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Review Article

# Remote sensing methods for power line corridor surveys

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ABSTRACT

To secure uninterrupted distribution of electricity, effective monitoring and maintenance of power lines are needed. This literature review article aims to give a wide overview of the possibilities provided by modern remote sensing sensors in power line corridor surveys and to discuss the potential and limitations of different approaches. Monitoring of both power line components and vegetation around them is included. Remotely sensed data sources discussed in the review include synthetic aperture radar (SAR) images, optical satellite and aerial images, thermal images, airborne laser scanner (ALS) data, land-based mobile mapping data, and unmanned aerial vehicle (UAV) data. The review shows that most previous studies have concentrated on the mapping and analysis of network components. In particular, automated extraction of power line conductors has achieved much attention, and promising results have been reported. For example, accuracy levels above 90% have been presented for the extraction of conductors from ALS data or aerial images. However, in many studies datasets have been small and numerical quality analyses have been omitted. Mapping of vegetation near power lines has been a less common research topic than mapping of the components, but several studies have also been carried out in this field, especially using optical aerial and satellite images. Based on the review we conclude that in future research more attention should be given to an integrated use of various data sources to benefit from the various techniques in an optimal way. Knowledge in related fields, such as vegetation monitoring from ALS, SAR and optical image data should be better exploited to develop useful monitoring approaches. Special attention should be given to rapidly developing remote sensing techniques such as UAVs and laser scanning from airborne and land-based platforms. To demonstrate and verify the capabilities of automated monitoring approaches, large tests in various environments and practical monitoring conditions are needed. These should include careful quality analyses and comparisons between different data sources, methods and individual algorithms.



## 1. Introduction

Electricity is vital for the activities of modern-day societies. To secure uninterrupted distribution of electricity, effective monitoring and maintenance of power lines are needed. The importance of the topic is increasing with the societies' increasing dependence on electricity, increasing occurrence of extreme weather conditions, such as storms, and tightening legislation and regulation in many countries (Pulkkinen, 2015).

Electrical networks typically include a nationwide transmission network, regional networks, and distribution networks. In forested countries, large parts of the networks are located inside forests. Monitoring of power lines basically includes two aspects: power line components and surrounding objects, especially vegetation. The condition of the components need regular checking to detect faults caused, for example, by corrosion and mechanical damage. Trees growing close to the power lines can damage the infrastructure and even cause large power failures or bush fires. Thus, there is also a need for regular inspections of vegetation inside and near the power line corridor to detect trees or tree branches that need to be cut. In addition, storms and other natural disasters can cause a great deal of damage to forests and power lines and a sudden need to detect the damage, often in difficult conditions. These general aspects of power line monitoring have been discussed, for example,

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by Aggarwal et al. (2000) and Katrašnik et al. (2010) related to power line components and Ituen and Sohn (2010), Mills et al. (2010) and Ahmad et al. (2013) related to vegetation. Fig. 1 shows the main components of power lines and terminology used in the present article. Power line conductors between two adjacent pylons (i.e., over a span) have the shape of a catenary curve (see, for example, McLaughlin, 2006).

Traditional methods used for monitoring of overhead power lines include field surveys and airborne surveys. The core methodology has remained unchanged for decades. The inspections are conducted by teams travelling on foot or from helicopters, depending on, for example, how costs, different types of problems (e.g., faulty components or encroaching vegetation) and the certainty of detecting them are prioritised. The ground-based method is labour-intensive, but it allows for longer evaluation times and thus a higher problem detection rate. The helicopter method has a more limited detection rate due to the high speeds used and the limited ability of the crew to simultaneously observe all possible problem types. Both methods, however, depend on human visual observations. In addition to visual inspections, video recordings and various cameras can nowadays be used. Airborne laser scanning (ALS; also called lidar) has also become an important data acquisition approach. The first studies on this topic were done in the 1990s (e.g., Reed et al., 1996; Axelsson, 1999). The use of digital data from cameras and laser scanners has made it possible to separate data collection from data analysis. This is particularly important since data collection operations can then focus on minimising costs, and the digital data allow exact measurements, repeated analyses and long-term storage for comparison of data over time. The analysis of the data has, however, remained a manual process, and despite improved problem detection rates, significant cost savings have not been achieved.

Vast areas need to be covered in power line surveys, and remote sensing techniques thus provide interesting alternatives. In the past, various different remote sensing methods have been proposed and applied for power line monitoring tasks in research literature (see, for example, Mu et al., 2009; Li et al., 2012b). Applied data sources range from coarse satellite images to detailed photographs of the power line components. EPRI (2008) presented scenarios and technologies for future inspection of overhead transmission lines. A wide range of sensing technologies was discussed. Mirallès et al. (2014) presented a review of computer vision approaches applied to the management of power transmission lines as a conference paper. They discussed methods used for detection and inspection of power lines and insulators, power line corridor maintenance, and pylon detection. The review was not focused on specific platforms.

The objective of our review is to present the state-of-the-art of remote sensing-based surveying of overhead power lines and their surroundings in research literature. Compared to previous reviews, our study is more extensive. We aim to give a wide overview of the possibilities provided by modern remote sensing sensors from the application point of view and to discuss the potential and limitations of different approaches. Therefore, we consider all platforms: satellites, fixed-wing aircraft, helicopters, unmanned aerial vehicles (UAVs), and ground vehicles. Related studies using, for example, climbing robots and cameras mounted on poles are also briefly reviewed. Applications of interest basically include all power line monitoring tasks that can be carried out by using remotely sensed data. This covers both power line components and vegetation around the components, and both regular monitoring and monitoring due to disasters. To complete the discussion, some recent studies are included that are not specifically related to power lines but show the potential of new datasets for forest monitoring, detection of individual trees or detection of pole-like objects. Considering the development of effective power line monitoring approaches, knowledge of this research is important.

The paper is organised according to the type of remote sensing sensors used, beginning with coarse spatial resolution datasets and ending with the most detailed ones. For each type of data, some basic principles are first introduced, concentrating on aspects that are important for power line surveys. This allows us to discuss the

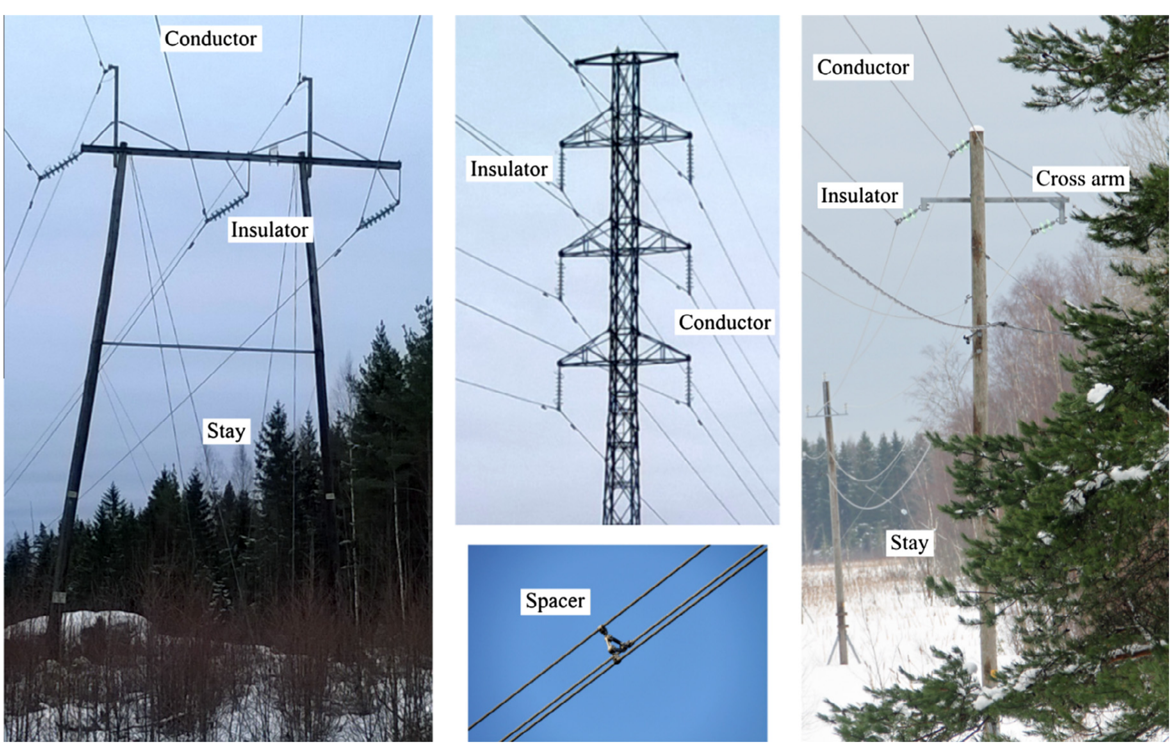


**Fig. 1.** Examples of transmission towers (left and middle), wood poles (right) and other power line components.