Electrical Power and Energy Systems 99 (2018) 107–120

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Review

Automatic autonomous vision-based power line inspection: A review of current status and the potential role of deep learning

Van Nhan Nguyen[a,b,*], Robert Jenssen[a], Davide Roverso[b]

[a] UiT Machine Learning Group, Faculty of Science and Technology, Department of Physics and Technology, University of Tromsø, 9019 Tromsø, Norway
[b] Analytics Department, eSmart Systems, 1783 Halden, Norway

A R T I C L E I N F O

Keywords:
Power line inspection
Vision-based inspection
Deep learning
UAVs

A B S T R A C T

To maintain the reliability, availability, and sustainability of electricity supply, electricity companies regularly perform visual inspections on their transmission and distribution networks. These inspections have been typically carried out using foot patrol and/or helicopter-assisted methods to plan for necessary repair or replacement works before any major damage, which may cause power outage. This solution is quite slow, expensive, and potentially dangerous. In recent years, numerous researches have been conducted to automate the visual inspections by using automated helicopters, flying robots, and/or climbing robots. However, due to the high accuracy requirements of the task and its unique challenges, automatic vision-based inspection has not been widely adopted. In this paper, with the aim of providing a good starting point for researchers who are interested in developing a fully automatic autonomous vision-based power line inspection system, we conduct an extensive literature review. First, we examine existing power line inspection methods with special attention paid to highlight their advantages and disadvantages. Next, we summarize well-suited tasks and review potential data sources for automatic vision-based inspection. Then, we survey existing automatic vision-based power line inspection systems. Based on that, we propose a new automatic autonomous vision-based power line inspection concept that uses Unmanned Aerial Vehicle (UAV) inspection as the main inspection method, optical images as the primary data source, and deep learning as the backbone of data analysis and inspection. Then, we present an overview of possibilities and challenges of deep vision (deep learning for computer vision) approaches for both UAV navigation and UAV inspection and discuss possible solutions to the challenges. Finally, we conclude the paper with an outlook for the future of this field and propose potential next steps for implementing the concept.

1. Introduction

The increasing dependence of modern-day societies on electricity poses corresponding challenges on the monitoring, inspection, and maintenance of the electric power grids to ensure an uninterrupted flow of electricity. Due to the lack of incentives to invest in aged national grid infrastructures, for example, in Europe and the US, power cuts are becoming more and more frequent [1]. While short-term power failures typically last only a few hours, long-term blackouts can last days or even weeks. Power outages, both short and long-term, can have catastrophic effects on unprepared businesses. For instance, blackouts can completely shut down production at companies and critical infrastructures such as telecommunication networks, financial services, water supplies, and hospitals [2]. Nowadays, most of the power grids are interconnected. Hence, a blackout in one region can trigger a domino effect that could result in supra-regional blackouts [3]. According to [1], a 30-min power cut in the US results in an average loss of US$15,709 for medium and large industrial clients, and nearly US $94,000 for an eight-hour interruption. Thus, power grids are required to be monitored, inspected, and maintained regularly to prevent faults which may cause power failures (Figs. 1 and 2).

The traditional methodologies for inspecting power networks typically include field surveys and airborne surveys, which have been unchanged for decades [4]. On a regular basis or in emergency situations, such as after storms, hurricanes, and earthquakes, teams of inspectors are sent out, traveling either on foot or by helicopters, to visually inspect the power lines with the help of binoculars and sometimes with InfraRed (IR) and corona detection cameras [5]. The main reason why visual inspection is popular is that it can cover a wide range of common faults on both power lines components (Fig. 2) and the power lines themselves (Fig. 1) in one inspection. However, this methodology is quite slow, expensive, potentially dangerous, and with detection rates limited by the visual observation skills of the inspectors. Although digital cameras can be used to separate the data collection from data

* Corresponding author at: UiT Machine Learning Group, Faculty of Science and Technology, Department of Physics and Technology, University of Tromsø, 9019 Tromsø, Norway.
E-mail addresses: nhan.v.nguyen@uit.no (V.N. Nguyen), robert.jenssen@uit.no (R. Jenssen), Davide.Roverso@esmartsystems.com (D. Roverso).

https://doi.org/10.1016/j.ijepes.2017.12.016
Received 19 September 2017; Received in revised form 20 November 2017; Accepted 16 December 2017

Fig. 1. Common faults on power lines (from left to right): trees growing too close to power lines, trees lying across power lines, icing on power lines. In warm countries, icing on power lines may not be a relevant fault; however, in cold countries, such as Norway, it is a very serious problem since thick icing accumulated on power lines can cause a great deal of damage to the lines.

Fig. 2. Common faults on power lines components (from left to right): broken poles, broken crossarms, missing toppads. In Norway, toppads are usually used for protecting wooden poles from rain; thus missing toppads are considered faults. In the US, however, they may not be considered as faults since toppads are not widely applied.

analysis, both processes have still been performed manually.

Over the past few years, many studies have been conducted to automate the visual inspection by using automated helicopters, flying robots, and/or climbing robots; however, there are very few published reviews of different approaches to the problem, including vision-based approaches. In this paper, with the aim of providing a comprehensive overview of the possibilities and challenges of automatic autonomous vision-based inspection of power lines, we conduct an extensive literature review. First, we examine existing power line inspection methods including foot patrol, helicopter-assisted, automated helicopter-assisted, climbing robots, and Unmanned Aerial Vehicles (UAV) inspection with special attention paid to highlight their advantages and disadvantages. Next, we summarize inspection tasks which are well suited for automatic autonomous vision-based inspection: mapping and inspection of power line components, vegetation encroachment monitoring, icing detection and measurement, and disaster monitoring. Then, we review potential data sources for vision-based inspection including Synthetic Aperture Radar (SAR) images, optical satellite images, optical aerial images, thermal images, ultraviolet images, Airborne Laser Scanner (ALS) data, land-based mobile mapping data, and UAV data and point out their applicable tasks. Further, we conduct a comprehensive review of current automatic vision-based power line inspection systems.

Based on that, we propose as a new potential solution an automatic autonomous vision-based power line inspection concept that uses UAV as the main inspection method, optical images as the primary data source, and Deep Learning (DL) as the backbone of data analysis and inspection.

To facilitate the implementation of the concept, we first discuss the potential role of deep learning in automatic autonomous vision-based power line inspection. We then highlight the possibilities and challenges of deep vision (deep learning for computer vision) approaches for both UAV navigation and UAV inspection. Finally, we propose possible solutions to the challenges and suggest potential next steps.

The remainder of the paper is structured as follows: Section 2 summarizes existing relevant literature reviews (related work) including inspection with vision-based approaches, before we present a brief introduction to power line inspection in general together with a summary of different inspection methods, inspection tasks, and data sources for visual inspection in Section 3. Next, in Section 4, we present a comprehensive review of existing vision-based approaches for both UAV navigation and UAV inspection. Finally, in Sections 5 and 6, we identify the remaining challenges of vision-based approaches in automatic inspection, discuss possible solutions to these challenges, propose potential next steps for implementing the automatic autonomous vision-based power line inspection concept, and conclude the paper with a summary and an outlook for the future of the field.

2. Related work

Although vision-based inspection is one of the most promising approaches for reducing or completely eliminating people, in both data collection and analysis, there are very few published reviews of vision-based approaches for power line inspections.

A review of recent techniques for vegetation encroachment monitoring was presented in [6]. According to the authors, current methods for vegetation monitoring, including visual field inspection, aerial video surveillance, aerial multispectral imaging, and LiDAR scanning are not viable due to their high cost, inaccuracy, and high time complexity. To increase the reliability of vegetation monitoring, satellite stereo and Wireless Multimedia Sensor Networks (WMSNs) were proposed to be the two future technologies. Based on that, the authors discussed the concept of utilizing multispectral satellite stereo images and WMSNs in detecting dangerous vegetation.

François et al. conducted a survey of computer vision applications in power line inspection in [7]. The surveyed applications include detection of power lines, inspection of power lines, detection and inspection of insulators, power line corridor maintenance, and pylon detection. According to the authors, computer vision appears to be one of the most important technologies for automatic vision-based power line inspection since both robots and UAVs need it not only for guidance, navigation, and control but also for inspection. Although this technology has been facilitating some applications, for example vegetation monitoring, it has not been widely used for other important applications such as inspection of defects on the cables or insulators.

Recent advantages in remote sensing sensors and data analysis approaches have opened new possibilities in automatic power line inspection. To facilitate the use of remote sensing techniques in power line inspection, a very comprehensive survey of the possibilities of modern remote sensing sensors for automatic power inspection was