This full text paper was peer-reviewed at the direction of IEEE Instrumentation and Measurement Society prior to the acceptance and publication.

Power Transmission Lines Inspection using Properly Equipped Unmanned Aerial Vehicle (UAV)

Alexandros Zormpas [1], Konstantia Moirogiorgou [1], Kostas Kalaitzakis [1], George A. Plokamakis [2], Panayotis Partsinevelos [3], George Giakos [4], Michalis Zervakis [1]

[1] School of Electrical & Computer Engineering, Technical University of Crete, University Campus, 73100 Chania, Crete, Greece, E-mails: azorbas@isc.tuc.gr, dina@display.tuc.gr, koskal@elci.tuc.gr, michalis@display.tuc.gr

[2] Hellenic Electricity Distribution Network Operator, 73100 Chania, Crete, Greece, E-mail: gplok@yahoo.gr

[3] School of Mineral Resources Engineering, Technical University of Crete, University Campus, 73100 Chania, Crete, Greece, E-mail: ppartsi@mred.tuc.gr

[4] Department of Electrical and Computer Engineering, Science and Technology Integration Research Laboratory, Manhattan College, Riverdale, NY, E-mail: george.giakos@manhattan.edu

***Abstract*—The inspection of power transmission lines is an important task that enhances the reliability of Electricity Distribution Network Operators. This task can be performed in a low-cost way using unmanned aircrafts. At the present study, we examine the effectiveness of using basic image processing methods on image data of the power lines acquired by an unmanned aerial vehicle (UAV). The specific UAV was assembled for the present work under the considerations that arise from the purpose of the inspection of power transmission lines. Two methodologies are proposed differing on the pre-processing required in order to detect the location of the lines on the video images. Both proposed methodologies were tested in real-world cases, with the image background in each case to be characterized of non-uniform texture, i.e. the natural terrain is rugged at some locations, wooded land at some other or it is road that appears at the same hue as the aerial power lines. We examined the case of a broken line where the methodologies result in successful detection of the power lines before and after the discontinuity of the power line. The proposed work offers a robust and low-cost way for the inspection of power transmission lines and so an effective way to detect the location where a cable fault has occurred.**

Keywords—UAV remote sensing; power line inspection, aerial video processing, Hough transform, parametric training.

I. Introduction

In terms of efficient electricity distribution, surveillance and maintenance on the electrical infrastructure are considered more than necessary tasks that need to be performed under a regular basis. A thorough power line inspection for fault detection could indicate a damage and provide useful information about the network. This proactive step can largely extend the lifespan of the lines. Faults like mechanical failure of conductors, electrical faults like malfunction of cables or even failure due to environmental factors like vegetation growth (e.g. trees), fire or intense weather conditions (lightnings, snow or wind) render the inspection of power transmission lines an essential process of the electrical network maintenance. In most cases and in many countries, a frequent power line inspection task is performed by a crew of technicians by performing ground surveillance. The solution of using manned helicopters or LiDAR is an expensive one. On the other hand, the use of unmanned aerial vehicles (UAVs) operating at a safe distance from the power lines, seems to offer an advantageous automated way to deliver the task of inspection.

The Hellenic Electricity Distribution Network performs inspection of the power transmission lines in a yearly basis as a preventive maintenance procedure, while corrective maintenance is performed in cases of storms or fires. Remote areas known for heavy load or areas with high vegetation require more frequent inspection in order to check the condition of the network. The inspection in all cases is performed visually by technical staff that scans the network from the ground in order to detect damages or obstacles on it. In any case, it is a fact that power lines require regular inspections to ensure a secure and uninterrupted network operation.

The use of UAV for intelligent inspection of transmission lines has been already proposed in other countries, like China [1]. In recent studies, a plethora of machine vision techniques has been proposed for confronting various aspects of power line inspection, like the automatic detection of obstacles in power line corridors using stereo imaging [2], use of thresholding and morphological operators for power line detection [3], edge detectors [4], Radon transform, Kalman filters or histogram analysis for efficient detection in cases where the images were acquired from big distance from the ground [5,6], etc. Similar techniques have been used for other applications associated with remote sensing, like automatic extraction of roads using aerial images [7]. Finally, Hough transform has been proposed for the same task [8, 9].

The main task of the present study is to track successfully the power lines in order to detect faults on the electric power network. During the design of the algorithm, we take into account the fact that the final code must be fast enough in order to be able to embed it on the UAV development board at a later phase. This is why the Hough transform was selected as best choice under these conditions. The methodology that is described at the following Sections is based on Hough transform but with some modifications necessary for the enhancement of the algorithm's accuracy and efficiency.

II. Hardware Setup

For the image data collection in the present study, an Unmanned Aerial Vehicle (UAV) was assembled from

978-1-5386-6628-9/18/$31.00 ©2018 IEEE

scratch. The components were delivered separately and the composition to the final UAV was performed at the premises of Technical University of Crete. More specifically, the unit responsible for the control of the vehicle, the Flight Controller (FC), is a Pixhawk PX4. It contains the STM32F427 integrated circuit with a Cortex M4 processor on board, that is an ARM 32-bit processor running at 168 MHz with 256 KB of RAM. A Ublox Neo-6M GPS and the receiver of the KDS AT9 Remote Controller are connected to the FC. The frame is the S500 for quadcopters, which hold the 2216 900KV SunnySky motors with 1047 propellers and the SIMONK 30A Electronic Speed Controllers. The system is powered by a 3S 45C 4000mAh Li-Po battery. For video recording, a Raspberry Pi 3 Model B running Raspbian, was used combined with its 8 MP Raspicam mounted at the bottom of the gimbal. The action camera SJ5000X was used to record video and images from a different point of view, transmitted by the TS800 AV 5.8GHz 1500mW Transmitter to the Boscam Galaxy RD2 FPV screen. The setup of the proposed UAV is presented in Fig. 1.

Fig. 1. Different views of the UAV that was used for the power lines inspection

III. Proposed Methodology

The inspection of power transmission lines using video frames can be a complex process due to the fact that the application conditions are outdoors. Hence, the illumination effects that depend on the sunlight along with the image background that reflects all the dissimilarities of the natural terrain are issues that had to be taken into account during the design of the proposed methodology. The main idea was to define regions of interest (ROIs) around the power lines using Hough transform and then follow the structure of each line along frames. The key idea was to exploit the parameters of line continuity, resemblance and fixed spacing between power line structures and, finally, the expected large differentiation factor in relation to the environment. These three critical parameters characterize uniquely the presence of power transmission lines in the video recorded by the UAV. Two different approaches were implemented; one with the ROIs defined using the image information and a second one where the ROIs were defined using the Hough table information.

A. *Power transmission lines detection using Hough transform*

The first step in the proposed methodology is the implementation of the Hough transform for every frame in order to detect the power lines. The block diagram of the line detection algorithm is presented in Fig. 2. Each image is converted to grayscale and edge detection is performed using Laplacian of Gaussian and Sobel operator before applying Hough transform and create the ROIs.

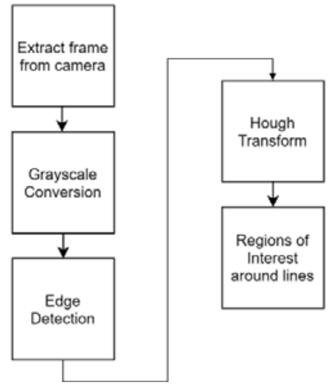

Fig. 2. Block Diagram of the power lines detection algorithm.

Hough Transform is a feature extraction technique, used to detect a certain type of objects (lines in this case) within an image through a voting procedure. A line is a collection of multiple points connected to each other in the Cartesian coordinate system. Given that a straight line is represented by:

$$y = ax + b \qquad (1)$$

a vertical line would result in an unbounded value of the slope parameter a. Thus, Hough Transform utilizes the Hesse Normal form:

$$\rho = x\cos\theta + y\sin\theta \qquad (2)$$

where ρ is the distance from the origin to the closest point of the line and θ is the angle between the x axis and the line connecting the origin with this closest point. As a result, one point in the parameter space is represented by a sinusoidal line in the polar space. The sinusoidal expresses all the possible lines in the parameter space that go through a certain point *(x,y)*. If any number of points in the Cartesian plane is converted to sinusoidals, the corresponding sinusoidal descriptors will intersect at a certain point *(ρ,θ)* or in a larger region around this point due to noise effects. This point expresses the line in the Cartesian plane that goes through those points. The most common case is the one of finding multiple intersections of the sinusoidals. In order to detect certain lines and ignore others, Hough transform follows a voting procedure. Each intersection of sinusoidals holds a number of votes for each new sinusoidal that intersects at the same point. After defining a threshold of votes, lines are detected by finding local maxima.

The final step in the main methodology is the creation of ROIs around the lines. The two approaches that were implemented for this process are described in the following sub-sections.

B. *Regions of Interest Definition using Image information*

The first issue here is to detect of the power lines by performing the methodology that was described in Section III.A, but only for a given number of initial frames. This process continues until the lines are detected for the first time. Then, a ROI is defined as an area around each detected line with 20 pixels width and height as the image's height. For every subsequent frame, the image processing is performed only at the information inside the ROIs and not at the whole frame. Grayscale conversion, edge detection and Hough transform are applied to each ROI in order to achieve faster detection. Since the lines can't always locate at the center of the frame, for each ROI and every frame, a shift location process is performed using the information of the line position at the previous frame (Fig. 3).

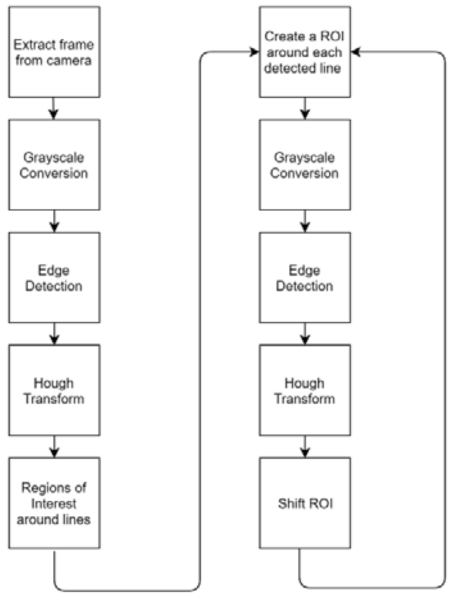

Fig. 3. Block Diagram of the ROIs definition procedure using the image information.

In order to detect the absence of a line in a series of frames, the methodology was expanded by adding two more steps. First, after detection of each set of 3-pair power lines and for every ROI and in every frame, the distance between lines is calculated. If the distance that is calculated in frame *t* is significantly different than the distance calculated in frame *t-1* then the detected line is considered as a false positive (Fig. 4). This situation actually reflects fault detection, the main problem that has to be identified during the inspection of power lines.

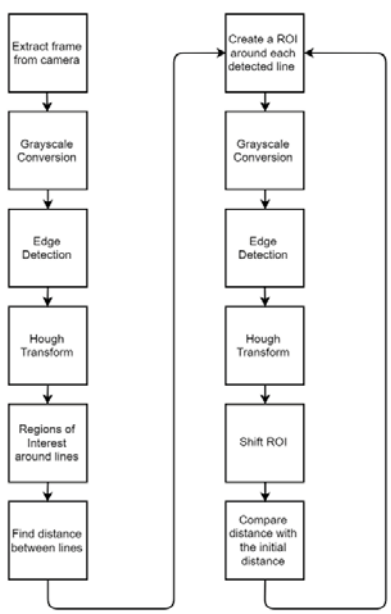

Fig. 4. Block Diagram of the power lines fault detection procedure using the image information.

C. *Regions of Interest Definition using Hough table values*

This approach for the ROIs definition takes advantage of the expected position of the lines, which is the center of the image. Thus, the image is divided into three regions of interest in order to detect one line in each region (Fig. 5). Here, all the steps of this approach are applied on the whole image, while the detection of the lines is not based on the Hough output but it is based on the Hough table values.

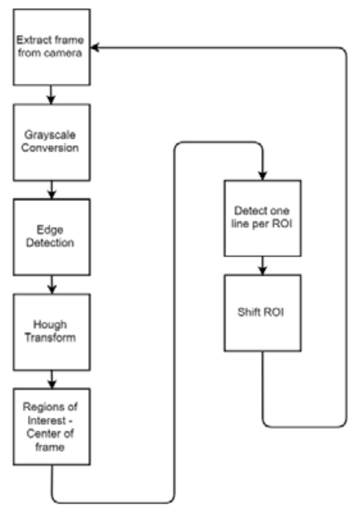

Fig. 5. Block Diagram of the ROIs definition procedure using Hough table values.

Regarding the fault detection process in this approach, the distance between the detected lines is also essential to be calculated in order to have a reference value for comparing in every subsequent frame. If the distance of a detected line-pair is higher or lower than this in the previous frame, then the detected object is not a power transmission line, while the expected position is shown by a cyan ROI (Fig. 6).

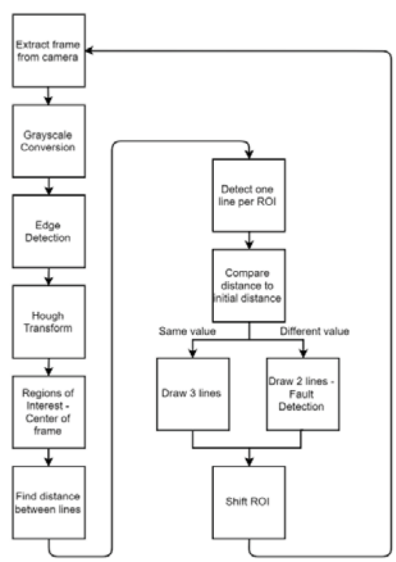

Fig. 6. Block Diagram of the power lines fault detection procedure using the Hough table values.

IV. RESULTS

The proposed methodology was tested at two different locations: the region of Fournes at Chania in Crete (Greece) and a region at the island of Chios (also in Greece). The videos were captured using the UAV described at Section II with the valuable help of staff of the Hellenic Electricity Distribution Network. The specific locations were selected due to the pattern irregularities that appears at the natural terrain (e.g. rocky ground, ground with intense vegetation, roads, etc).

The results of the application of the module for the ROI extraction using the image information are presented in Fig. 7 for both test cases, while the results in the case of the module with the ROIs to be extracted using the Hough table values are presented in Fig. 8.

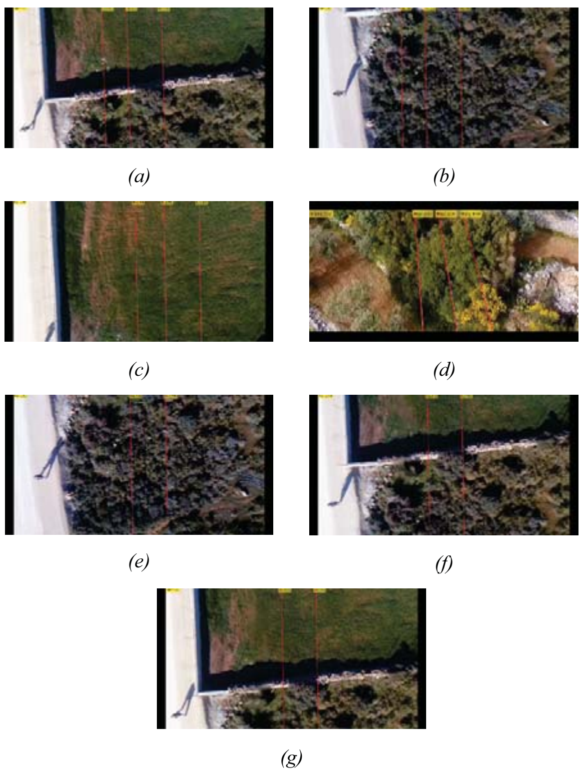

Fig. 7. (a), (b), (c): Correct detection of power lines at subsequent frames - Chania test case, (d): correct detection of power lines - Chios test case, (e), (f), (g): correct fault detection of power lines at subsequent frames - Chania test case.

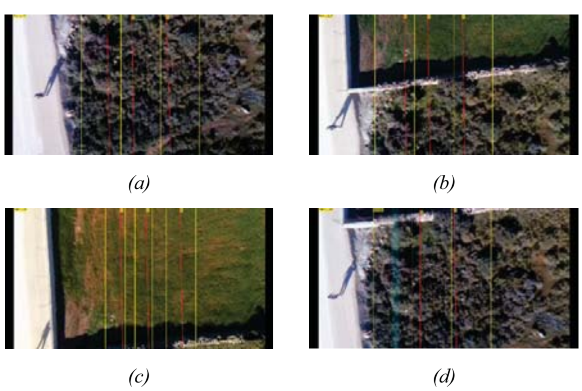

Fig. 8. (a), (b), (c): Correct detection of power lines at subsequent frames - Chania test case – with red the lines / with yellow the ROI boxes, (d), (e), (f): correct fault detection of power lines at subsequent frames - Chania test case.

The results in both Fig. 7 and Fig. 8 reveal the robustness of the proposed algorithm in the inspection of power transmission lines. Although the natural terrain may alternate between rough (e.g. rocky) and smooth (e.g. road) texture and occupy a wide range of different color intensities (e.g. from green vegetation to brown rocks or to road that often has similar color intensity with the power lines), the proposed methodology achieves continuous track of the lines and successfully detects the fault if any. The test cases chosen are indicative of the situations where the technical staff of the Hellenic Electricity Distribution Network needs an automatic way to inform of possible problems of the network without spending human resources to inspect the lines, a case that happens only if a problem at the network occurs.

Regarding the performance of the proposed algorithm, the device that was used for the evaluation was a PC with an Intel Core i7-7700HQ at 2.8GHz CPU, 16 GB RAM, running Windows 10 64-bit. The code was implemented in Matlab environment. The processing time in each case was:

Define ROI using Image – Test CASE Chania:

Processed 297 frames at a total of 13.96sec (0.22sec for the first frame, 0.046 sec for every other frame)

Define ROI using Image – Test CASE Chios:

Processed 297 frames at a total of 15.48sec (0.24sec for the first frame, 0.051 sec for every frame)

Define ROI using Image – Test CASE Chania – Fault Detection:

Processed 297 frames at a total of 10.79sec (0.25 sec for the first frame, 0.035 sec for every other frame)

Define ROI using Hough table – Test CASE Chania:

Processed 297 frames at a total of 76.47sec

Define ROI using Hough table – Test CASE Chios:

Processed 297 frames at a total of 86.19sec

Define ROI using Hough table – Test CASE Chania – Fault Detection:

Processed 297 frames at a total of 76.54 sec.

V. CONCLUSIONS

The present study focuses on providing an automated way for fault detection at the Hellenic Electricity Distribution Network that will help on the network maintenance, especially in areas that are not easily accessible by humans. The key concept is to obtain the exact location of the power line fault avoiding to scan the whole area from the ground forces.

The main idea was to explore the area of image processing in order to see if a simple combination of customized techniques would be enough to handle with the problem under investigation. The reason for that, as future work, is to enable the proposed algorithm to be coded in Python and run on the UAV during its flight, in a way to provide real-time binary information of fault detection. The first results are encouraging since both the accuracy of the power line detection and the processing time are close to expectations.

The ongoing and future work will focus on the optimization of the algorithm and the expansion of its capabilities. The detection of power lines can be improved by applying machine learning techniques in order to train for power lines and reduce the detection of false positives. Fault detection can be extended to find lines that are not physically cut but with thinning wire structure (ready to be broken), which generates increased heat patterns using a thermal camera. Furthermore, we plan to enable the system to obtain measurements of the electromagnetic field, as a means to improve the sensitivity of our optical inspection method, as well as to successfully detect lines in extreme terrain cases such as the gray background of roads.

REFERENCES

[1] Linxin Li. “The UAV intelligent inspection of transmission lines”. 2015 International Conference on Advances in Mechanical Engineering and Industrial Informatics.

[2] Zhang, Yong, et al. "UAV low altitude photogrammetry for power line inspection." ISPRS International Journal of Geo-Information 6.1 (2017): 14.

[3] Hrishikesh Sharma, et al. “Vision-based detection of power distribution lines in complex remote surroundings”. 2014 Twentieth National Conference on Communications (NCC)

[4] Cuneyt Akinlar and Cihan Topal. “Edlines: Real-time line segment detection by Edge Drawing”. 2011 18th IEEE International Conference on Image Processing

[5] Guangjian Yan, et al. “Automatic Extraction of Power Lines From Aerial Images”. IEEE Geoscience and Remote Sensing Letters, Volume: 4 Issue: 3

[6] Lingli Zhu and Juha Hyyppä. “Fully-Automated Power Line Extraction from Airborne Laser Scanning Point Clouds in Forest Areas”. Remote Sens. 2014, 6, 11267-11282; doi:10.3390/rs61111267

[7] Yan Li and Ronald Briggs, "Automatic Extraction of Roads from High Resolution Aerial and Satellite Images with Heavy Noise", World Academy of Science, Engineering and Technology, Vol. 54, pp.416-422, 2009

[8] Liang Liu, et al. “Automatic Extraction of Power Lines from Aerial Images Based on Hough Transform”. 2016 2nd International Conference on Energy, Materials and Manufacturing Engineering (EMME 2016)

[9] Lewis Baker et al. “Power line detection using Hough transform and line tracing techniques”. 2016 International Conference on Image and Vision Computing New Zealand (IVCNZ)