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The new version of contact-less method for localisation of catenary contact wire – theoretical assumption

Abstract. *This article presents the theoretical basic of a new version of contact-less method for localising the catenary contact wires, using the advanced video techniques and image analysis. So far, contact line diagnostic systems exploited nowadays uses the contact measuring methods with special design current collector. This solutions make it impossible to measure the contact line geometry in a static way. The proposed measurement method using the optical techniques, makes that the static geometry measurements are possible even at high speed of diagnostic car.*

Streszczenie*. W artykule przedstawiono założenia teoretyczne nowej wersji bezkontaktowej metody lokalizacji przewodu jezdnego sieci trakcyjnej wykorzystującej zaawansowane techniki wizyjne i analizę obrazu. Obecnie eksploatowane systemy pomiaru położenia przewodu jezdnego bazują na specjalnie wykonanych odbierakach prądu. Takie rozwiązanie uniemożliwia pomiaru geometrii sieci trakcyjnej w sposób statyczny. Proponowana metoda bezkontaktowa umożliwia taki pomiar nawet przy dużej prędkości poruszania się pojazdu diagnostycznego.* ***(Nowa wersja bezkontaktowej metody pomiaru położenia przewodu jezdnego sieci trakcyjnej – założenia teoretyczne)****.*

Keywords: diagnostics, contact lines, electric traction
Słowa kluczowe: sieć trakcyjna jezdna, diagnostyka, trakcja elektryczna

Introduction

Increase in the power consumed by electric traction vehicles moving on the railway network and increase in their speed result in a greater number of problems connected with delivery of energy to the vehicle. Delivery of energy is the basic element of trouble-free and reliable operation of electrified rail. The quality of energy collected by the vehicle depends on several factors:

- construction, adjustment and maintenance of contact line,
- construction, adjustment and maintenance of current collectors;
- speed at which the vehicle is moving;
- technical condition of the track;
- external factors (wind speed, humidity, icing etc.).

Technical diagnostics plays an important role in maintenance, in good technical condition, of the components which are responsible for supplying energy to the vehicle. Diagnosis of contact line used on PKP railway lines is performed with the use specialized measurement cars (see Fig. 1a.). This system was developed by a team of Department of Electrical Engineering in Transport (formerly Department of Electric Traction) and implemented in 1994. Since then, it has been continually upgraded and modernized, and currently there are plans for its reconstruction. In this system the measurement of contact wire position is realised by use of the contact method, which employs a specially modified current collector with a sectional contact tip (see Fig. 1b.).

a)

b)

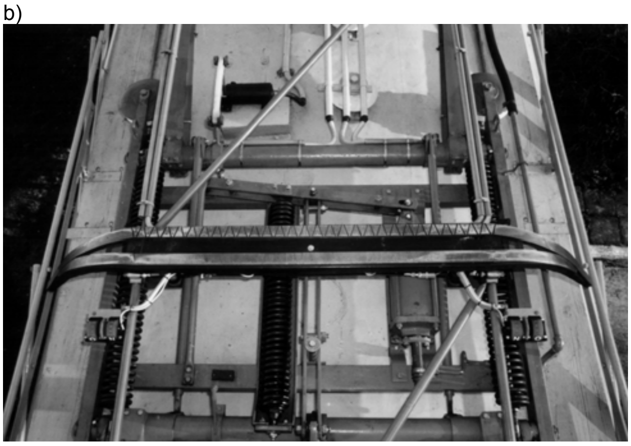


Fig. 1. Currently operating contact line diagnostic system DST, where: a) view of measuring car; b) measuring current collector with sectional contact tip [5]

Measuring current collectors are also used in diagnostic cars operated by other railway companies, including the German, French, Italian, Japanese or Russian railways [1-3, 5-9]. They allow for registration of characteristic quantities, which are important for the proper exploitation of the catenary. Usually the following quantities are checked: height of contact wire suspension, stagger of contact wire and parameters of the overhead junctions. The stiff points of catenary are also detected in the process. The main weak point of contact measurement methods is the inability to measure geometry of contact wires in a static way, i.e. in the situation where the contact wire is not lifted by a current collector. Sometimes only quasi-static measurements are performed, with very limited speed of measurement car. The slow speed eliminates aerodynamic influence of current collector on the contact line. However, it does not solve the problem of measuring the contact line geometry in a static way. The contact-less method for measuring geometry of contact wires, which is described in this article allows for performing the measurements in a static way, even when the diagnostic car moves at high speed [12].

Specificity of contact-less measurement systems

In contact-less measurement systems, electromagnetic radiation with different wavelengths is the transmission medium, which allows for recording of selected parameters by a sensor. In the video measurements system the most frequently used medium is radiation from the visible spectrum and near-infrared (imaging cameras, laser range finders) and the far-infrared (thermography). It is possible to distinguish two basic vision measurement methods:

- passive – the sensor detects the radiation emitted directly by the tested object or reflected from by it, while the source of the radiation is not connected with the measuring equipment (i.e. sunlight);
- active – the measuring equipment contains the source of radiation, which is directed in an appropriate way on the tested object, and the reflected flux reaches the sensor (i.e. laser diodes or illuminators).

A common feature of the video measuring techniques is higher or lower degree of susceptibility to disturbance associated with the presence of external radiation. When a measuring device operates in a closed room the problem of disturbance is not too troublesome. In a closed room the level of external radiation is constant, and it is easy to eliminate its influence on the measurement process. A different situation occurs when the measurements are performed in field conditions, where there is considerable variability of radiation (light) level associated with the daily light cycle, annual light cycle and current weather conditions. Of course, different measuring devices have different susceptibility to external disturbances. Comparatively, the least sensitive systems are the ones using laser radiation (such as range finders, scanners, etc.). On the other hand, where the measuring signal is an image captured from the camera, the influence of external radiation on the measurements result is the most significant.

Idea of the measurement method

The contact-less method of localization of catenary contact wires, which is presented in this article, uses optical technology combined with advanced video image analysis. The concept of the measurement method is presented in Fig. 2.

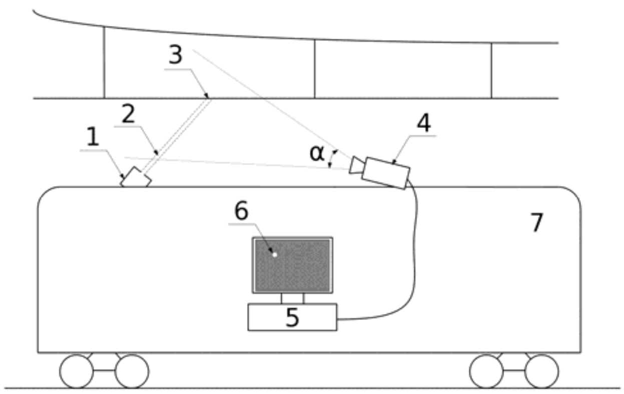


Fig. 2. The concept of contact-less measurement method for localisation of catenary contact wires (described in the main text)

The source of light (1) placed on the roof of the diagnostic car (7) emits a slotted light beam which looks like a light curtain (2). This light beam falls on the catenary contact wires (3). The light reflected by from these wires is recorded by a video camera (4). The view angle of the camera lens must be chosen in such a way that the contact wire in the surface of intersection with the light beam is always situated within the coverage area of the camera picture. This picture field area must include a range of possible position changes of contact wires, together with the assumed area of overflow of the nominal values. The measurement image, which is the light spot reflected by from the contact wire (6), is stored by a computer recorder (5). The movement of the light spot in the picture field corresponds to the movements of catenary contact wire. The computer analysis of image allows for obtaining the target measurement results. Measurements performed with the use of the proposed method make it possible to register the following quantities:

- height of contact wire suspension measured in a static way;
- stagger of contact wire measured in a static way;
- localisation of suspension points;
- localisation of section insulators.

Phases of measurement image processing

In the presented measuring method the following two phases of image processing can be distinguished:

- The first phase (pre-processing), in which the measurement source data (camera image) is converted by image analysis methods in such a way that the required target image is obtained, i.e. a bright spot showing the location of contact wire on black background;
- The second phase (main processing) is gaining from the target image (after pre-processing), information on the location of contact wire in space. This is a replacement of graphic data with numerical data which are the outcome of the measurement.

I. Pre-processing

The purpose of pre-processing is such convertion of the source image that, regardless of its parameters, the obtained output image contains only the searched information. In the current case, such information is a bright spot on black background, which shows the location of contact wire.

The desirable result may be achieved by use of two methods. The first involves using a universal algorithm which allows for obtaining proper parameters of the output image, irrespective of the input image parameters. The second method involves preliminary evaluation of main parameters of the input image (brightness, contrast, saturation). Based on this one of several algorithms, which is best adapted to current parameters of the input image, is selected. It is to be expected that the second method, although more complex and more difficult to implement, will allow for obtaining correct analysis results for a wider range of changes in input image parameters.

Regardless of the chosen method, the algorithm of image analysis consists of a series of basic operations carried out in a different sequence. The most common basic operations are as follows [4, 10, 11; 13, 14]:

- region of interest – a procedure whose aim is to speed up image processing by pre-limiting its analysis to the area, where the desired result, i.e. the image of light spot reflected from contact wire is expected to be found;
- LUT conversion (Look up Tables) – transformation of the image consisting of, which involves changing the parameters of each pixel in accordance with certain dependencies. This procedure makes it possible to change such image parameters as brightness, contrast and gamma slope;
- colour thresholding – transformation involving of extraction, from the image, of colour information assigned to only one basic colour, and removal of the other two colours;
- binary conversion – changes a mono-colour image into a black and white binary image;
- morphological transformations – allows for such modification of the image that the desired features are extracted from it, while the impact of unwanted items is

minimised. Basically, morphological transformations depend on veryfing the whole image area pixel by pixel, and checking if the surroundings of each pixel satisfy a certain condition. Based on this comparison a decision about parameters of each pixel in the image is taken. The most important morphological transformations are: dilatation, erosion, closing, opening, peak detection, valley detection, separation, shearing and morphological skeleton;

– median filter – this transformation allows for balancing and smoothing the edges of picture elements, which results in efficient removal of the noise from images;

– morphological fragmentary filter – transformation which allows for removal of image elements with specific dimensions, shapes, etc., such as elimination of objects which are too large;

– low-pass filter – makes it possible to eliminate small unwanted disturbances from the image.

Selection of specific image transformation operations depends on parameters of source image. Sometimes it may be necessary to apply a certain transformation several times, each time with different modification parameters.

II. Main processing

Following pre-processing the image should contain only a bright spot on dark background, which is the image of contact wire. However, this information is not the measurement result. The position of the light spot has to be converted into the values of suspension height and stagger of contact wire. Relative geometric position of individual elements of the measurement system is shown in Fig. 3.

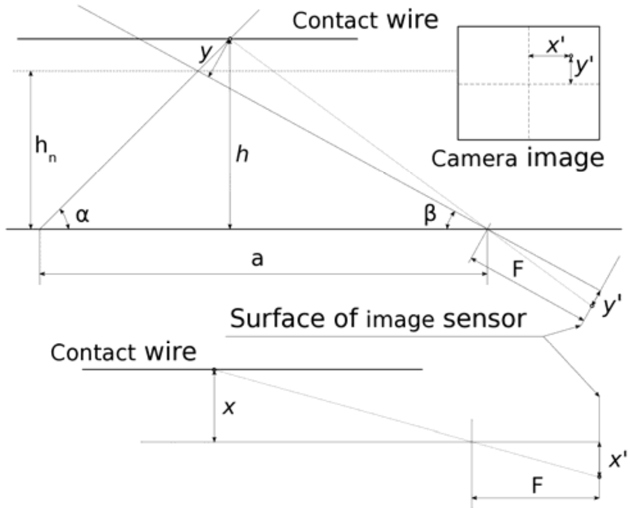


Fig. 3. Geometry of measurement device, where: α – inclination angle of light source; β – inclination angle of measurement camera; a – distance between light source and camera focus lens; F – camera lens focal length; x', y' – coordinates of the light spot on the camera sensor to the center of the image, corresponding to the position of light point with coordinates x, y; h_n – nominal suspension height of contact wire in relation to basic height (level of the measuring car roof); h – real (measured) suspension height of contact wire (in relation to basic height)

The camera should be positioned in such a way that the light spot reflected from the contact wire, when being in the neutral position (at a nominal suspension height – in Poland 5.6 m) and symmetrical position in relation to the track axis, is in the centre of the measurement image. In this situation the suspension height of contact wire is as follows:

$$h = \frac{a \cdot \tan\alpha}{1 + \dfrac{\tan\alpha \cdot \left(1 - \dfrac{y'}{F} \cdot \tan\beta\right)}{\tan\beta + \dfrac{y'}{F}}} \tag{1}$$

The calculated value of contact wire height depends only on one variable, namely on vertical position of the light spot in relation to the central point of the image. The situation is different during the calculation of contact wire stagger, which quantity is given by the formula:

$$x = \frac{\dfrac{x'}{F} \cdot a \cdot \tan\alpha}{\tan\alpha + \left(\dfrac{\tan\beta + \dfrac{y'}{F}}{1 - \dfrac{y'}{F} \cdot \tan\beta}\right)} \tag{2}$$

As it can be observed, the calculated value of contact wire stagger depends on both coordinates of the light spot. This is due to the fact that the plane of luminous flux and plane of the camera image sensor are not parallel, and also to the trapezoidal distortion of the image associated with it. If the above mentioned parallelism has been preserved, i.e. the sum of the angles α and β = 90°, then the calculated value of contact wire stagger would depend only on one variable. However, this simplification is not possible, because then the luminous flux would be reflected in the direction of the camera to a much lesser degree which, in the extreme situation, would make it impossible to perform the measurement.

Results of preliminary laboratory research

In order to check the assumptions of the method, some preliminary research has been done, using a laboratory model of catenary made in 1:5 scale. The images were recorded by a Samsung SHC-737 camera equipped with a Computar lens 8 mm f/1.2. A line of semiconductor, high brightness diodes was used as the illuminator, which was properly diaphragmed so as to obtain a slotted light beam. The images were registered in different lighting conditions and then exposed to the processing described above. It was decided to use a universal algorithm consisting of steps presented below in Fig. 4.

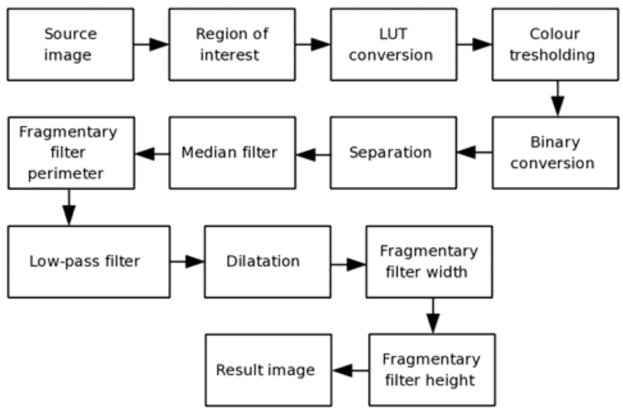
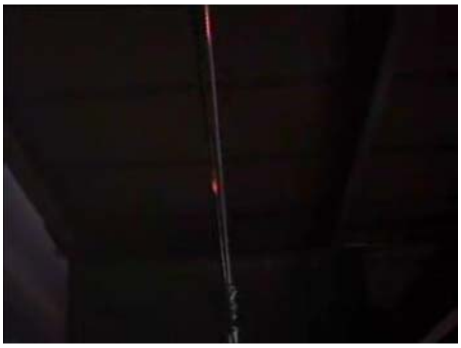
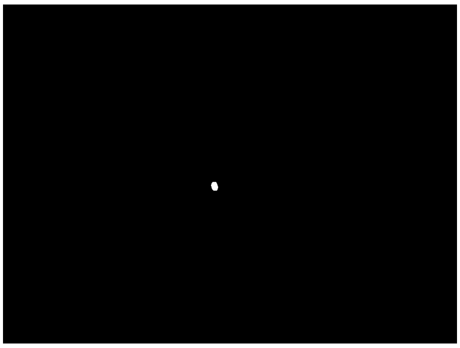
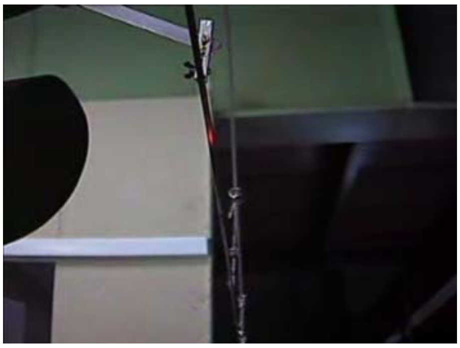
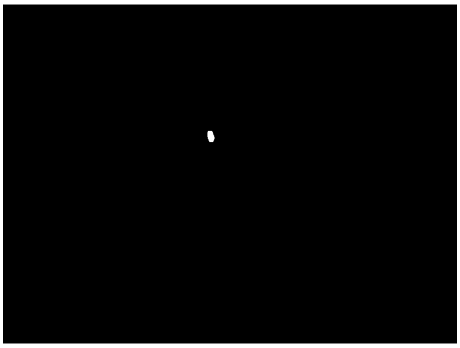
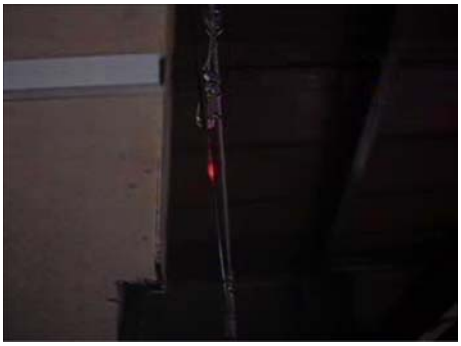
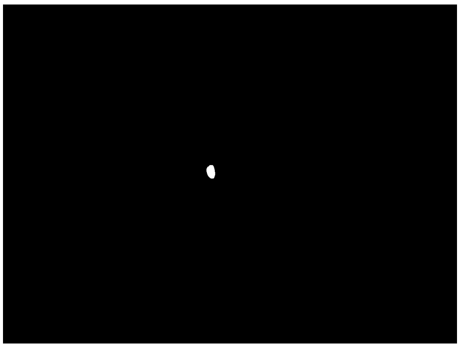


Fig. 4. Graphic processing algorithm

Table 1. Sample measurement results

Source image	After pre-processing	After main processing	Real values
		h = 47.3 cm x = -1.2 cm	h = 47.0 cm x = -1.5 cm
		h = 51.4 cm x = -11.1 cm	h = 49.0 cm x = -10.5 cm
		h = 51.3 cm x = -1.4 cm	h = 49.0 cm x = -1.8 cm
		h = 48.4 cm x = -1.5 cm	h = 48.0 cm x = -2.0 cm

Afterwards, the main processing was performed. Based on the location of light spot and geometrical dimensions between the camera and illuminator, the final measurement results were obtained. Sample results, together with the intermediate stage of the analysis are shown in Table. 1.

As it can be observed, a good coincidence between measurement results from contact-less method and direct method was obtained. Some inaccuracies are caused by unevenness of the model railway track and the image distortion contributed by the measuring camera lens.

Planned research and problems to solve

Image processing algorithm should ensure obtaining solely the image of contact wire. The main problem which may occur is elimination of unwanted signals from the components which are not the contact wire, particularly the catenary wire, droppers and steady arms. Removing the signal which comes from the catenary wire and droppers should be possible thanks to logical elimination. It is known that the catenary wire is always located above the contact wire. Therefore, as images lying at different heights are obtained simultaneously, it can be assumed that the top spot is a reflection from the catenary wire or the dropper, and it can be deleted. Reflection of light coming from steady arms will have a different shape than the image reflected from the contact wire. Hence it should not be difficult to eliminate this kind of signal. However, this signal can be used to locate contact wire suspension points. Another issue is selection of the way in which the signal for contact lines with two contact wires is displayed. It seems that double signalisation makes it possible to obtain more complete information about the technical condition of contact line. It means that the information on localisation of both contact wires will be displayed. Research on the processing algorithm will be continued in order to allow for practical relisation of the above assumptions.

Conclusion

The proposed measurement method allows for performing measurements of contact line geometry in a static way, even when the diagnostic car moves at high speed. Measurements of this kind have been practically impossible to perform so far. The implementation of this measurement method will allow for much more complete and more comprehensive diagnosis of the contact line. A wider range of diagnostic tests will improve the technical condition of contact line and will reduce the amount of line and rolling stock damage. This, in turn, will increase reliability of rail transport, as well as reduce its maintenance costs.

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