at determining the level at which the automated system can address the aforementioned challenges for their literature review.

5.0 Result

The results of analysis show that the proposed framework of UAV/GIS Integrated inspection in collaboration with a UAV/GIS system has a more efficient approach to pre commissioning inspection compared to traditional technique used in inspection by human

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observation. The image analysis based automated system allows for the systematic detection of transmission tower structures identification independent of the experience of a human inspection expert. The system also identifies any deficiency in installed equipment and detects in structure setup.

Integration of inspection results in GIS environment enhance the traceability and organisation of inspection results in GIS environment. Tower-specific inspection results are now visualised and retrieved effectively, and it helps in better identification of location-related issues in transmission corridor. Against conventional inspection process, the purposed method shows a significant reduction in the time required for inspection, consistency of results and safety, as it reduces the need to climb towers manually. The results are in line with the trend shown in the literature survey conducted.

6.0 Conclusion

This study demonstrates that the integration of UAV based images analysis with GIS spatial management provides a suitable and effective approach for the pre commissioning inspection of high-tension transmission towers. Based on existing literature that primarily focuses on UAV assisted inspection for operational maintenance and fault detection this work extends the application of computer added inspection system to pre commissioning stage, where construction completeness and structural conformity for critical importance.

The reviewed literature establishes the individual effectiveness of UAV platform for high resolution data acquisition and automated image-based assessment as well as the utility of GIS for spatial visualization and infrastructure data management. By combining these technologies into single inspection framework, the proposed approach addresses the limitations of fragmented inspection workflow identified in previous studies. The framework enables systematic verification of critical structural components, geo reference documentation of inspection outcomes and improved traceability go of inspection findings prior to commissioning.

The implications of this research extend to the broader energy transmission sectors, as improved pre commissioning inspection has the potential to enhance construction quality reduce commissioning delays and lower the likelihood of post commissioning maintenance interventions. By shifting the rule of automated inspection systems from predominantly maintenance-oriented applications to pre commissioning quality assurance, this study provides a foundation for more reliable efficient and data driven inspection practices in future energy transmission projects.

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7.0 Recommendations

Consequently, the findings such as that all power transmission utilities and infrastructure developers should adopt UAVs and GIS-based automated inspection system as part of standard pre-commissioning procedure. Future research could be directed to integrating advanced deep learning models further improvement of component-level detection accuracy, integrating thermal or LiDAR data to enable multi-sensor inspection and framework validation across diverse terrain and tower configurations. Additionally extending the system to support post-commissioning monitoring and predictive maintenance will further enhance its practical value and operational impact

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