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Video-based technique for damaged spacers detections during power line inspections

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Abstract

In the paper a digital image processing algorithm useful for video-based analysis of power lines spacers' mechanical condition is proposed. For testing purposes the semi-synthetic images of some damaged typical spacers have been used but for the verification of the detection of spacers' location working properties the real images taken from the camera have been used. Presented method is based mainly on the geometrical features' extraction techniques and can be applied in the systems for the analysis of data acquired by e.g. aerial fly-by patrols.

Keywords: spacer, geometrical features' extraction, fault detection.

Wizyjna technika detekcji uszkodzeń odstępników podczas inspekcji linii energetycznych

Streszczenie

W pracy zaproponowano algorytm cyfrowego przetwarzania obrazów użyteczny w analizie wideo uszkodzeń mechanicznych odstępników w liniach energetycznych. Do celów testowych zostały użyte półsyntetyczne obrazy uszkodzeń typowych odstępników, natomiast weryfikacja działania detekcji położenia odstępników została przeprowadzona w oparciu o obrazy rzeczywiste uzyskane z kamery. Proponowana metoda jest oparta głównie na technikach ekstrakcji cech geometrycznych i może być użyta w systemach automatycznej analizy danych uzyskiwanych np. podczas inspekcji lotniczych.

Słowa kluczowe: odstępnik, ekstrakcja cech geometrycznych, detekcja uszkodzeń.

1. Automatic power lines inspection techniques

The most crucial elements of electrical power systems are the power plants and transmission lines. The malfunction of each of their elements may cause the serious economic losses and damages. The power plants are controlled continuously by a number of their employees ready for the immediate solving of the potential problems. However, the wide spread of transmission lines makes the fast reaction almost impossible in the case of any mechanical damages. The main sources of such damages of the overhead transmission lines are weather conditions and the lapse of time causing the aging of the infrastructure. For the highest voltage lines some periodic inspections are performed. Nevertheless, such procedures are time consuming and troublesome because of the length of the lines and some other difficulties with the accessing to the lines in the various terrain conditions.

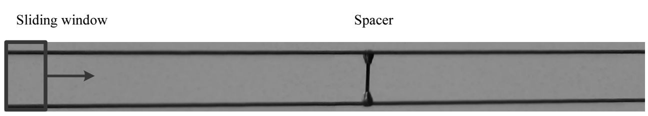
Contemporarily, inspections from the ground as well as the airborne patrols are used worldwide. The most promising solution for the future seems to be the automatic inspection using autonomous flying robot vehicles [1]. Some research efforts in this field cause the rapid development of the methods related to the automatic inspection of the aerial power lines [2, 3, 4]. Such automatic approach can be very useful even if the presence and the assistance of human ground service is necessary. Applying the automatic inspections may cause the increase of the inspections' frequency with lowering their average cost related to the improvement of the network's reliability. Another advantage may be the automation of the inspection documentation processes.

One of the sources of mechanical failures of the transmission lines are the damages of the spacers and the lines in the direct neighbourhood of the spacers. Some results of the research in this field based on the synthetic images and models are presented in [5]. Typical spacer faults in two-wire lines are missing claws, loose of claws, released springs and mechanical split. The loose of claws is extremely hard to detect as it requires specific 3-D spatial configuration of the high resolution camera relatively to the spacer with the lighting conditions taken into account. Because of the poor availability of the images illustrating damaged spacers, usually synthetic 3-D models are used [5].

2. Estimation of the spacer location

The first step of the spacers' fault detection is their extraction from the image, preceded by the extraction of the wires, which can be performed using a number of line position estimation techniques e.g. Hough transform, Markov Chain, morphological operations. Because of the sag of the wires (especially in summer) some algorithms may fail in detection of such curves. However, using local analysis approach and narrow angle camera the visible parts of the wires are almost linear.

In order to simplify further steps, the image is rotated after the detection of the wires' end points at the borders of the image so that the lines representing the wires are almost horizontal. Then the image clipped to the area of interest is analysed locally using the sliding window for the noise reduction and the detection of the spatial differences (Fig. 1).



Rys. 1. Sliding window applied to the rotated image
Fig. 1. Przesuwne okno zastosowane do obrazu po rotacji

In the effect of the local analysis the average luminance value of each row, representing the local vertical profile of the image (Fig. 2), inside the window is subtracted from the luminance of its central pixel. Four small positive peaks visible on the plot on Fig. 2 (near the greater negative ones, representing the wires) are caused by the lossy JPEG compression of the image (implemented inside the camera). In the case when the spacer is not visible inside the sliding window on the image the obtained difference image corresponds to the noise only. For the parts of the image containing the spacer the significant peaks can be easily detected on the obtained differential image after additional low-pass filtration (Fig. 3).

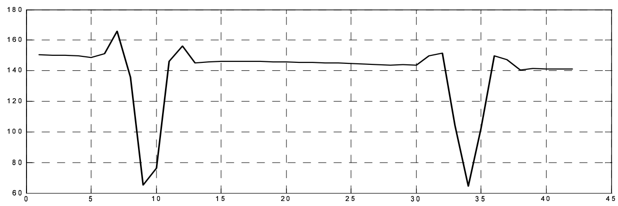


Fig. 2. Example vertical profile of the image
Rys. 2. Przykładowy profil pionowy obrazu

Fig. 3. Obtained absolute differential image after low-pass filtration
Rys. 3. Uzyskany obraz różnicowy (wartości bezwzględne) po filtracji dolnoprzepustowej

A reliable method for the estimation of the spacer's centre position is the application of Centre of Gravity for such image. Obtained coordinates are given as:

$$\begin{bmatrix} x_c & y_c \end{bmatrix} = \begin{bmatrix} \dfrac{\sum_{i,j} i \cdot A_{i,j}}{\sum_{i,j} A_{i,j}} & \dfrac{\sum_{i,j} j \cdot A_{i,j}}{\sum_{i,j} A_{i,j}} \end{bmatrix}, \qquad (1)$$

where $A_{i,j}$ denotes the luminance of the pixel and i, j are the coordinates. The most relevant in such configuration is the horizontal coordinate x_c.

3. Fault detection technique

Having estimated the position of the spacer, regardless of its mechanical condition, the locations of both claws should be detected. After the low-pass filtration of the image for the elimination of noise additional thresholding has been also used. Then searching for the claws is performed in parallel from the top and from the bottom of the previously obtained image. It is worth noticing that horizontal coordinates of both claws after rotation may be different because the perspective should be taken into account. For each row of the image the maximum values are computed and then they are compared to those from the neighbouring rows. The rapid change of them can be easily observed at the ends of both claws.

The image is then rotated in order to ensure the same horizontal position of both claws (vertical orientation of the spacer). For the column representing the spacer (between two different local maximum values) the horizontal profile of that column is calculated as the relative change of the value in comparison to the maximum one. For the homogeneous structure of the spacer the resulting curve does not contain very low values and both boundary values should be close to 1. The presence of low minimum values (below 0.5) indicate the possible damage as well as any of the boundary values below 0.5. In the first case the spacer can be broken and in the second case the missing claw fault occurs. Results obtained for various types of faults with original semi-synthetic images are presented in Fig. 5.

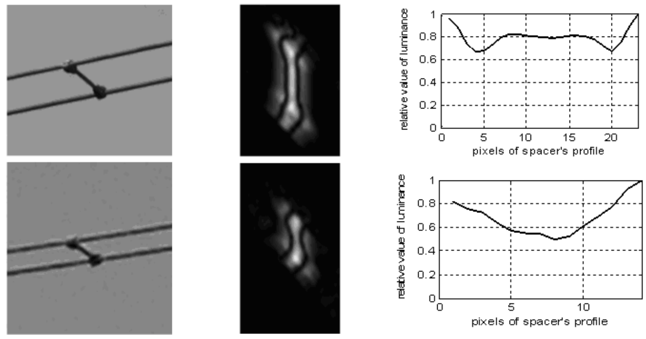


Fig. 4. Original images, rotated differential images and horizontal profiles obtained for spacers without any faults
Rys. 4. Oryginalne obrazy, obrócone obrazy różnicowe i profile poziome uzyskane dla odstępników bez defektów

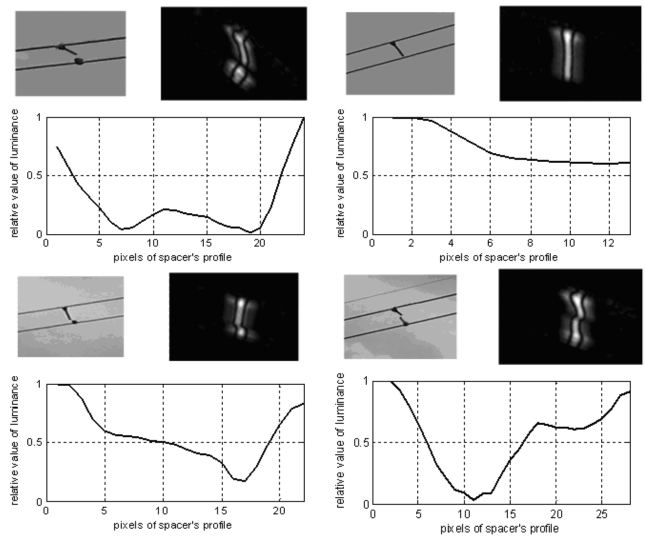


Fig. 5. Original images, rotated differential images and horizontal profiles for various types of spacer faults
Rys. 5. Oryginalne obrazy, obrócone obrazy różnicowe i profile poziome dla różnych rodzajów defektów odstępników

4. References

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Artykuł recenzowany