Digital Twins of Transformer Substations: 3D Modeling with Oblique Photogrammetry, Asset Management and Web-based Visualization

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SUMMARY

The digital transformation of critical power infrastructure necessitates advanced asset management methodologies in transformer substations. This study provides a comprehensive research opportunity on the development and application of digital twin technology in transformer substations, using advanced camera systems integrated into unmanned aerial vehicle platforms and oblique photogrammetry techniques, in order to achieve high precision three-dimensional modeling capabilities. Empirical verification is carried out in the form of a comprehensive, up-to-date and live operational system implementation that involves the systematic digitalization of 800 active transformer centers within the infrastructure network of the Turkish Electricity Transmission Corporation. The methodology includes RTK-GNSS supported UAV data acquisition, the integration of detailed asset inventory information within Geographic Information Systems (GIS), and the development of a hybrid web-based visualization system, remotely accessible from desktop, tablet, and mobile platforms, which combines 3D mesh models with high-resolution oriented imagery.

The implementation produced 3D models with high geometric accuracy, meeting infrastructure asset management requirements. The developed web-based platform provided 24/7 real-time remote access to field personnel and management , demonstrating high success in equipment identification and positioning. The methodology was measured to provide significant operational efficiency gains and substantial cost reductions by optimizing field visits and planning processes through these remote access capabilities. The oriented imagery integration considerably accelerated equipment inspection processes. This study positions the created high-fidelity 3D models as the foundational 'static twin' infrastructure, providing the necessary spatial framework for future 'living' digital twins to be integrated with IoT sensor data. The findings demonstrate the transformative high-resolution potential of integrating advanced and site-specific photogrammetric techniques with digital twin

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frameworks to achieve comprehensive asset management capabilities in complex power transmission facilities.