Measurement of the Wheel-rail Relative Displacement for the Active Wheelsets Steering System using the Image Processing Algorithm

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Abstract: - The central problem of the active wheelsets steering systems of the railway vehicles is the measurement of the lateral movements of wheelsets with the noncontact manner. This paper describes the development of a real-time vision system for active steering of a railway vehicle to detect a lateral displacement between wheel and rail in various dynamic environments. An active steering system has proven its ability to reconcile the contradicting requirements of running stability and track friendliness on curve sections and it consists of one actuator, a controller, and sensors. As one of the sensor system for detecting the wheel/rail relative displacement in active steering bogie, the image processing techniques were investigated with the aid of the vision based image processing algorithm. Running test results show that our proposed lateral displacement measurement method is accurate in each sampling rate, and make it a sensor to be placed in the active steering control systems.

Key-Words: Image Processing Algorithm, Wheel/rail Relative Displacement, Active Steering

1 Introduction
In urban transit systems, rail passenger vehicles are often required to negotiate tight curves. During curve negotiation, the wheelsets of conventional vehicles generally misalign radically with the track increasing wheel/rail contact forces and resulting in increased wheel and rail wear, outbreak of squeal noise, fuel consumption, and risk of derailment. To alleviate these problems, it has been also included the study and development of different wheelsets steering devices, modified suspension system designs, application for alternate wheel profiles, active and semi-active steering techniques.

Importance of computer based vision system has been increasing by a cheap, plenty of information source for the control systems of rail vehicles. The vision sensor is applied to digital image processing techniques for detecting wheel/rail displacement in the active steering bogie in the various dynamic environments. This paper describes the development of an image processing algorithm for calculation of the wheel/rail lateral movements in the railway systems. The system is based on the real-time image processing method in order to guarantee a uniform sampling rate. This wheel/rail interaction is also applied to analyzing the wheel/rail interaction as a part of the monitoring systems in dynamic environments.

In this paper, we present the design and implementation of a real time vision system for a railway vehicle to measure its wheel/rail displacement. In order to extract wheel and rail features, this paper uses the various successive image processing algorithms which consist of the camera compensation algorithm against the degradation image quality, the algorithm for improving the contrast effect based on the block of the input image, the pre-processing algorithm coped with the dynamic illumination environment based on the edge, the line segment extraction algorithm of the wheel and rail using the RHT (Random Hough Transformation), and the wheel-rail lateral displacement calculation algorithm.

This paper is organized as the followings. Section 2 describes an active steering wheelsets system. Section 3 deals with an image processing algorithm for measurement of lateral displacement. Section 4 contains the experiment results. The main conclusions are then summarized in section 5.

2 Active Wheelsets Steering System of Railway Vehicle
When a railway vehicle negotiates a curve, significant lateral forces develop between wheels and rails. The dynamic interaction forces of the vehicle and the bogie develop owing to the
kinematics of profiled wheels and the imbalance between gravitational and centrifugal force.

One of the basic concepts of steering control strategies is to apply a controlled torque to the wheelsets in the yaw direction. This can be achieved through longitudinal actuators as shown in Fig. 1. This strategy is founded on the coupling of the lateral and yawing motions of the wheelsets by using the laser sensor signals represented in the wheel/rail displacement.

![Fig.1 Active steering control strategy: apply a controlled torque to the wheelsets in the yaw direction](image)

The relative movement between the wheel and the rail should be measured by the sensor systems. On the assumption that the relative displacement is observed, this measured value is compared with the reference value which is calculated as equation (1).

\[ y_d = \frac{r_0 l}{R \lambda} \]  

where \( r_0 \) represents a wheel radius, \( l \) denotes a half gauge of wheelsets, \( R \) is a radius of the curved track, and \( \lambda \) means a wheel conicity.

Therefore the measurement of wheel/rail displacement is the key to tracking the reference line as the input signals of the active steering controller.

3 Image Processing Algorithms for Measurement of Lateral Displacement

The input image of the wheel/rail passes to a feature extractor which is to reduce the data by measuring certain properties that can distinguish features of wheel/rail. These features are then passed to a pre-processing and/or post-processing that evaluates the evidence presented and calculates the wheel/rail displacement.

![Fig.2 Examples of several different types of wheel-rail contact image](image)

Fig. 2 shows examples of several different types of images representing the relative displacements between wheel and rail under the running vehicle.

![Fig.3 Proposed image processing algorithms for extracting the relative displacement of wheel-rail](image)
Figure 3 show a flow chart of the proposed image processing algorithms to calculate the relative displacement between wheel and rail of the active wheelsets steering bogie. We capture color images from a color CCD camera in a running subway vehicle. And the input image should be digitized and stored by a frame-grabber device because the cameras are generally analog.

Fig. 4 represents the procedure of the proposed image processing algorithms for extracting the relative displacement of wheel-rail.

(a) Input Image           (b) Detection of wheel
(c) Sobel vertical edge image  (d) Blurring image
(e) Canny edge image      (f) Extracting line
(g) Detection of rail   (h) Displacement calculation

Fig.4 An example of the proposed image processing algorithm for extracting the relative displacement of wheel-rail

Our goal for image processing is to measure the wheel/rail displacement then uses its values as a sensor output in the active steering control system. We achieve this in combination with the several image processing algorithms. First, we use the camera compensation algorithm to improve the degradation image quality. Second, the contrast improvement algorithm with the block of the input image to separate the wheel/rail features from the background image using the template matching SSD (Sum of Square Difference) algorithm is applied. Third, the pre-processing algorithm based on the edge features is considered in order to correspond to changing the illumination environment. And then, the line segment extraction algorithm is used to identify the wheel and rail using the RHT (Random Hough Transformation). Finally, the wheel-rail lateral displacement is calculated and executed in real time.

4 Experimental Results

4.1 Experimental Environments
We capture color images from a small CCD camera in a running subway vehicle. For display and program execution, the image is stored in a buffer memory of the frame grabber at a resolution of 320×240 pixels at 30 [frames/s] to produce a visibly continuous. We develop and debug our vision algorithms using Visual C++ for execution on the vision computer. Fig. 5 shows the CCD camera and the Matrox Meteor-II frame grabber.

(a) A CCD camera
(b) A Frame Grabber

Fig. 5 The CCD camera and the frame grabber
An algorithm was developed that the displacement between wheel and rail is dynamically calculated in the running vehicle. To detect the wheel/rail image under the running subway tunnel environment, an artificial illumination system is required because of dark underground condition. The installed CCD camera and illumination system on the bogie frame is shown in Fig. 6.

![Fig. 6 The CCD camera and illumination system mounted on the bogie frame](image)

The subway section between Gil-dong station and Kang-dong station is used for analysis and verification the proposed image processing algorithm to detect the wheel/rail relative displacement. The track information (the radius, cant, gradient of the curved track) between Gil-dong and Kang-dong station is shown in Fig. 7.

### 4.2 Results

Experimental investigations were also conducted in this study. We applied the proposed image processing algorithm to measure the relative displacement to two type experiments which consist of real-time processing and off-line processing.

The experimental result of lateral displacement measurement based on real-time image processing method is shown in Fig. 8. The left part is a source image and the right part is a calculated image by applying the real-time image processing algorithm.

![Fig.8 Experimental results of the relative displacement measurement based on real-time image processing method](image)

Off-line experimental investigation was also made in this study. It is important to apply the proposed algorithm to the collected image which has already been made. The developed off-line method consists of three steps. First step is the dividing the collected movie clips into the still images with 30 frames per a seconds. Next step is extracting the wheel-rail features from the source image using the proposed image processing algorithm. Final step is calculating the relative displacement by analyzing the features.

![Fig.9 Experimental results of a subway section between Gil-dong and Kang-dong station using the off-line processing method](image)
Fig. 9 shows the left/right wheel displacement of the section from the Gil-dong station to the Kangdong station by applying the off-line image processing algorithm and by analyzing the post-processing using MATLAB.

The two experimental results clearly show that the proposed image processing algorithm is relatively accurate in the real-time as well as off-line.

5 Conclusion

This paper presents the measuring system for the relative displacement with the noncontact method using the image processing techniques for the active wheelsets steering system in the railway systems.

Our goal is to measure the wheel/rail relative displacement without contact then uses its values as key information of the active control strategy in the steering control system. We use the combination of the various image processing algorithms: the camera compensation algorithm, the algorithm for improving the contrast effect based on the block of the input image, the pre-processing algorithm coped with the dynamic illumination environment based on the edge, the line segment extraction algorithm of the wheel and rail with the RHT (Random Hough Transformation).

Running test results examined that our proposed lateral displacement measurement method is accurate in full frame rate, and make it a sensor to be placed in the active steering control systems.

References:


