

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

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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. 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. 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.

Keywords—Image Processing Algorithm, Wheel/rail Relative Displacement, Active Steering

I. 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[1][2].

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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.

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.

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.

II. ACTIVE WHEELSETS STEERING SYSTEM OF RAILWAY VEHICLE

Control strategy for the active steering mechanism can be divided into three types. When the wheelsets of railway vehicle runs on the curve, due to the radius gap by track gauge which is defined as the distance between the inside rail and the outside

rail, the tangential speed of the outer wheel should be faster than that of the inner wheel so that can lead pure rolling. But the wheel and axle of the conventional railway vehicles are constrained one wheelsets, and because rotational speed of inner and outer wheels is the same, consequently, the outer radius of the wheel is larger than the radius of the inner wheel so that it can make pure rolling. Therefore, the radius difference of two rotation wheels by the wheel tread gradient (i.e. the wheel conicity) will be generated by means of moving the wheel and axle to the left or right direction in order to drive curve smoothly, generally the radius difference is determined by the geometric calculations[23]~[25].

A. The lateral displacement control of wheelsets for pure rolling

The first control strategy for the active steering mechanism is a way that control properly through the controller to keep the radius difference in order to lead pure rolling of radius difference of left or right wheel that is determined by curve radius. While driving curve, pure rolling of the wheelsets must take place to remove longitudinal creep force which causes abrasion of wheel and rail. When the wheelsets of the railway passes through curved tracks, it is necessary to be different the radius of two wheels to prevent it from slippage generated as a result of the long moving distance of the outer wheel than the inner wheel. The quantity of the lateral displacement that is necessary for pure rolling is calculated as equation (1).

$$y_d = \frac{r_0 l}{R \lambda} \quad (1)$$

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

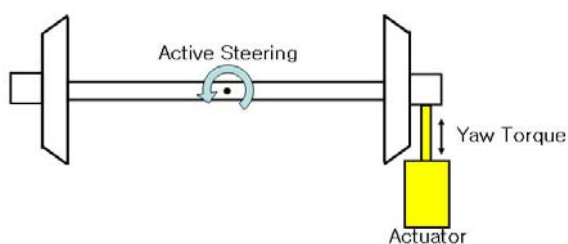


Fig.1 active steering control strategy: apply a controlled torque to the wheelsets in the yaw direction

The method to control the lateral direction displacement of wheelsets is to acquire information about curve radius and wheel conicity every time. And 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.

B. The yaw-moment control of wheelsets for pure rolling

The second control strategy for the active steering mechanism is the yaw-moment control technique of the rail-wheelsets for pure rolling. Another conditions for pure rolling is found in terms of contact force, when the wheel strayed out of its pure rolling line, the one rolling radius from two wheelsets is to increase and the other one is to decrease owing to the wheel conicity. In consequence, lateral slip between wheel and rail will be occurred into opposite directions of each wheel. Such contact force of the wheel-rail is called creep forces, which will influence yaw-moment. There is an only case where moment caused by these creep forces does not occur when the wheelsets exists on the pure rolling line.

As the only force acting on the wheelsets apart from the contact forces are the ones transmitted by the primary suspension, if the inertia forces are neglected it can be stated that the pure rolling implies that there is no yaw moments propagated from the bogie to the wheelsets.

C. The relative angle control of the front and the rear wheelsets

The third control strategy for the active steering mechanism is how to control the relative angle of the front and the rear of wheelsets. This method is that lateral force of the wheelsets received by centrifugal forces can make all of them equal by means of equalizing the attack angle.

The centrifugal force generated in the curve is compensated by lateral contact force of wheelsets. Therefore, in order to minimize the lateral contact force, all maximum values of the contact forces generated from each wheelsets should be make equal.

Because the creep forces at the contact point are mainly due to longitudinal creepages, so the contact lateral force of a wheelsets is dependent on the attack angle. Therefore the method for distributing evenly lateral direction contact force is a way to match the attack angle of wheelsets as given:

$$\Psi_{w1} - \Psi_{w2} = 0 \quad (2)$$

If L_b is the distance of two wheelsets, the demanded relative angle for making the attack angle of two wheelsets equal is expressed by curve radius R as equation (3).

$$\alpha = \frac{L_b}{R} \quad (3)$$

III. IMAGE PROCESSING ALGORITHMS FOR MEASUREMENT OF LATERAL DISPLACEMENT

The measurement of the relative displacement between the wheel and the rail is the key to tracking the reference line as the input signals of the active steering controller for the lateral displacement control strategy. 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.



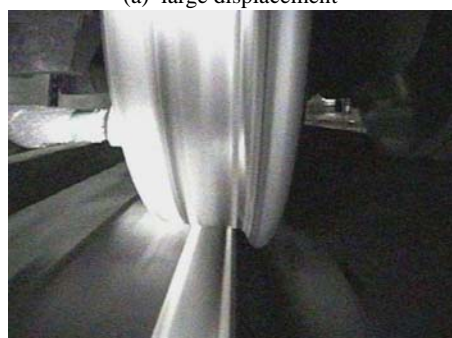
(a) template for detecting the wheels (b) line component of the rail

Fig. 2 wheel/rail features for calculating the relative displacement of the wheel-rail

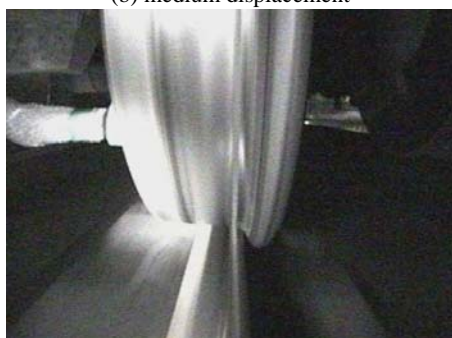
Fig. 3 shows examples of several different types of images representing the relative displacements between the wheel and rail under the running vehicle.



(a) large displacement



(b) medium displacement



(c) small displacement(contact wheel flange)
 Fig. 3 examples of several different types of wheel-rail contact image

Fig. 4 shows 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. 5 represents the procedure of the proposed image processing algorithms for extracting the relative displacement of wheel-rail.

Fig. 5-(a) shows input image derived from CCD camera. The input image finds the wheel position by applying SSD algorithm or it gets rid of partial image noise by applying low pass filter (LPF) before rail extraction by means of Hough transform.

Then, it performs wheel extraction process based on the template matching using SSD (Sum of Square Difference) algorithm.

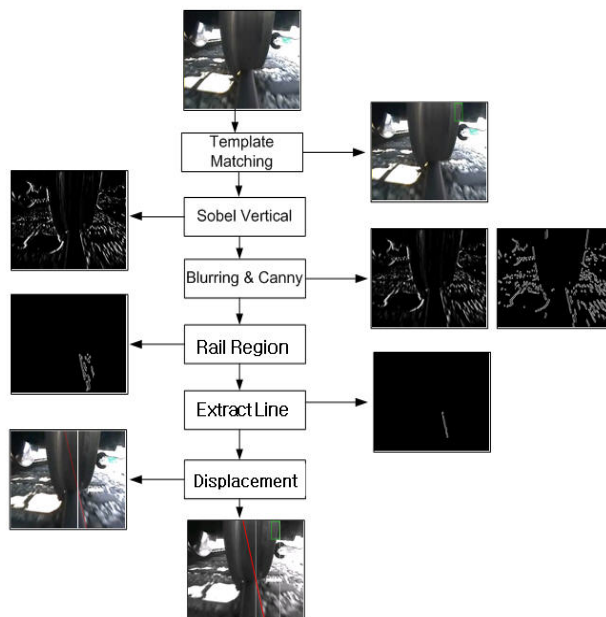


Fig. 4 proposed image processing algorithms for extracting the relative displacement of wheel-rail



(a) input image

(b) detecting the wheel

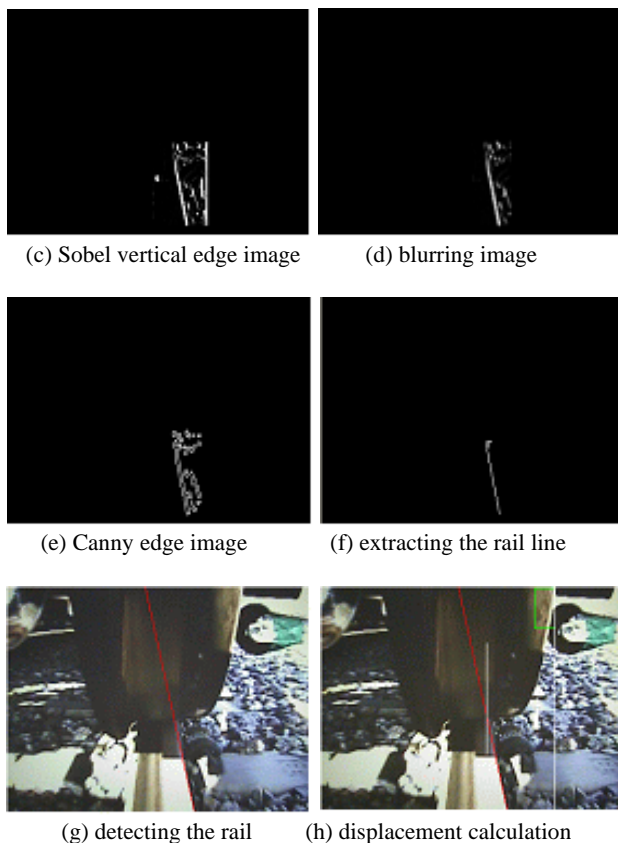


Fig. 5 an example of the proposed image processing algorithm for extracting the relative displacement of wheel-rail

Fig. 5-(b) shows result which was found by input image. Then it applies LPF for finding the rail position by Hough transform and it also sequentially applies Sobel edge detection operator. The small edge ingredients were removed from the result image which is performed with Sobel edge operator by applying the blurring operator before obtaining Canny edge image. Some unnecessary edge ingredients were removed from result image gained by applying Canny edge operator and we perform clustering process for obtaining only rail candidate edges.

Fig. 5-(f) shows result image which was performed clustering by applying Canny edge operator. When candidate rail edges are detected like Fig. 5-(f), Hough transform is performed and then the wheel position would be found on the wheel-rail image. The highest position of accumulated array was decided as a straight line of the rail in the parameter space through Hough transform because long and strong straight ingredient was detected from rail edge which is obtained from steering bogie image.

Fig. 5-(g) shows the rail detection by the wheel-rail image detected through Hough transform. The most adjacent position at the wheel and rail was used for a feature vector of rail to reduce measurement errors in the process of the camera compensation. When a position feature vector of the rail is

detected through Hough transform, and then project the feature vectors on the three-dimensional real world coordination by the camera compensation algorithm for detecting the displacement between the wheel and rail.

Fig. 5-(h) shows measurement results of the relative displacement of the wheel-rail. The displacement is measured by considering only X-axis from the 3-dimensional displacement position vector of wheel and rail on the real world coordinates.

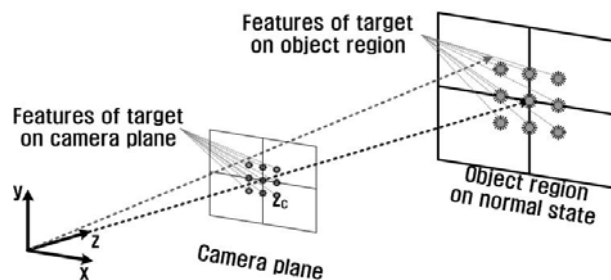


Fig. 6 pin-hole camera model for converting the features vector of the wheel into position vector on the three-dimensional coordinate

As the Fig. 6 indicates, the wheel position measured on the image converts features vector of the wheel into position vector on the three-dimensional coordinate by camera compensation algorithm.

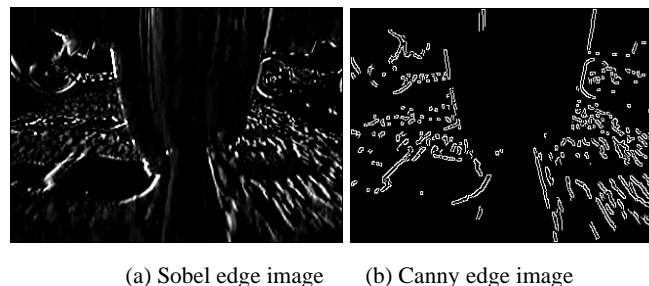


Fig.7 edge operator applying image

Because an image processing system generally is vulnerable when the observed target objects exposes to light of the sun directly. According to adjusting the brightness of the light, noise is occurred around the rail and the additional line vectors of the rail are eliminated. It was able to detect the rail line even though with only 10-30 pixels through removing of straight ingredients of rail, as a consequence the wheel-rail displacement has approximately within 3 [mm] measuring error by lighting changes.

Yellow lighting changes are similar to the average of wheel-rail displacement value measured from original images which are not applied with any lighting changes rather than white lighting changes.

In conclusion, we finally found that it is better to use yellow light than white light when the outside lighting is investigated in tunnel.

IV. EXPERIMENTAL RESULTS

A. 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. 8 shows the CCD camera and the Matrox Meteor-II frame grabber.

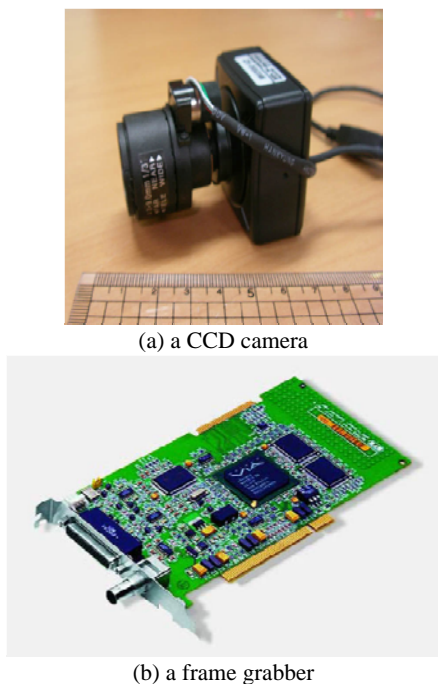


Fig. 8 the CCD camera and the frame grabber

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. 9.

Sampling rate from the CCD camera is 30 [fps], processing rate for the image processing to calculate the wheel-rail relative displacement is conducted as 22 [fps] and limit of resolution of the relative displacement was calculated to 0.9091 [mm]. It is also possible to reduce the displacement measurement resolution up to 0.4 [mm] in the case that input image size collected from CCD camera enlarges into 640x480, however, the image resolution maintained as 320x240 to keep image processing rate more than 15 [fps].

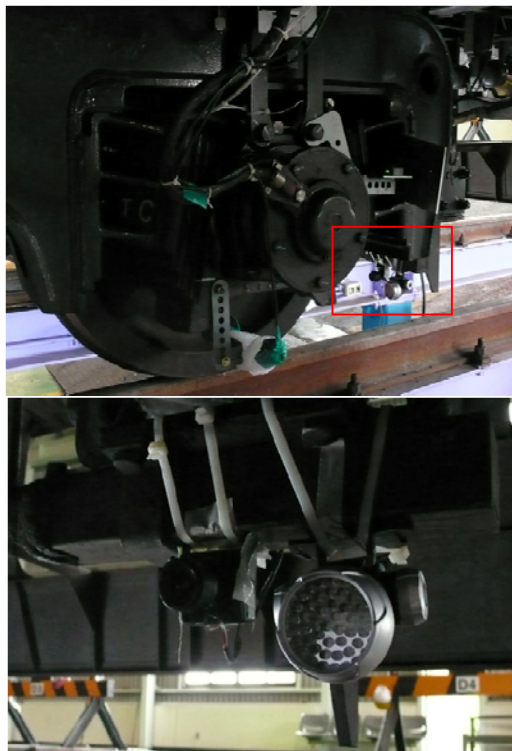


Fig. 9 the CCD camera and illumination system mounted on the bogie frame

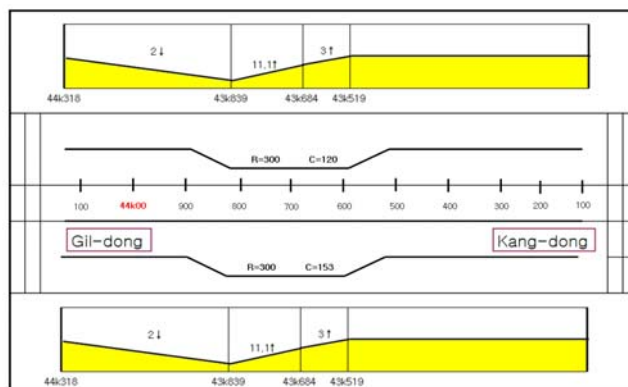


Fig. 10 the track information between Gil-dong and Kang-dong station: curve radius, gradient, and distance

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. 10.

B. 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. 10. The left part is a source image and the right part is a calculated image by applying the real-time image processing algorithm.



Fig.11 experimental results of the relative displacement measurement based on real-time image processing method

Fig. 12 shows the vision program developed for displacement measurement of wheel-rail which is on the real train test.

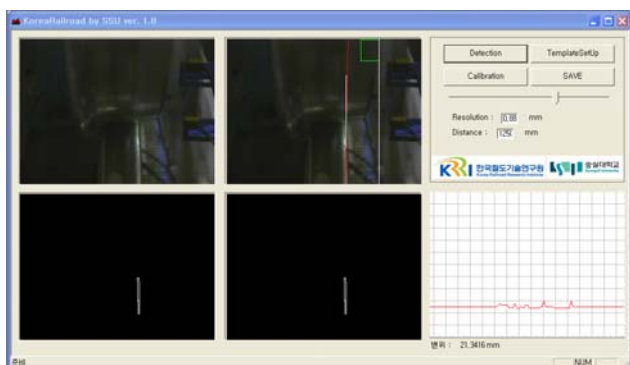


Fig. 12 the developed program of real-time measuring of the relative displacement between wheel and rail

Off-line experimental investigation was also conducted 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. 13 shows the left/right wheel displacement of the section from the Gil-dong station to the Kang-dong 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.

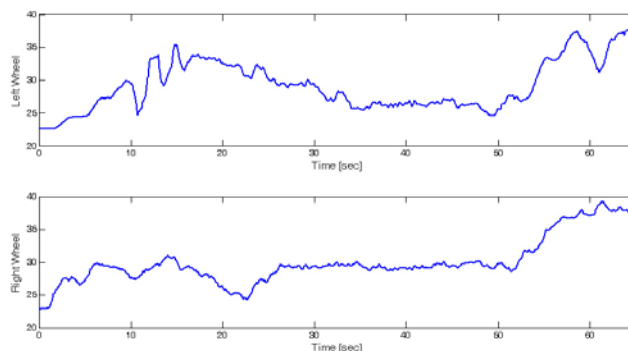


Fig.13 experimental results of a subway section between Gil-dong and Kang-dong station using the off-line processing method

V. 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.

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.

The resolution of the relative displacement of the wheel-rail was measured in 0.9091 [mm] with an accuracy by detected features vector of the wheel-rail from steering bogie image and projected the features of target on camera plane to those of the on object region by the compensation algorithm. The suggested algorithm which is robust to environmental changes performed the SSD algorithm based on the template matching in order to detect the position of the wheel and it applied Hough transforming algorithm in order to detect the position of the wheel from the input images.

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.

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