APS/123-QED

Visible and Infrared imaging based inspection of power installation

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The inspection of power lines is the crucial task for the safe operation of power transmission: its components require regular checking to detect damages and faults that are caused by corrosion or any other environmental agents and mechanical stress. During recent years, the use of Unmanned Autonomous Vehicle (UAV) for environmental and industrial monitoring is constantly growing and the demand for fast and robust algorithms for the analysis of the data acquired by drones during the inspections has increased. In this work, we use UAV to acquire power transmission lines data and apply image processing to highlight expected faults. Our method is based on a fusion algorithm for the infrared and visible power lines images, which is invariant to large scale changes and illumination changes in the real operating environment. Hence, different algorithms from image processing are applied to visible and infrared thermal data, to track the power lines and to detect faults and anomalies. The method significantly identifies edges and hot spots from the set of frames with good accuracy. At the final stage we identify hot spots using thermal images. The paper concludes with the description of the current work, which has been carried out in a research project, namely *SCIADRO*.

Keywords: Image analysis, RGB Images, Infrared Images, Wire detection, Unmanned Aerial Vehicles.

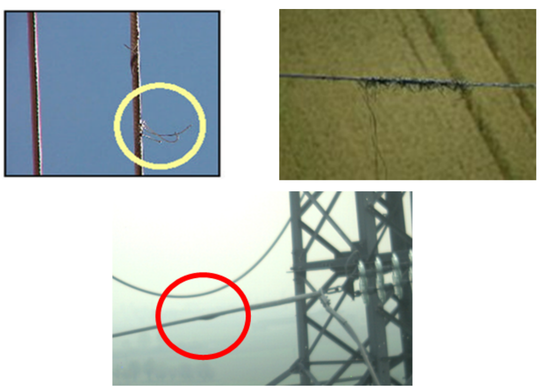

FIG. 1. A sample of common defects in power transmission lines *e.g.* broken/damaged wires, Hot spots *etc.*

1. INTRODUCTION

Defect detection in power lines at early stage can save the life and ultimately cost of the power system maintenance and it is of extreme importance to ensure their continuous supply and high performance. At the same time, defect detection at an early stage not only can save the life of the system but also the operational cost. In addition to that, it can save the damages and can predict future anomalies too. Therefore, the continuous surveillance and inspection of power lines can play a vital role to ensure the continuous electric transmission. 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 inspection, without losing in quality. In this paper, we will present different studies based on these methods using visible and thermal imaging cameras. The main focus will remain at the inspections via UAVs. We will present different computer vision methods used to analyze visible and infrared image data. Before presenting these methods, we will first briefly introduce different modes of inspection. The most common defects in these transmission lines are shown in Fig.1.

2. INSPECTION MODES

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). In this work we will focus mainly on the inspection of power transmission lines.

A. Foot Patrolling

The most widely used method to inspect power lines is the foot patrolling: a team of technicians inspects these lines by or with a ground vehicle. The team uses binoculars, and/or visible and infrared cameras, this process may be tedious and long.

B. Helicopter Assisted Inspection

Helicopter-assisted inspection is also becoming commonly used for power line inspection. The pilot flies the helicopter over the power lines, while the camera operator films the transmission lines, conductors,insulators and the objects below the lines. The filming is typically done with a color, IR or thermal camera. In this case, the inspection is faster but more expensive. Later, the acquired data are either manually inspected by a skilled operator, or automatically processed for fault detection.

C. Inspection Robots

In order to overcome the risk for the operator, and to reduce the operational cost, climbing robots came up as an alternative solution. The climbing robot travels along the conductors, achieving similar speed as in helicopter assisted inspection. In comparison to the foot patrolling, the climbing robot is a safer and not time consuming solution. Although having specific benefits, climbing robots are still not a practical solution to inspect the huge network of distribution lines [1].

D. UAVs based Methods

Recent advances in flight control techniques and image processing allow UAV, equipped with a proper payload of acquisition (such as visible, thermal, and also multispectral cameras), to carry out fast inspection from some distance. Hence, in the last decade, UAV 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, UAV and manned aerial vehicles share some common problems: camera stabilization, pole tracking and automatic detection of anomalies. Monitoring an electrical infrastructure using UAV 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).

3. THE SCIADRO PROJECT

This paper deals with the ongoing work being done in SCIADRO[2], 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. 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. 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. In the following sections, firstly we present bibliographic survey of computer vision methods used to analyze visible and infrared image data, for the detection and inspection of power lines.

4. BIBLIOGRAPHIC SURVEY

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 UAV. Focusing on the detection and tracking of the power lines, Zhang et al. [3] 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 [4] proposed a more complex filter based on a simplified pulse coupled neural network model. Li et al. in [4] proposed a more complex filter based on a simplified pulse coupled neural network model. This filter can simultaneously remove the background noise as well as generate edge maps. An improved Hough transform, performing knowledge-based line clustering in the Hough space, detected the power transmission lines. Song and Li described in [5] 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 [6, 7] for a more detailed summary of other methods. Candamo detected power transmission lines from low quality videos combining the motion estimation at the pixel level with the edge detection, followed by a windowed Hough transform [8]. Yan et al. extracted straight line segments by Radon transform, followed by a Kalman filtering to connect segments into whole lines [9]. More detailed summary of some more methods were given by Katransnik and Miralla in [6, 7].

Hongwei et al. [10] had presented a fusion algorithm for the infrared and visible power lines image. They extracted the SIFT features from the images and calculated the optimal homograph matrix to fuse the visible and infrared images by bicubic interpolation algorithm. Similarly, Larrauri et al. [11] identified areas of vegetation, trees and buildings close to power lines and calculated their distance from power lines. Simultaneously, the sys-

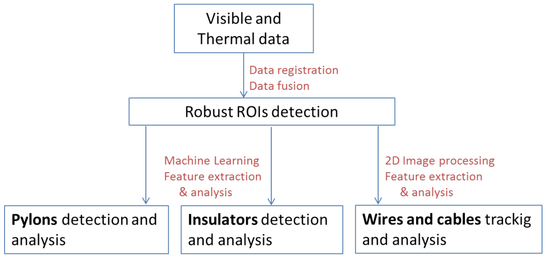

FIG. 2. Both RGB and infrared are processed in order to detect and analyse pylons, insulators, and conductors.

tem processed the infrared images to detect hot spots in the power lines by estimating the threshold based on Otsu method and later segment the lines from the background. On the other side, Lages et al. captured video streams from both an infrared and visible cameras, simultaneously [12]. They used both statistical and morphological methods to highlight the hot spots in the lines. Oliveira et al. discussed in detail the generation of hot spots in the transmission lines and later they had also used the same thresholding based segmentation to highlight hot spots [13].

5. DATA ACQUISITION

When inspecting the power line corridor for obstacles, the flight parameters must be designed according to the camera parameters mounted on a UAV. We calibrated our UAV and camera before flying. 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. We use FLIR Thermal camera(FLIR A65sc) with standard lens (25mm focal length H-FOV x V-FOV = 25deg x 20deg) to acquire thermal images and Nikon J1 + SD card 32gb + NIKKOR lens 10mm f / 2.8 optimized for movie recording + extra battery to acquire RGB images. Data includes images containing common defects *e.g.* broken wires and hot spots. We used these data to test our method 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)* detection of power lines by image processing applied to images.; *(ii)* Identification of hot spots using these images. In the following section we provide a description of these tasks.

6. METHODS

The images were processed following the steps listed here:
i) Infrared and visible image fusion.
ii) Detection of edges by using Canny edge detector.
iii) Hough transform to detect all lines in the images.

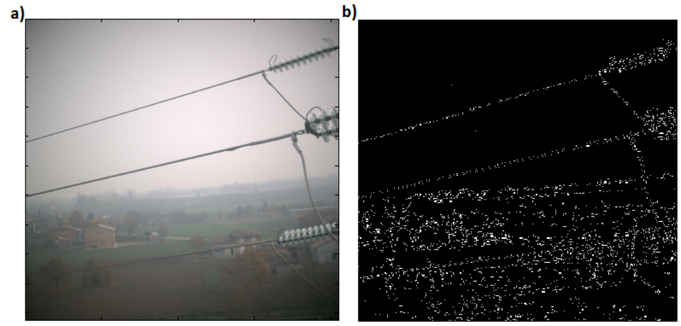

FIG. 3. a) Visible image of the tower and power cables, b) Edges extracted from the visible image using Canny edge detector.

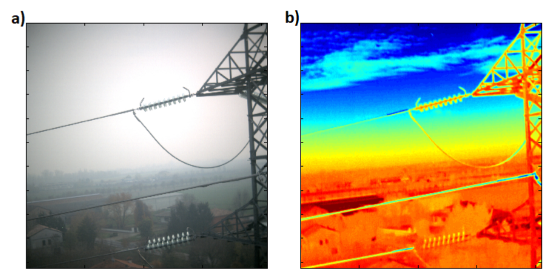

FIG. 4. Registered visible and IR image.

iv) Extraction of power lines.
v) Identify hot spot by thresholding.

Image registration is defined as a mapping between two or more images both spatially (geometrically) and with respect to intensity. By mathematically expressing [14]:

$$I_2 = gI_1(f(x_1; x_2)); \tag{1}$$

where I_1 and I_2 are two-dimensional images. We used fusion algorithm based on manual control point selection of the infrared and visible image. Affine transformation is sufficient to match two images of a scene taken from the same viewing angle but from a different position as in the present case. The registered images are shown in Fig. 4

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 image fusion and 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 [15] 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.
ii) Image gradient magnitude and direction are computed.
iii) Non-maxima suppression, according to the gradient

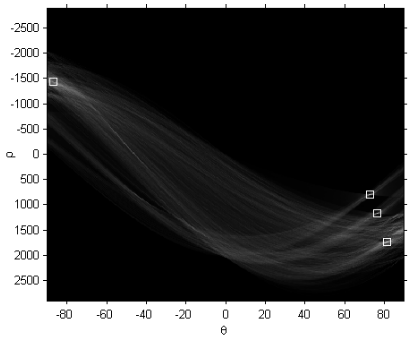

FIG. 5. Detected peaks with Hough transform, where peaks correspond to the length of the line. ρ is the perpendicular distance of the peak to the origin and θ correspond to the angle. Occurrence of all positive angled peaks correspond to power lines.

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. 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 [4, 8]. 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 [16]. 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 parameterizes a line in the Cartesian coordinate to a point in the polar coordinate using the point-line duality equation:

$$x\cos\theta + y\sin\theta = \rho \qquad \rho \geq 0 \quad 0 \leq \theta \leq \pi \tag{2}$$

Where (x, y) is the point in image in Cartesian coordinates. ρ is the perpendicular distance of the peak to the origin and θ 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. 5 highlights the detected peaks: here we filtered the three close perpendicular θ peaks corresponding to power lines.

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

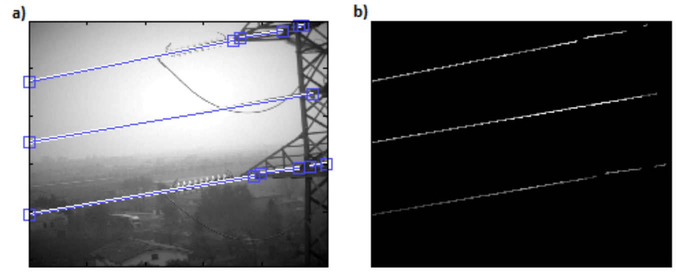

FIG. 6. a) Power lines highlighted on visible image, b) Binary mask of the detected power lines.

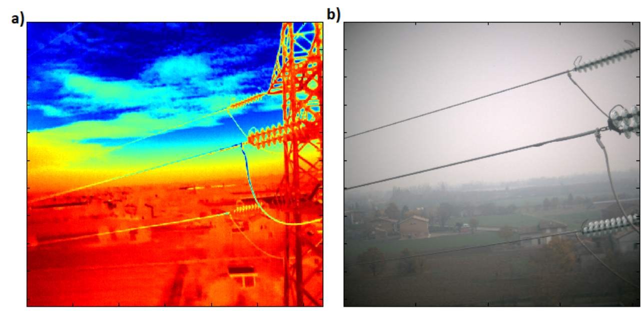

FIG. 7. a) Infrared image of the tower and power cables, b) Visible image.

complete video sequence. The detection obtained from a single frame is shown in Fig. 6. All detected lines are marked in the visible image; at the 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 [3], and make the processing faster (approximately real time) by integrating the prior knowledge of the drone motion.

A. Histogram base thresholding

At the final stage, we applied histogram based thresholding on the segmented image in Fig. 6. As both visible and infrared images are registered, therefore by using the segmentation of power lines in visible image, we mapped power lines from infrared images too. The histogram of

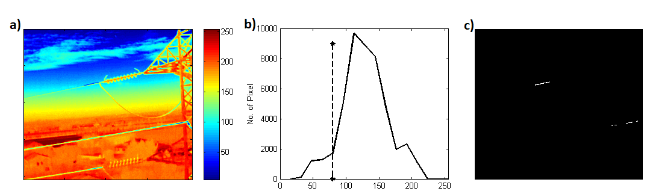

FIG. 8. a) IR image, b) Histogram of thermal intensity and selected threshold to highlight fault area, c) Histogram based thresholding of IR image to identify hot spots in power lines.

segmented infrared image is shown in Fig.8b. We applied thresholding on infrared thermal intensity and it results shown in Fig.8c in highlighting hot spots present in the image. Although at this stage, we used intensity value of infrared images but in future we intend to use actual temperature value from the infrared image to classify the severity of damages in the wire.

7. 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. Image processing based methods applied to RGB images is able to provide localization of the inspected power lines. We applied manual control point based image fusion to use multimodal imaging. Later, computer vision based methods to identified power lines from visible images. Canny edge detector has highlighted significant transition in the images and later by utilizing linear property of power lines, we used Hough transform to identify power lines and hot spot were identified by simple threholding. In future, we intend to extend image registration from manual control points to automatic selection of robust control point selection. The correct registration between data, along with the 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.

ACKNOWLEDGMENTS

This work is partially supported by the Tuscany Regional Projects SCIADRO and MOSCARDO (FAR-FAS 2014).

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