Automatic Optoelectronic System for Inspection of Wire Wear Using High-Speed Image Analysis

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Abstract. *Advanced automated optoelectronic system for contact wire wear inspection on the go using a structured light method is presented. The algorithm of the video stream analysis and approaches to its implementation using high-performance electronic equipment are given. The automated system described has allowed measuring wear parameters with 10 mm interval at the inspection wagon velocity of 60 km per hour. The root-mean-square error for the measurements of the remaining height and contact plot constitutes 0.15 and 1.5 mm*^{2}. *The system also can be utilized to inspect public transportation network and to measure the geometric parameters of cables and tubes being fabricated with rolling technique.*

Keywords: Contact Wire, Wear Measurement, Structured Light Method, High Speed Real-Time Image Processing

1. Introduction

To ensure the safety in industry, transport and nuclear power system, it is required to inspect the geometry of distant industrial articles. Particularly, safety of railroad transportation takes continuous inspection of the geometric parameters of wearing constructions, especially a contact wire wear and defects of a railroad network. A number of automated systems [1-3] utilized by the industry that detect the wear on the go using the noncontact method are put into operation on Italian, Germany and Japanese railroads. At the present time there is no functional automated system in Russia, which meets construction features and operational conditions of our railroads. In this article we are presenting a problem of contact wire flaw detection, significantly improved method for wire wear calculation and fast automated system for real rail applications.

During long operation period the contact wire can be subjected to some geometrical defects that require their timely detection and removal. Unworn-out contact wire (Fig. 1a) and possible geometrical defects are shown in Fig. 1 b, c, d. The standard defect is decreasing of the cross-section area due to the friction against a current collector that result in increase of the specific resistance and may cause a wire break (Fig. 1b). In this case the wear is characterized by the two key parameters (Fig. 1b): the width of the wear contact area (w) and the wear depth (D).

The system to be developed must meet the following requirements: 1) noncontact principle of measurement; 2) simultaneous flaw detection of up to 4 wires in a catenary suspension; 3) the measurement error must not exceed 0.2 mm; 4) the measurement space interval of at least 10 mm at inspection wagon velocity of 60 km/h.

There are many methods and systems for inspection of geometric parameters of industrial articles under their fabrication or operation [4]. The shadow method [5] being the simplest and widely applied cannot provide flaw detection of contact wires due to the construction features of wire networks.

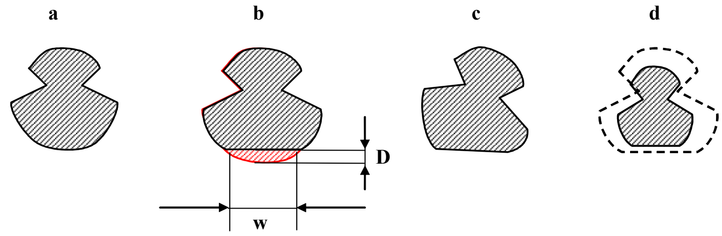

Fig. 1. A contact wire profile and its flaws: an unworn wire (a); a standard defect (b); a "turn" defect (c);"neck" defect (d).

Currently the majority of the automated optoelectronic systems in use are based on so-called a contact pad measurement method [1, 2]. The significant disadvantage of this method is informational limitation of the regular signal received. Being high-performance these systems [3] are not capable to detect and correctly determine such defects as a 'turn" or a "neck" defect and cannot process a big set (up to four) of contact wires in one catenary suspension system.

A part of the above-mentioned problems can be solved using the structural light method [6]. As for the problems of transferring and processing of large video information flows as well as the measurement of wire residual height with sufficient accuracy under the high wear values, they has not been solved for the present time.

2. Optical Layout and Electronic Components

The optical layout of the measurement unit is displayed in Fig. 2. The pulse mode of the laser provides high brightness of the radiation scattered on the surface of the contact wire that has significantly increased the S/N ratio of the image. The small exposure time (from 5 to 20 μs) allows us to filter a significant part of background noise. Thus, the images obtained could be segmented into connected regions for subsequent processing. The images of unworn and worn wires, taken at frequencies of ~1000 Hz with structured light method, are displayed in Fig. 3.

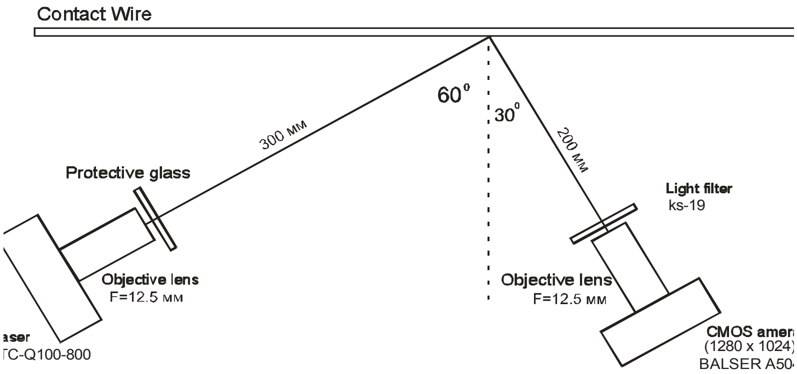

Fig. 2. Optical layout of contact wire wear inspection system.

The A504k camera includes the following benefits: a rugged housing designed for use in industrial environments, 500 frames per second at one megapixel resolution, area of interest (AOI) scanning allows higher frame rates. Matrox Odyssey Xpro+ is a scalable, vision processor board. It has a processing section and supports an optional frame grabber module for image acquisition. Video processor mainly unloads connected pixel area processing from CPU. The laser illuminator source has to provide a given value of radiation-intensity distribution for every point of the observational volume, and the registration unit has to provide a contrast image with constant magnification for each point of the volume. The inspection productivity of the new system developed is limited by the impulse frequency of the laser, which is connected to the frame grabber of the video processor via a synchronization circuit and no longer limited by other elements as in [6]. Using camera with laser pulse timing generator with the same frame size we reach performance peak with 1000 frames per second.

3. Fast Image Processing

The first step of the image processing is indication of the informative sections of an image i.e. those that contain the image of the cross section of the wire illuminated by the laser beam. Such sections reveal themselves as connected pixel areas with quite a number of pixels. To simplify the search the areas are being traced in the frame sequences while the measurements are carried out. We assume a shape of contact wire to be constant in range of laser beam width. So it is enough for us to calculate the centers of mass by the brightness for every vertical column of pixels, converting the radiation intensity shape in a line. Doing that one should take into account the geometric distortion caused by the fact, that wire illumination angle and wire acquisition angle are not equal [6].

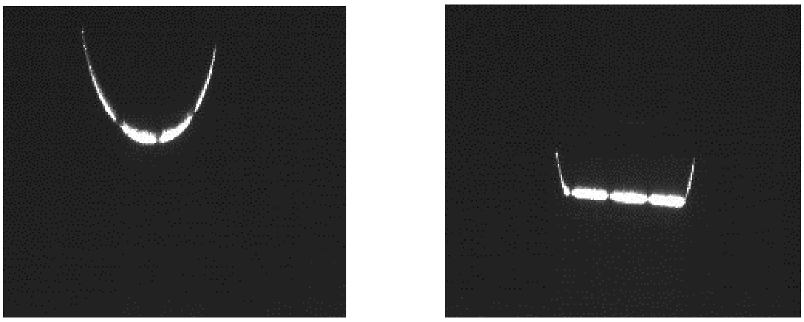

Fig. 3. Real nonprocessed (raw) image of contact wire under structured light for unworn wire (left) and worn wire (right) cases.

Processing the curve, represented by the centers of mass detected one determines the profile of the contact wire cross section. To do that one selects using algorithmic analysis, the centers that mark unworn sections of the wire surface. Within the sections the cross section of the wire has round shape. It allows us to calculate the center of the cross- section outline as the center of a circle with the similar set of points using statistic methods.

In more details the computational procedure could be described as the following: a) one searches for all possible combinations (A_i, B_k), where A_i is running through all the points of the first group, and B_k - of the second (see Fig. 4); b) for each cross section one finds circle's center $C_{i,k}$ with known radius R containing the both points; c) one calculates standard deviation $d_{i,k}$ for all the points of the both groups from the circle as it has been determined previously; d) after determining all possible combinations one searches a center of a cross section according to the following formula: $C=(\sum_{i,k} C_{i,k} * \frac{1}{d_{i,k}})/(\sum_{i,k} \frac{1}{d_{i,k}})$ i.e., one determines the center of mass for previously determined points $C_{i,k}$ with weight function $\frac{1}{d_{i,k}}$.

It is supposed that the size of a cross section and its allowable wear height are determined for each contact wire mark and are set initially. The groups of the centers of mass and the results of cross-section profile determination are displayed in Fig. 4. The video processor also computes the array of the vertical centers of the connected components. The wire cross-sections recognized together with the information on spatial location and wear of a contact wire are placed into a special database. The data allow one to reconstruct the history of inspection sessions and to control performance quality of the system at the critical points of the contact network inspected.

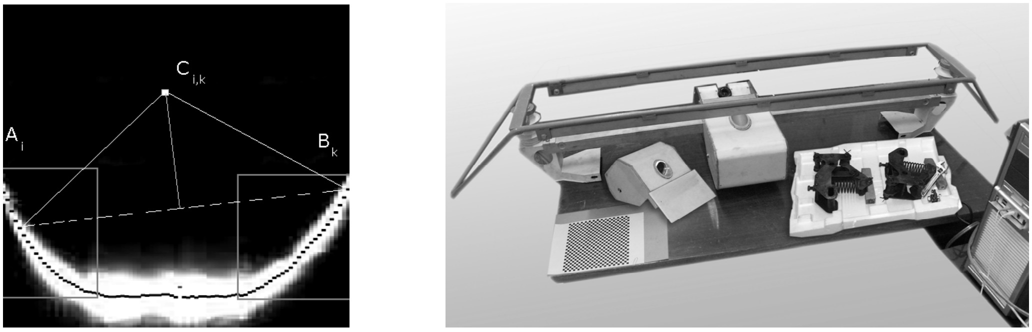

Fig. 4. Groups of mass centers inside square marks used for determination the center of a cross section (left) and real system (right) dismantled from inspection vagon after series of tests.

System has been tested on the «Seyatel» train station. Measurement system was fixed on the current collector of inspection vagon moving with 60 km per hour speed along a track section contains 2 contact wires in catenary suspension. The root-mean-square error for the measurements of the remaining height and contact pad constitutes 0.15 and 1.5 mm^2 correspondently.

4. Conclusion

We have presented an advanced automated optoelectronic system for fast contact wire wear inspection. The algorithm of the video stream analysis and the variant of its implementation using high-performance electronic equipment were developed.

The automated system described has allowed measuring wear parameters with 10 mm interval at the inspection wagon velocity of 60 km per hour. The system also can be utilized to inspect contact wire wear in public transportation network and to measure the geometric parameters of cables and tubes being fabricated with rolling technique.

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