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Anomaly detection using a modified kernel-based tracking in the pantograph–catenary system

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ABSTRACT

Condition monitoring is very important in railway systems to reduce maintenance costs and to increase the safety. A high power is needed for the movement of the electric train and collection of the current is critical. Faults occurred in the current collection system cause serious damage in the line and disrupt the railway traffic. When a wear occurs on the contact strip, the asymmetries and distortion are generated in supply voltage and current waveforms because of pantograph arcing. Therefore, the monitoring of pantograph–catenary system has been a hot topic in recent years. This paper deals with a method based on kernel-based object tracking for identifying the interaction between pantograph–catenary systems that gives useful information about the problems of catenary-pantograph systems. The method consists of two key components. The first component is based on the kernel based tracking of the contact wire. The contact point between pantograph and catenary is tracked and the obtained positions are saved as a signal. In the other hand, the foreground of each frame is found by using Gaussian mixture models (GMMs). The occurred arcs are detected by combining tracking and foreground detection methods. The second component employs S-transform for analyzing the pantograph problems, which are used to detect the faults occurred on pantograph strip. The experimental results imply that the proposed method is useful to detect burst of arcing, and irregular positioning of the contact wire.

1. Introduction

In overhead electrified railways, the reliability and safety are important for a safe operation. The current is transmitted to the train from a sliding contact between the moving pantograph and the overhead contact line (Landi, Menconi, & Sani, 2006). The quality of the current collection is based on a continuous contact between pantograph and overhead wire. When the contact wire has lost, an electric arc will occur (Barmada, & Tucci, 2011). Poor contact may cause arcing and wearing of the contact strips. A maintenance scheduling is required to ensure the efficiency of the contact strips. The railway companies replace them before their maximum wear because there is not any method to measure the useful life of the contact strips. Therefore, the monitoring of the pantograph and catenary system has gained a great interest in recent years. The breakdown of pantograph and catenary system causes great economic losses. The maintenance costs can be reduced by monitoring critical points in the overhead lines and by predicting the wear of contact wires at an early stage. Arcing generally occurs at higher speeds, under increased load, and in cold weather conditions (Midya, Bormann, Schütte, & Thottappillil, 2009a, 2009b). A pantograph draws a lateral zigzag pattern on the overhead line (Zhang, Zhou, Li, Mei, & Song, 2011). However, the overhead line applies more contact to some locations of the pantograph as a result of faulty conditions. Pantograph arcing faults occur because of following reasons (Keen, 1998), including

- Incorrect static contact force,
- Excess friction,
- Incorrectly set aerodynamics,
- Worn components, and
- Poor geometric adjustment.

Condition monitoring is a very important process in critical components of industrial systems. Many methods have been proposed to prevent catastrophic faults in these components (Aydin, Karakose, & Akin, 2010; Vachtsevanos, Lewis, Roemer, Hess, & Wu, 2006). A critical subsystem in railway industry is the pantograph–catenary system because a defect occurred in this system causes serious injuries and the disruption of the railway traffic. The most used maintenance technique is based on the periodic

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inspection of the line by using an inspection vehicle. However, this method is expensive and it requires the line to be temporarily out of service during inspection (Barmada, Landi, & Sani, 2003). Additionally, the locomotive must be taken into service for inspection. Therefore, an automatic implementation of a diagnostic process is required to detect defects in the pantograph–catenary system at an early stage. Signal and image processing based methods have been proposed for automatic diagnostic of the pantograph and catenary system. The vibration signals were obtained by establishing an experimental setup and the mechanical behavior of the pantograph were analyzed (Boffi et al., 2009; Collina, Fossati, Papi, & Resta, 2007). This approach does not give accurate results when small defects are present. An accelerometer based data acquisition system is mounted directly to the train and condition of the pantograph and catenary system is monitored (Daadbin & Rosinski, 2010). However, the experimental setup is established on the contact strip and this prevents making a reliable measurement. Signal processing methods have been applied to current and voltage signals for detection of arcing in the pantographs of DC and AC railways (Balestrino et al., 2002; Barmada et al., 2003; Barmada, Raugi, Tucci, & Romano, 2014; Barmada & Tucci, 2011; Midya et al., 2009). To verify the arc occurrence through the ultraviolet emission, phototube signals are also acquired. A threshold value is determined on the phototube signal to distinguish healthy and anomaly condition. The features are extracted from current and voltage signals by applying signal processing techniques. After the healthy and anomaly data set has been obtained, arcing related anomalies are detected by using features extracted from current and voltage signals. However, the threshold value defined on the phototube signal is not sufficient to distinguish healthy and anomaly condition. The experimental setup stores only the relevant signals and diagnostics are performed offline. In recent years, some attempts to analyze the infrared and normal images taken from the pantograph have been made; in particular, image processing methods such as edge detection (Aydin, Karakose, & Akin, 2012; Heng, Rong, Yong, Li, & Kai, 2010), Hough transform (Landi et al., 2006), image segmentation (Boguslavskii & Sokolov, 2006) are used for analysis of the contact point. The main aim of all studies is to find the contact point and pantograph overhead in order to analyze the pantograph–catenary system. However, the used edge detection algorithms are affected from noises such as trees, weather condition, and so on. So, the developed methods inspect the pantograph image taken in a laboratory environment. In the most case, the contact position may not be accurately detected by using Hough transform. The mechanical sensors are expensive and the setup of an experimental mechanism is difficult. The pantograph arcing and disorders of the contact wire was detected by tracking the contact wire by using mean-shift algorithm and foreground detection (Aydin, Karakose, & Akin, 2013).

In the literature, computer-vision based methods are very limited for monitoring of pantograph–catenary interaction. The used image processing based methods first apply a transformation such as edge detection, Hough transform, and image segmentation. Afterwards, the contact point and pantograph overhead are searched in the new transformed image. A new method is proposed to analyze the condition of pantograph–catenary system with the modified kernel based object tracking. In the proposed method, the contact wire is selected in the first frame and it is tracked along all frames. While the modified kernel based tracking method tracks the contact wire, the foreground of the frame will also be obtained. Pantograph arcing is found by applying blob analysis to the foreground image near the contact wire. There is no need to search the pantograph overhead in the overall image. The irregularities in the contact wire are detected by applying S-transform to the obtained positioning signal of the contact wire. The research based on object tracking is totally new for pantograph studies and its results are meaningful to detect the pantograph arcing and the irregular positioning of the contact line.

The paper is organized as follows. Section 2 introduces the interaction between pantograph and catenary system. Section 3 explains the details of the proposed method for anomaly detection. Experimental results are shown in Section 4. Conclusions are given in Section 5.

2. Pantograph–catenary interaction

The pantograph–catenary system is the most used equipment for collecting electric energy in today electric trains. A constant power can be taken from this system when the continuous contact has been ensured. The contact force affects the pantograph–catenary interaction. In an ideal condition, pantograph–catenary system should be operated under low contact forces. An illustration of pantograph–catenary system is given in Fig. 1.

In Fig. 1, the contact wire is connected to the messenger wire via dropper wires. The continuous contact between the pantograph and an overhead wire affects the quality of current collection. The pantograph must apply a sufficient force to the overhead wire in order to ensure a permanent contact. Achieving a good balance between the pantograph and the contact line depends on the quality of the current collectors and the lifetime of the contact wire. The continuity of the contact is important to ensure better electrical performance.

Catenary system is constant system constructed along railway line. There are many elements which constitute a catenary system. A catenary system is given in Fig. 2 in a detailed form.

In Fig. 2, the components of a catenary system are depicted. Some catenary systems vary according to usage conditions. Catenary system is fixed at regular intervals by using poles. These poles are generally a concrete structure and they are linked to contact wire thorough iron arms. The pantograph is used to ensure permanent contact with sufficient force. A pantograph moves over the contact wire by drawing zigzags. The interaction between pantograph and overhead wire is given in Fig. 3.

When the contact between the pantograph and catenary system has lost, an electric arc will occur. This arc causes the degradation of contact strip on bow and contact wire. If there is a continuous contact between pantograph and catenary system, any voltage difference does not occur. However, an arc occurs because of below reasons:

- Mechanical vibrations,
- Wear of contact wire,
- Frozen contact wire,
- Contact force at the same points.

Above effects create a voltage difference between two electrodes. This leads to the gas discharge and occurred high temperature causes burning arcing.

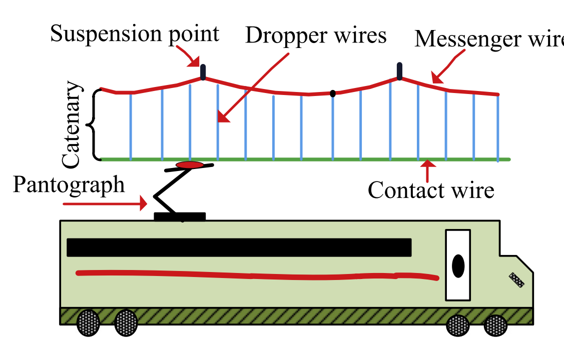

Fig. 1. Catenary system and pantograph in an electric train.