# Multimodal image analysis for power line inspection

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***Abstract*—The use of Unmanned Aerial Vehicles (UAVs) for environmental and industrial monitoring is constantly growing. At the same time, the demand for fast and robust algorithms for the analysis of the data acquired by drones during the inspections has increased. In this paper we provide a concise survey about a peculiar case study: the monitoring of the high-voltage power grid which includes: *(i)* the detection of the power lines and of the electric towers along with their components more subject to wear and tear; *(ii)* the diagnosis of maintenance status. In this work different algorithms from image processing are applied to visible and infrared thermal data, to track the power lines and to detect faults and anomalies. We applied Canny edge detection to identify significant transition followed by Hough transform to highlight power lines. The method significantly identify edges from the set of frames with good accuracy. The paper concludes with the description of the current work, which has been carried out in a research project, namely *SCIADRO*.**

***Index Terms*—Image analysis, RGB Images, Infrared Images, Machine Learning, Wire detection, Insulators, Unmanned Aerial Vehicles**

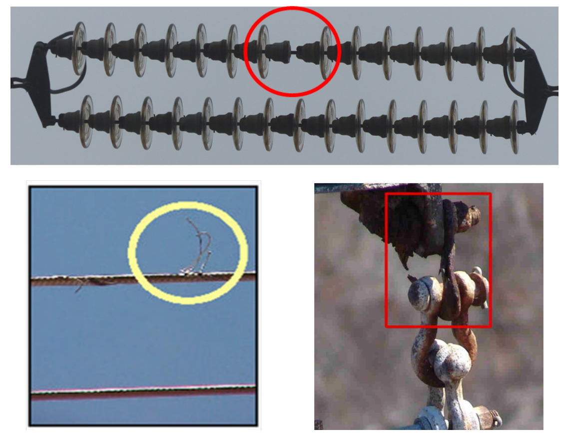

Fig. 1. A sample of common defects: deformed/broken/missing insulators(top), broken/damaged wires (bottom left), loose/corroded connections (bottom right).

## I. Introduction

The electricity distribution network must be constantly monitored to be safe and efficient. Hence, the detection of any defects at an early stage can save the life of the system, prevent damages, and predict future anomalies too. Much research on how to improve power lines detection and inspection has been carried out: the main objective is to reduce the time and cost of the monitoring, increasing the safety of the staff during the inspection, without losing in quality. The most common defects of the infrastructure are shown in Fig.1. Generally the inspection proceeds in steps, as follows: (*i*) detection of wires and cables; (*ii*) analysis of wires and cables; (*iii*) detection and classification of electric towers; (*iv*) analysis of tower components (insulators, hanging points).

There exist different methods to monitor the electric power lines. The most widely used method is the foot patrolling: a team of technicians inspects the lines by or with a ground vehicle. The team uses binoculars, and/or visible and infrared cameras, and this process may be tedious and long. Also, the inspection may be performed using a manned aerial vehicle, e.g. a helicopter equipped with visible or infrared cameras, acquiring images of conductors and insulators from high above the power lines, and quickly. In this case, the inspection is faster but usually more expensive. Then, the acquired data are either manually inspected by a skilled operator, or automatically processed for fault detection. When a fault is detected, skilled operators are required to climb in order to check and eventually fix the damage.

Recent advances in flight control techniques and image processing allow UAVs, equipped with a proper payload of acquisition (such as visible, thermal, and also multi-spectral cameras), to carry out fast inspection from some distance. Hence, in the last decade, UAVs are being used for a wide spectrum of applications, including the inspection and maintenance of power equipment. For example, there are algorithms able to perform automatic tracking of power lines using the GPS data of both the UAV and the electric towers. Compared with conventional inspection methods, UAV-based inspection has a number of advantages: it is more advanced, less expensive and safer. On the other hand, UAVs and manned aerial vehicles share some common problems: camera stabilization, pole tracking and automatic detection of anomalies. Monitoring an electrical infrastructure using UAVs requires to make the inspection fully automatic and almost real-time, and to get a reliable detection of defects and damages (such as hot spot in cables, or broken insulators).

In the following sections, firstly we present different computer vision methods used to analyze visible and infrared image data, for the detection and inspection of power lines and of the whole infrastructure. For sake of completeness we will present also other methods from machine learning, recently used to perform the task of recognition and classification of electric towers and their components. Then we devote the remaining sections to the description of the ongoing work carried out in the framework of the SCIADRO project. The overall objectives of the project are: *(i)* achieving computer vision techniques and algorithms able to detect complex objects and extract information on local anomalies which might affect them; *(ii)* developing suitable policy and algorithms to effectively organize and guide the overall swarm motion and actions during a mission; *(iii)* studying, developing and demonstrating network architectures and protocols allowing communication among multiple drones within a swarm, possibly increasing the communication reliability towards the ground station.

## II. State of the Art

The diagnosis of the electric infrastructure status is performed by analysing the visible or infrared data acquired during the inspection. To this aim, in the last two decades, thermal and infrared imaging have been increasingly studied and exploited both to test and inspect different electric parts, and to do preventive maintenance work. Recently, UAV-based inspection systems are used to comprehensively inspect power transmission line in urban and rural areas.

In this section we provide a review of the state of the art literature about the image processing methods used to analyse visible and infrared 2D images. Generally, such images may have several backgrounds: green fields, water, mountains or buildings. Therefore, in order to investigate the condition of the lines, the very first step is to identify them in the images. Detecting power lines from a cluttered background is one of the most important and challenging tasks. In general, all methods share this two-step process: i) Identify expected power lines and remove the background. ii) Connect the expected power lines and remove unwanted straight lines.

### *A. Processing of thermal-infrared data*

Infrared thermography uses infrared sensors to capture images of thermal objects based on temperature variations. Also, thermal imaging is considered as a robust, non-destructive and contactless methodology to inspect electrical wires and connections (which are more subject to stress), as the inspection can be performed by keeping some distance, avoiding to halt or cut down electric supply during the inspection. Li et al. presented in [1] an image fusion algorithm (based on SIFT feature extraction) to support inspection robots in the automatic detection and identification of power equipments. Similarly, Larrauri et al. [2] identified areas of vegetation, trees and buildings close to power lines and calculated their distance from power lines. Simultaneously, the system processed the infrared images to detect hot spots in the power lines by estimating the threshold based on Otsu method [3] and later segment the lines from the background. Lages et al. in [4] describe a piece of software designed to acquire and process automatically two video streams, made of thermal and visible images. The processing results in the annotation of the video stream with faults. More recently, Luque-Vega et al. presented in [5] an inspection system based on a quadrotor helicopter, equipped with stereoscopic system made of a thermal-infrared and a color camera, to detect hot spots and other damages. The aerial video aquired are transmitted to the ground control station and then processed. Several of the above mentioned and similar methods require manual operations to adjust threshold values; measurement errors may occur, for example, due to the influence of the background, or to the lack of reference values for temperature. In this perspective Wronkowicz proposed in [6] the automatic detection of hot spots in power lines from IR images, without any reference temperature value. The thermal image is segmented by automatic thresholding.

### *B. Processing of RGB data*

The recent boost of the UAV technology has increased the need of reliable automatic method of object tracking and detection from RGB images, supporting the UAV intelligence or improving the functionalities of a real-time monitoring system based on UAVs. Focusing on the detection and tracking of the power lines, Oberweger et al. presented in [7] a method to detect the insulators in aerial images, and to automatically analyze them for possible faults. The method is based on discriminative training of local gradient-based descriptors and a subsequent voting scheme for localization. In [8], Candamo describe a method to detect power lines from low quality videos, combining the motion estimation at the pixel level with the edge detection, followed by a windowed Hough transform. Yan et al. extracted straight line segments by Radon transform, followed by a Kalman filtering to connect segments into whole lines [9]. Zhang et al. [10] extracted the power lines by applying the Otsu thresholding to the gradient image. Hence, the straight lines are clustered and filtered; and Kalman filtering to track smoothly the power lines in the video sequence. Similarly, Li et al. in [11] proposed a more complex filter based on a simplified pulse coupled neural network model. This filter is used to remove the background noise as well as to generate edge maps, while the power lines are detected using an improved Hough transform. More recently, Li et al. [12] modeled the human attention mechanism model and the binocular vision to detect and track power lines in image sequences. The authors showed that the system is effective even in complex backgrounds and under different conditions. Song and Li described in [13] a method to detect not only the straight lines but also the curve ones. The method is based on a line segment pooling followed by a graph-cut model, to group together the lines corresponding to the same power line. We refer to [14], [15] for a more detailed summary of other methods.

Actually, monitoring the electric infrastructure means not only to understand the status of wires and cables, but also to detect and analyse electric towers and insulators.

Regarding the detection of electric towers and pylons, interesting results are reported by Sampedro et al. in [16] and by Dutta et al. in [17].

As regards the electric insulators, very important components of the electric grid, much research have been carried out. Recently, Zhao et al. proposed a method for the ac-

 

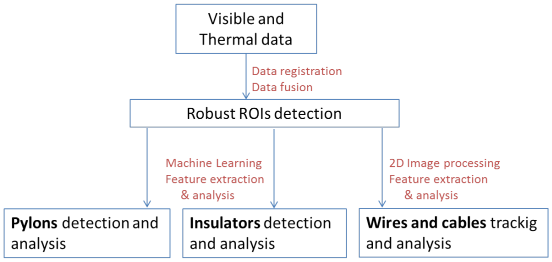


Fig. 2. Both RGB and infrared are processed in order to detect and analyse pylons, insulators, and conductors.

curate and real-time locatization of multiple insulators with different angles [18];while in [19] classical methods of image processing are used to separate the insulators from the complex background, and template matching to recognize the insulators. Most of classical methodsare usually badly affected by changes in illumination and background; this may result in a poor generalization ability. Hence, the problem of detection, classification and location of insulators benefited from the recent advances in machine learning. In this line, Zhao et al. in [20] designed a multi patch convolutional neural network to extract deep features from the images representing insulators, and used such features to classify (via SVM) the status of the insulators; Liu et al. in [21] proposed to use a three-class dataset (insulator, tower, background) to train a convolution neural networks (CNN)used to predict the candidate insulator position.More recently, Tiantian et al. in [22] applied feature fusion techniques to the histogram of oriented gradients (HOG) feature and local binary pattern (LBP). Results reported are promising, but improvable, as the location is strongly dependent on the recognition of the insulator.

## III. The SCIADRO project

This paper deals with the ongoing work being done in SCIADRO [23], a research project. The project aims at developing the enabling technologies, which are key to accomplishing a rather rich and diverse span of missions through the use of a swarm of drones within a civilian environment. The main idea of our work in the SCIADRO project is to provide a tool to support simultaneously the detection of the infrastructure components; and the diagnosis of the maintenance status of the detected insulators. Also, such algorithms should be specifically designed for the collaborative setting of an UAV swarm. As shown in Fig. 2, the image processing aims at the detection and analysis of the main components of the electrical infrastructure: electric towers, insulators, and conductors.

Traditional image processing is currently used to track power wires, both in thermal and visible images (possibly registered); while a multi-layer perceptron neural network will be used both to predict whether the region inside an image is a tower (or not), and to distinguish the tower type on the basis of a dataset of training. A rich dataset of images is needed to train the neural networks. A feature fusion step will be probably added in order to reduce the dependence on the training set. The correct classification of the tower (by adding a context knowledge given by the closeness of the tower and its components) would improve the performance of the automatic detection and analysis of the tower subcomponents (i.e., insulators and hanging points), which will use a region-based segmentation and template matching.

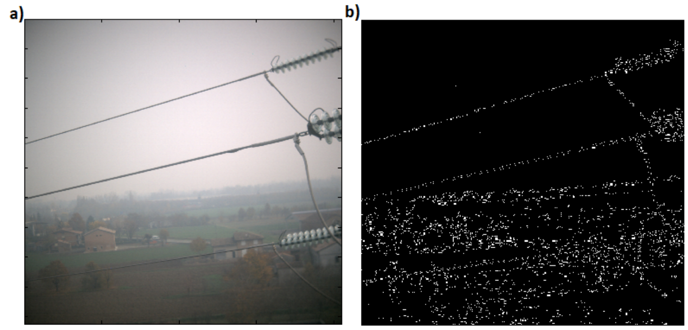


Fig. 3. a) Visible image of the tower and power cables, b) Edges extracted from the visible image using Canny edge detector.

Thermal data and images in the visible spectrum have been acquired by a drone flying at a distance of approximately 10 mt from the power lines, with different cameras, near Parma in December, 2017. Data include also a small number of images containing common defects. These data have been used to test our methods for the detection of the infrastructure and the diagnosis of its status.

At this stage, two tasks have been implemented and partially tested on real data: *i* classification of insulators as normal or rusty, using a convolutional neural network trained on our data; *ii* detection of power lines by image processing applied to RGB images. In the following section we provide a description about the second task.

## IV. Methods

In this work, keeping in mind the typical linear characteristics of power lines, we applied Hough transform on visible images to identify power lines. Several methods based on Hough transform had been proposed in the past to identify power lines as in [8], [11]. The images were processed following the steps listed here:

i Preprocessing to improve contrast in the image.
ii Detection of edges by using Canny edge detector.
iii Hough transform to detect all lines in the images.
iv Extraction of power lines.

As explained before, we had analyzed images acquired by a camera mounted on the drone flying close to the electric power lines. By way of example, an image is shown in Fig. 3a. After the contrast enhancement, we applied the Canny edge detector to identify edges and remove unwanted objects from the background of interest area. Canny edge detection algorithm [24] consists of the following steps:

i In order to smooth the image, Gaussian filtering is applied to reduce noise effects by convolving image with Gaussian filter.

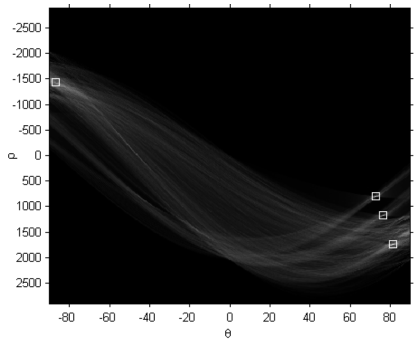


Fig. 4. Detected peaks with Hough transform, where peaks correspond to the length of the line. $\rho$ is the perpendicular distance of the peak to the origin and $\theta$ correspond to the angle. Occurrence of all positive angled peaks correspond to power lines.

ii Image gradient magnitude and direction are computed

iii Non-maxima suppression, according to the gradient direction, to get unilateral edge response and to preserve local maxima as these maxima correspond to the edges. (The output of maxima suppression contains some local maxima which correspond to noise elements)

iv Double threshold method, in order to detect and connect edges.

The results obtained by using the Canny edge detector is shown in Fig. 3: power lines along with sharp edges of background were detected. The next step is to highlight only those edges which correspond to power lines. Hough transform is used to detect parameterized shapes through mapping each point to a new parameter space in which the location and orientation of certain shapes could be identified [25]. In this work we applied Hough transform to identify power lines, as the method identifies all straight lines in the image, maybe including roads, buildings etc. Therefore, in order to discriminate power lines from other linear object we applied clustering in the Hough space. The method usually parametrizes a line in the Cartesian coordinate to a point in the polar coordinate using the point-line duality equation:

$$x \cos\theta + y \sin\theta = \rho \qquad \rho \geq 0 \quad 0 \leq \theta \leq \pi \tag{1}$$

Where $(x, y)$ is the point in image in Cartesian coordinates. $\rho$ is the perpendicular distance of the peak to the origin and $\theta$ correspond to the angle to the origin. Before detecting power lines in the Hough space, we applied the Canny edge detector to identify all edges in the images. Fig. 4 highlights the detected peaks: here we filtered the three close perpendicular $\theta$ peaks corresponding to power lines.

## V. Results and Ongoing Works

We applied the method explained in the previous section to the video sequence acquired during the acquisition campaign. The method is applied on 44 frames of 2 mega pixel size and it took 117 seconds to process the complete video sequence. The detection obtained from a single frame is shown in Fig. 5. All detected lines are marked in the visible image; at the

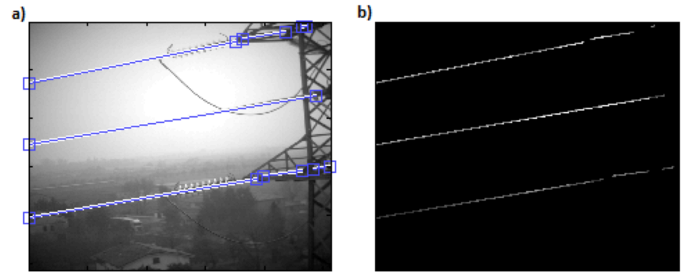


Fig. 5. a) Power lines highlighted on visible image, b) Binary mask of the detected power lines.

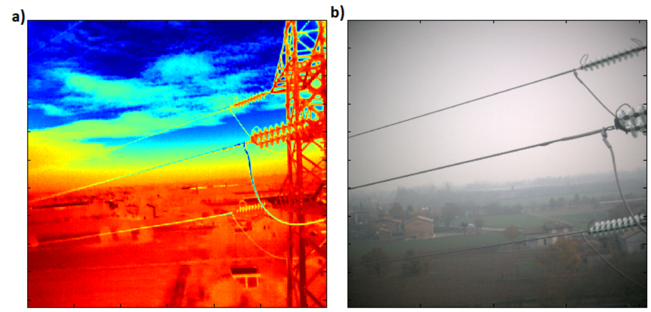


Fig. 6. a) Infrared image of the tower and power cables, b) Visible image.

same time we generate the mask by segmenting power lines for better visualization and inspection. In future, we aim at improving the accuracy of the power line tracking by Kalman filtering [10], and make the processing faster (approximately real time) by integrating the prior knowledge of the drone motion. We had acquired simultaneously visible and infrared images with drones; in this work we used only visible image to detect power lines. The next step is to anayze IR images to identify defects and broken wires. In order to do so, a key point is to register the RGB and IR images, as cameras have different focal length and position. Therefore, in order to closely identify defected area it is of extreme importance to perform an efficient sensor fusion.

## VI. Conclusions

In this paper, we have studied different inspection methods based on visible and infrared images designed to detect and inspect power transmission lines. Infrared imaging applied to power lines monitoring account for the differences of temperature at the joints; hence it is used for the fault diagnosis. On the other hand, image processing applied to RGB images and videos is able to provide quite an accurate localization of the inspected power lines, by applying standard computer vision techniques (e.g. denoising, filtering, segmentation, line detection). At first, We used vision based methods to identify power lines in visible images only. Canny edge detector has highlighted significant transition in the images and later by utilizing linear property of power lines, we applied Hough transform to identify power lines. We applied the described method on a short video sequence, and obtained encouraging results. We plan to further extend the method to thermal images too, possibly improving the robustness of the method exploiting the registration of both data (i.e., thermal infrared and visible). The correct registration between data, together with a proper data fusion, is a key point to have not only an accurate detection and tracking of the power lines, but also to get a reliable and robust assessment of the maintenance status of the whole infrastructure.

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