Engineering Applications of Artificial Intelligence 71 (2018) 293–311

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

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

The Power Line Inspection Software (PoLIS): A versatile system for automating power line inspection

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ARTICLE INFO

Keywords:
Power line inspection
Machine learning
Visual tracking
Computer vision

ABSTRACT

A large amount of data, provided in the form of video data, is acquired during manned inspections flights of electric power lines. This data is analyzed by expert human inspectors to detect faults in the power lines infrastructure and prepare the inspection reports. This process is extremely time consuming, very expensive and prone to human error. In this paper, we present PoLIS: the Power Line Inspection Software, which has been developed with the objective of assisting the analysis of the data acquired during inspection flights. PoLIS is based on the cooperation between computer vision and machine learning techniques to automatically process video sequences acquired during inspection flights, resulting in a set of representative images per electric tower which we call Key Frames. These representative images can then be used for inspection purposes, leading to a drastic reduction of the human operators' workload. At the core of the strategy lies an electric tower detector, which is in charge of estimating the location of the towers within the images based on the combination of a sliding window search technique and a supervised classifier. The location of the tower is then tracked using a tracking-by-registration algorithm based on direct methods, estimating the position of the tower in different images. Finally, different criteria are applied for defining whether the image corresponds to a Key Frame image or not. Extensive evaluation of the proposed strategy is conducted using videos acquired during manned helicopter inspections. The videos constituting this database contain several thousand frames representing both medium and high voltage power transmission lines in the infra-red (IR) and visible spectra. The obtained results show that the proposed strategy can reduce the large amount of data present in the inspection videos to a few Key Frames for each tower. It is also demonstrated that the learning-based approach proposed in PoLIS is appropriate for detecting electric towers, a process which is made faster and more robust by coupling it with a tower tracking algorithm. A Graphical User Interface allowing the application of PoLIS to user-provided videos is also presented in this paper, illustrating the whole process and the automated generation of an inspection report.

1. Introduction

Nowadays society relies heavily on electric power to satisfy many vital necessities and amenities, this is why uninterrupted electrical power supply is absolutely crucial. Thus the inspection of transmission lines with highly demanding requirements, including accuracy, frequency and cost is required. In order to provide safe, steady and reliable electricity supplies to its consumers, electric power companies invest significant resources in inspection and pre-emptive maintenance of these infrastructures. The most common inspection strategies consist of scheduling regular manned helicopter flights over the power lines, while recording multi-spectral data, typically of visual, infrared, and ultra-violet types; in addition to Lidar and/or radar data.

This data is recorded, tagged with global positioning coordinates and commented whenever necessary by the helicopter's crew over thousands of kilometers. This data is then handed over to ground-based operators in order to identify faults in the power line infrastructure and generate the corresponding reports. Two different types of inspection are conducted: intensive and non-intensive. Intensive inspections provide close views of the electric towers and their components. Non-intensive inspections are faster and safer for the helicopter crew at the cost of a lower level of detail. These inspections have two major drawbacks. First,

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https://doi.org/10.1016/j.engappai.2018.02.008
Received 12 May 2017; Received in revised form 13 December 2017; Accepted 12 February 2018

the flights are very dangerous for the crew while performing intensive inspection because it requires flying close to the power lines. Second, the global inspection process is extremely costly both in hardware and personnel expenses. Hence companies in charge of the power network are willing to automate both data gathering and data processing stages.

Multiple solutions have been investigated in the past decades to answer this demand. Some of the most interesting ones are the use of Unmanned Aerial Vehicles (UAVs), Rolling On Wire (ROW) robots or hybrid approaches for replacing the helicopter-based data acquisition with a safer and cheaper alternative. This paper is focused on the software aspects of the solution, we will not expand on the hardware part since the proposed Power Line Inspection Software (PoLIS) applies both to manned and unmanned inspections.

Computer vision techniques have played a key role in the automatic identification of power line elements such as electric towers, insulators or cables. They target the automation of the data analysis for finding faults in the inspected power lines in a more cost-effective manner. However little research has been done using multi-spectral data, especially with synchronized frames. In addition, few researchers target the inspection of multiple components, multiple defect types and/or inspection type; instead focusing on only one combination component/defect for either intensive or non-intensive inspections. Indeed, detecting multiple components or defects is a challenging task (different types of towers, insulators, meters, etc.), since scales (tower scale: dozens of meters, insulator plate scale: dozens of centimeters) and defects (e.g. rust, contamination, current leak, flashover damage, etc.) vary widely. The range at which the inspection is conducted also conditions the potentially detectable defects.

In previous papers (Martínez et al., 2013; Sampedro et al., 2014), we have presented a machine learning-based detection algorithm for finding electric towers inside video footage and a tracking algorithm capable of keeping track of the detected towers. We present in this paper a global strategy applied to the inspection of power lines using multi-spectral synchronized frames assuming the *a priori* knowledge of the voltage category of the power line, i.e. medium or high voltage. The output of this process consists of the most suitable images for inspection, that is to say images that allow to check the state of the tower and its components. These images, which we call Key Frames, are the ones used by the operator to determine the state of the electric tower and its components in order to generate the inspection report. The scope of this paper is limited to non-intensive inspection although the presented inspection software has a much more general scope and is applicable to intensive inspections as well.

This paper is organized as follows: Section 2 will first present a state of the art of power line inspection using computer vision; Section 3 will then introduce PoLIS; Section 4 will present performance evaluation and optimization of the tower detector presented in Sampedro et al. (2014), its integration with the tower tracking strategy presented in Martínez et al. (2013) and the Key Frame selection strategy we propose. Section 5 will present our conclusions and introduce future evolutions of PoLIS.

2. State of the art

Pagnano et al. (2013) highlighted some of the most important general challenges for UAV based power line inspection:

- *visual servoing*, extended by information from other sensors in order to ensure power line tracking and autonomous navigation;
- *obstacle detection and avoidance* since an UAV should not crash into the power line equipment;
- *robust control* for providing high stability and positioning, hence allowing close-up and comprehensive inspections.

In resolving these general challenges, computer vision is expected to play a key role. A UAV platform with on-board visual sensing and processing equipment can greatly facilitate the autonomous inspection task. Some of the main problems that need to be solved are related to autonomously:

1. detect and localize the tower, when it appears in the field of view (FOV);
2. track the tower in subsequent frames;
3. steer the camera to bring and maintain the tower in the center of FOV;
4. once the tower is in the FOV, depending on the kind of inspection, maneuver the UAV and the camera, in order to focus on the tower components to be inspected.

Much of the state of the art has focussed on the first two problems (primarily the first one). Several researchers have applied computer vision techniques for electric tower detection and segmentation in aerial images (Whitworth et al., 2001; Golightly and Jones, 2003; Sun et al., 2006; Cheng and Song, 2008; Tilawat et al., 2010). Since towers are usually linear structures, most of these approaches are based on detecting lines in an image. The detected lines are post-processed by applying user-defined heuristics, in order to keep only the lines belonging to the tower. Various image segmentation methods are then applied to extract the tower from the image, e.g. direct template matching is used in Whitworth et al. (2001), watershed segmentation in Sun et al. (2006), graph-cut in Cheng and Song (2008). Golightly and Jones (2003), instead of using lines, used corner features to detect a tower in the image. The rest of this section reports in more detail the current state of the art in tower detection and tracking in videos captured from aerial inspections.

Whitworth et al. (2001) defined an abstract electric tower model as having two straight, near-vertical edges close to each other. This simple model describes towers used for 11 and 33 kV overhead lines which typically consist of two or three bare conductors supported on ceramic insulators mounted on a steel cross-arm at the top of a wood pole (Golightly and Jones, 2003). A template matching is performed between the abstract model and the features in the image for locating the tower candidates. Other features, such as two straight edges of the cross-arm and three equi-spaced pin insulators, are used to refine the tower detection and segmentation. This template matching approach was designed for segmenting simple "T-shaped" towers from the video sequences. The template based approach is then recursively applied for tracking as well. The reported results showed good performance in varying quality video sequences, albeit only on a single type of tower.

Golightly and Jones (2003) used a modified corner detector (Cooper et al., 1993) to detect and track the tower tops. The original corner detector is modified so that the proximal pixels are clustered together such that only a single point is chosen as the representative of a particular corner. The detected corners exemplify a tower top in an image. The results were reported only for a single type of tower which supports medium voltage (11–33 kV) lines (similar to Whitworth et al., 2001). Additionally, a corner matching criteria was proposed to find the correspondence between consecutive frames (beyond the scope of the paper).

Tilawat et al. (2010) reported a three step approach to tower detection. The first stage applies the "optimal line detector" for detecting the straight lines in an image, giving a set of possible tower candidates. Another linear transformation is then applied to the filtered image. The transformed image is divided into a set of non-overlapping windows, and each window is weighted based on the number of lines passing through each window. The windows with the highest number of lines are considered to be a tower. The proposed approach is simplistic, and as the authors suggest, presence of other linear objects in the image (roads, buildings etc.) will render the approach less useful.

Cheng and Song (2008) defined the shape and appearance of a tower by a general rule set such as the tower and the cross-arm are straight; the main tower and the cross-arms intersect at a right angle; the cross-arm is shorter and narrower than the pole. The line segments detected in the pre-processing stage are filtered to remove the segments which, based on the rule-set, are detected as not belonging to the tower. It is assumed that the remaining segments roughly describe the tower. Given the filtered