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Application of a Robust Photogrammetry Method for Uplift Measurements of Railway Catenary Systems in Noisy Backgrounds

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Abstract

A portable vision-based tracking system is proposed and applied to enable low-cost, remote, noncontact and non-marker uplift measurement of railway catenary wires. The challenge in measuring the vertical displacement of the railway catenary systems is to detect linear rigid body motion in front of a noisy background with a high sampling frequency. To detect wires in front of noisy backgrounds, a novel line tracking method is proposed and used to achieve robust and accurate measurements. The vision-based tracking system with the line tracking method has been successfully applied to measure the vertical displacements of the railway catenary wires in front of a noisy background. The vibration of the catenary wires is simultaneously obtained by the vision-based tracking system and laser displacement meter at the same high sampling frequency. The accuracy, robustness and applicability of the proposed tracking system are demonstrated through the comparison with the laser displacement meter. From the obtained results, it can be concluded that the vision-based tracking system can be used for filed uplift measurement of railway catenary systems, and offers the attractive advantages of remote, noncontact and non-marker measurement, without track access, easy to installation and application.

Keywords: vision-based line-tracking system, image processing, photogrammetry, railway catenary, contact wire uplift.

1 Introduction

Pantograph-catenary system is one of the critical components of the electrified railways, a system used to ensure stable and continuous power supply for trains [1]. The interaction between the pantograph and catenary system will produce a contact wire uplift when a train pass. Any excessive uplift will increase the risk for either mechanical contact between components or loss of contact between the contact wire and the pantograph [2]. The latter is more common and will not only interrupt the train power supply but also generate arcs that will accelerate the wear of the contact wire and the collector strip of the pantograph [3]. The uplift measurement of existing contact wires is an important method to survey and assess the operational state of the system. The response of contact pressure between pantograph and contact wires will give uplift vibration over the system. Therefore, the operation state of pantograph can also be obtained by monitoring the uplift of the contact wire.

The traditional uplift measuring equipment usually requires installing of targets on the catenary wires, or by fixing the measuring devices on either the support structure of catenary systems or on temporary poles mounted for the measurement. These methods demand track access and manpower for installation and measurement. Thus, a portable vision-based tracking system with a novel line tracking method is proposed and applied to enable low-cost, remote, noncontact and non-target uplift measurements of catenary systems. The camera system can be installed far from the railway track and measure without any contact to the system, i.e., no track access is required. The proposed line tracking algorithm has addressed several challenges of tracking the catenary wires in front of a noisy background. An application of the tracking system for uplift measurements of catenary wires in front of noisy background is demonstrated.

2 Methods

The vision-based tracking system consists of a camera, a fixed-focal optical lens, a trigger, a laptop computer and a laser range finder, as shown in Figure 1(b). To test the performance of the proposed tracking system, field uplift measurement of the catenary wires at Oppdal railway station in Norway was carried out. In the field test, the vision-based tracking system was mounted at a secure distance from the railway track and measurements were carried out without contact to the catenary system. A laser displacement meter was also mounted on the support structure above the contact wire, and a reflective plate installed on the contact wire to measure the uplift in an alternative way and to assess the performance of the proposed tracking system. A schematic overview of the uplift measurement is shown in Figure 1(a). The catenary system was fixedly excited by a hit of a hammer, the two measurement systems simultaneously obtained the uplift data at the same sampling frequency of 200 Hz.

A novel line tracking algorithm used to track the line object in front of the noisy background has been proposed, and the open-source code has been published in [4]. Generally, it is expected that there can be plants, other infrastructure objects or other disturbing things on either side of the railway line. Thus, backgrounds of catenary wires are usually nonuniform or noisy, which makes it challenging to identify and track a moving wire element. To tracking the catenary wires without targets in front of the noisy background, digital image correlation (DIC) cannot work very well due to loss of correlation caused by the noisy backgrounds, which was tried before in [5]. Therefore, a novel line tracking algorithm [3, 4], based on coarse search and subpixel detection, has been proposed to track the catenary wires without the target in front of the noisy backgrounds while avoiding the above issues, as shown in Figure 2. The purpose of the coarse search method is to quickly search the whole image and identify the approximate locations of the catenary wires from the noisy background. The subpixel detection is to accurately detect the subpixel location of these catenary wires, determined by the coarse search, by grayscale bi-cubic interpolation method.

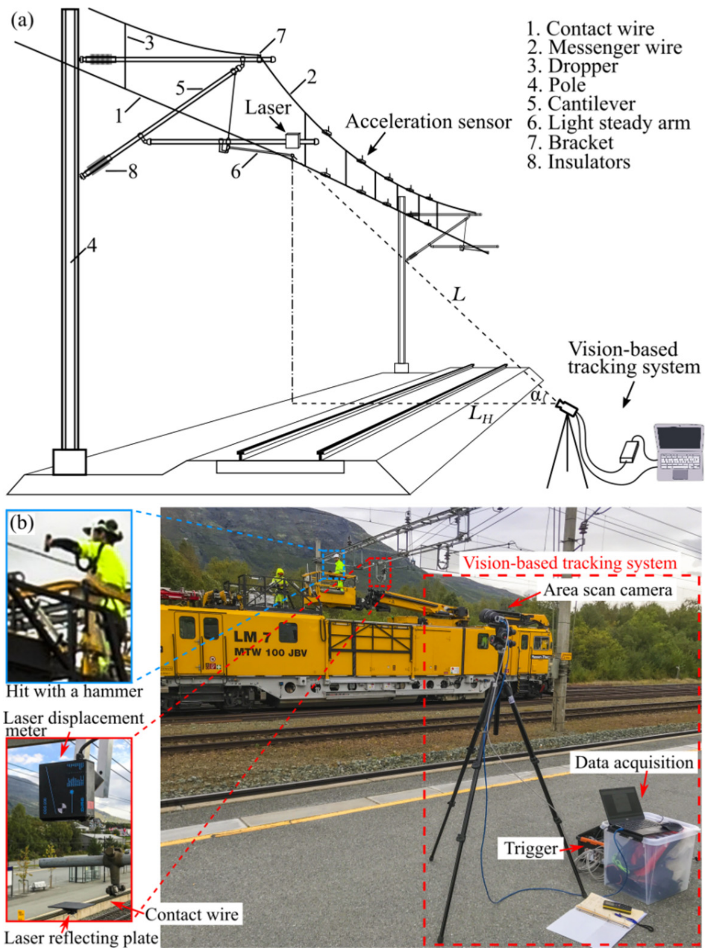

Figure 1: Uplift measurement of the catenary wires by the vision-based tracking system and laser displacement meter.

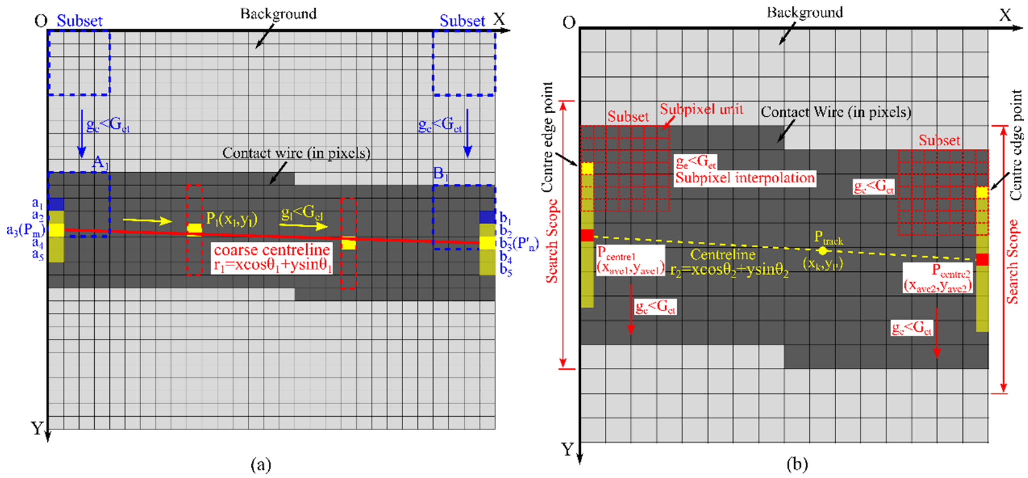

Figure 2: A novel line tracking algorithm based on coarse search and subpixel detection. (a) coarse search method; (b) subpixel detection method.

3 Results

The accuracy, robustness and applicability are the criteria for testing tracking algorithms. The robustness and applicability of the system is tested against the background of swaying trees to see if the catenary wires can be tracked without interruption. Figure 3 shows the identification result of the catenary wires by using the line tracking algorithm, and the centre red points are the selected tracking points. Figure 4 shows the displacement response of the below catenary wire in time series by stitching slices of all images.

The accuracy of the tracking system is compared with the data of the laser displacement meter. The accuracy of the laser is approximately 0.05 mm for the measuring range 10 to 30 cm and is considered to be ground truth for this application. For the sake of clarity, Figure 5 shows the first 20 seconds of the displacement comparisons between the vision-based tracking system and laser displacement meter. Figure 6 shows the distribution of the displacement difference between these two measurement systems. It can be concluded that the accuracy of the proposed tracking system is very close to the laser displacement meter. Gaussian distribution fits well with the displacement difference, while the mean values of group 1 and 2 are 0.077 and -0.0036 mm, and the standard deviations are 0.32 and 0.31 mm, respectively. The accuracy of the proposed vision-based tracking system is therefore ± 0.6 mm at 95% confidence. From the application results, it can be concluded that the proposed vision-based tracking system, with the novel line tracking method, can successfully and accurately measure the uplift of the railway catenary system.

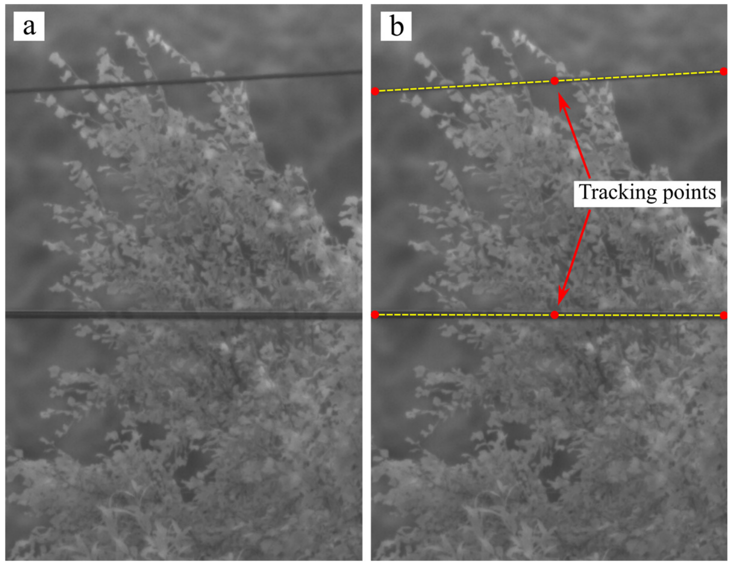

Figure 3: (a) Original image of the catenary wires; (b) The identification results of the catenary wires.

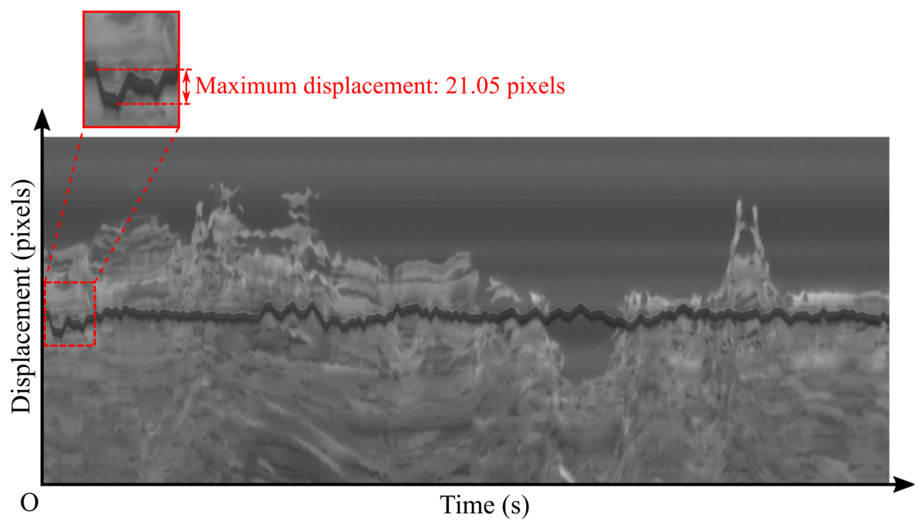

Figure 4: Displacement response of the catenary wire in time series (slices of the images).

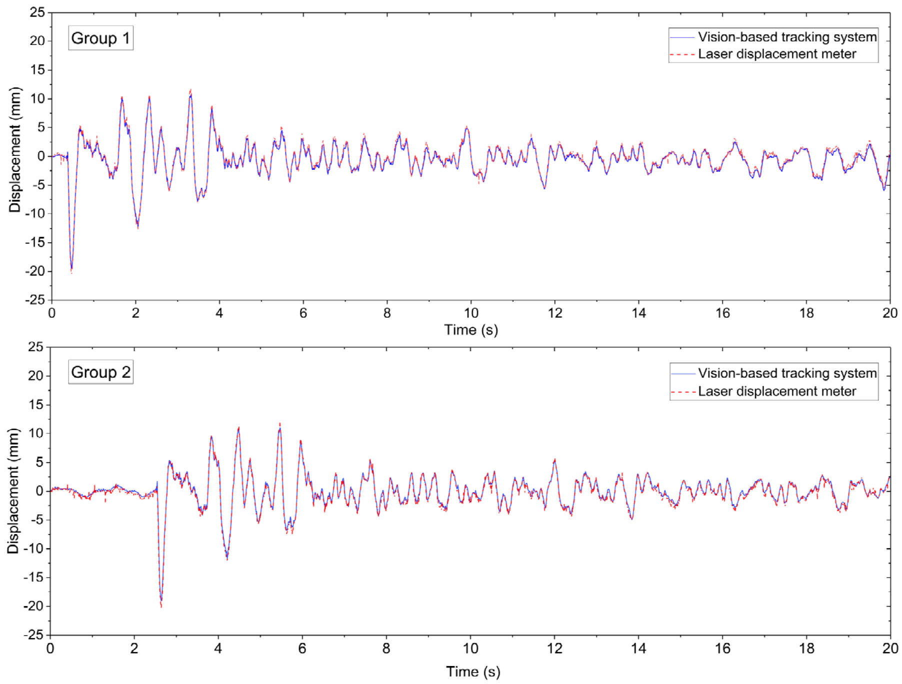

Figure 5: Displacement comparison between the vision-based tracking system and laser displacement meter.

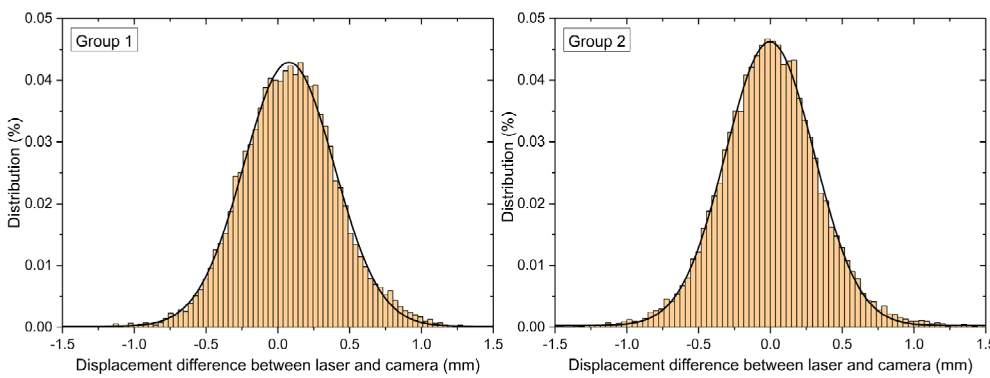

Figure 6: Distribution of the displacement difference between the vision-based tracking system and laser displacement meter.

4 Conclusions and Contributions

A portable vision-based tracking system is proposed to be applied for a low-cost, remote, noncontact and non-marker uplift measurements of a railway catenary system. To address the general problem, which is that the catenary wire is challenging to track with the targets in front of a noisy background, a robust line tracking method is proposed to track linear objects in front of a noisy background.

The accuracy, robustness and applicability of the system are demonstrated through the application in the uplift measurement of the catenary wire and comparison with the laser displacement meter. From the obtained experimental results, it can be concluded that the proposed line tracking method can successfully and accurately track the catenary wires in front of noisy backgrounds.

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