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Visual Recognition System of Elastic Rail Clips for Mass Rapid Transit Systems

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ABSTRACT

In recent years, the railway transportation system has become one of the main means of transportation. Therefore, driving safety is of great importance. However, because of the potential of multiple breaks of elastic rail clips in a fixed rail, accidents may occur when a train passes through the track. This paper presents the development of a computer visual recognition system which can detect the status of elastic rail clips. This visual recognition system can be used in mass rapid transit systems to reduce the substantial need of manpower for checking elastic rail clips at present. The visual recognition system under current development includes five components: preprocessing, identification of rail position, search of elastic rail clip regions, selection of the elastic rail clip, and recognition of the elastic rail clip. The preprocessing system transforms the colored images into grey-level images and eliminates noises. The identification of rail position system uses characteristics of the grey-level variation and confirms the rail position. The search system uses wavelet transformation to carry out the search of elastic rail clip regions. The selection system finds a suitable threshold, using techniques from morphological processing, object search and image processing. The recognition system processes characteristics and structures of elastic rail clips. Experimental testing shows the ability of the developed system to recognize both normal elastic rail clip images and broken elastic rail clip images. This result confirms the feasibility in developing such a visual recognition system.

INTRODUCTION

The speed of track vehicles is very fast from 80 km/hr to 300 km/hr. Therefore, driving safety is very important. Trains running off rails have caused serious casualties in various countries. The module that fixes rails above the track supports is called the elastic rail clip system. Because of continuous rocking and hitting, the elastic rail clip system can easily wear off or even break. This causes the train to jolt on the way. Therefore, the status of elastic rail clips used in the fixed rail becomes very important.

In order to achieve the goal of high efficiency of transportation and the safety and comfort of driving, inspection of elastic rail clips becomes very important. At present, there is still no track maintenance vehicle for inspecting the elastic rail clip system. Instead, engineers have to physically walk on the track and perform the inspection. This kind of inspection work done by human beings takes considerable amount of time and is a waste of manpower. To avoid human-made mistakes and to reduce the waste of manpower and time, This paper proposes to use a digital image processing technology with a visual recognition algorithm. The proposed automatic detection system can monitor the status of elastic rail clips with images. Images are acquired by a CCD camera while the train is running, and then the system detects the damage or break of the elastic rail clips. This method provides information necessary for maintenance worker to do the repair work, prevents trains from going off tracks, and helps achieve the goal of traffic safety.

Due to different environmental factors encountered in different road sections, the elastic rail clip images also differ. For example, under weather conditions of continuous rain and sun, the rail and elastic rail clips can easily get rusted. This causes the colors of the rail and elastic rail clip images to be similar. In addition, sunlight can produce effects of shadow in the images. Further, the designs of road section for track vehicles are different depending on the environment. For example, concrete tracks, ballast tracks, wooden sleeper tracks and concrete sleeper tracks are respectively used over the viaduct, on the ground, and in the underground tunnel. These factors increase the difficulty for the recognition system. The current system is examined with the German VOSSLOH elastic rail clip which is the most used elastic rail clip in mass rapid transit systems of Taipei. Two kinds of road sections are considered: the non-concrete sleeper road section (the concrete tracks) and the concrete sleeper road section (the ballast tracks). The inspection is taken while the train is actually in motion. No matter the inspection is taken on the viaduct, on the ground, or in the underground tunnel, the recognition system can be applied. This is because each road section uses the same elastic rail clip system. Therefore, by using the algorithm in current system, the computational time can be reduced to achieve ideal real-time recognition.

SYSTEM OVERVIEW

The current system uses 640×480 digital images. This system includes five components: preprocessing, rail position identification, elastic rail clip regions search, elastic rail clip selection, and elastic rail clip recognition as shown in figure 1.

The first section describes the preprocessing step at which the colored images are transformed into grey-level images. Then, image processing techniques are used to eliminate noises and strengthen contrasts of the image. This process helps us avoid potential recognition failures that can be caused by noises and insufficient light.

The second section checks characteristics of the grey-level variation of the elastic rail clip image. These characteristics are used to search for information of the rail regions. Then, the horizontal runs smooth theorem is introduced for horizontal scan and for finding the correct rail region.

The third part discusses the search for the elastic rail clip regions. Wavelet theorem is used to transform images from the spatial domain into the frequency domain so as to detect vertical edge of the base plate and the wooden sleeper. Then, images are transformed back into the spatial domain by means of the inverse wavelet. Subsequently, the black and white color of the images are inverted and images are binarized Finally, vertical edge identification is used to search for the elastic rail clip regions.

The fourth part describes the process to select preliminary and details of elastic rail clip regions from the elastic rail clip image. Then the cavities are mended by the morphological method. Finally, the object search algorithm is used to select the elastic rail clip.

The fifth part discusses the step of elastic rail clip recognition, including the feature point search and the characteristic value calculation to find seven feature points. With characteristic value algorithm, the elastic rail clip can be recognized and the status of the elastic rail clip (intact or break) can be determined.

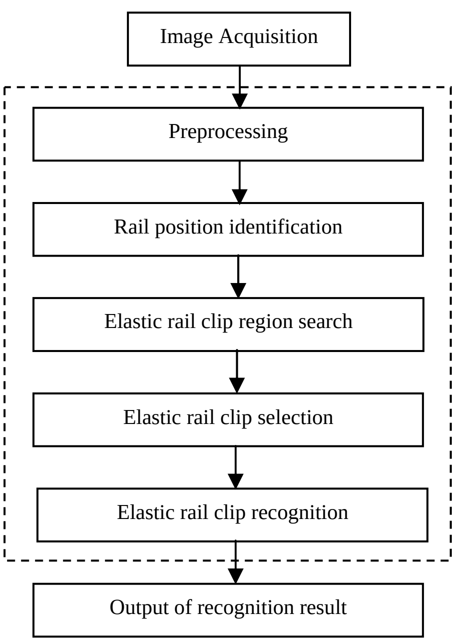

Fig 1. System Overview

THE RAIL POSITION IDENTIFICATION

After preprocessing, the grey-level images are inspected by the computer vision system during which different environment and different elastic rail clip types must be considered. Therefore, first search of the elastic rail clip. Then search for the elastic rail clip region from the edge of the rail and expands either rightward or leftward. This process can reduce time for recognition. The first step in the rail position identification is to search the possible rail region by the grey-level variation of each group of column vector. This region is called the candidate rail position. Later, the true rail position can be confirmed from a set of candidate rail positions.

Examining the grey-level histogram of individual column vectors of the elastic rail clip image, in the rail region and the concrete tracks region the grey-level of column vectors have less variation. On the contrary, in the non-rail region the grey-level of column vectors have more variation. Statistics is scanned on each grey- level value of column vectors appearing in the images. The variation in the grey-level figure of a concrete track is shown in figure 2(a) and a ballast track is shown in figure 2(b). From these two figures, values of grey-level column vectors does not variation much in the concrete region and the rail region.

Therefore, only a single threshold value is required to determine whether to retain this region or not. If the variation of grey-level value of column vectors is smaller than the threshold, this column vector is possibly the rail region or the non- ballast region. If the variation of grey-level of column vectors is bigger than the threshold, this column vectors is possibly the ballast region or some dirty environment. Because of differences in each image, the threshold would not be the same. Therefore, the average value of the kind of grey-level of each column vector is calculated. This average is then used as the threshold for the final decision of the candidate rail region.

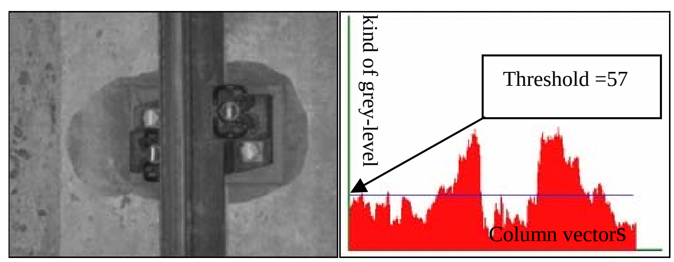

Fig 2(a). Variation of the grey-level value of column vectors of a concrete track

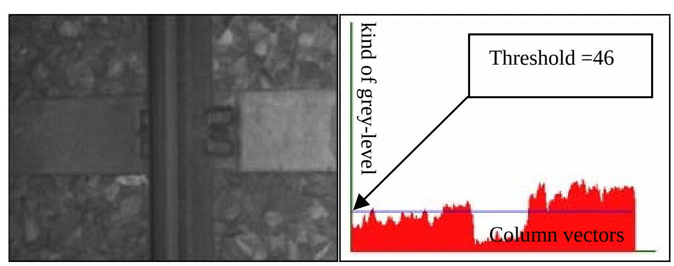

Fig 2(b). Variation of the grey-level value of column vectors of a ballast track

The candidate rail regions of a concrete track and the candidate rail region of a ballast track are shown in the middle figure of 3(a) and figure 3(b) respectively. The correct rail region is determined in the candidate rail region. After using horizontal runs smooth theorem [1] to scan one row of vectors horizontally, statistics are taken on each sequence of the horizontal widths with a grey-level value of 255. Then, each sequence of the horizontal width with a grey-level value of 255 are sorted. Because the largest and the second sequence widths of a horizontal scan are likely to be the elastic rail clip region and the ballast region, the third sequence width of horizontal scan is selected as the threshold. Values smaller than the threshold is filled. Figure 3(a) below shows a concrete track after fill effect, and figure 3(b) below shows a ballast track after fill effect. The correct rail region is located in the middle of the image. Therefore, the middle of the sequence of a horizontal scan in the image is selected as the correct rail region. This method is applicable to each kind of tracks and each kind of elastic rail clips.

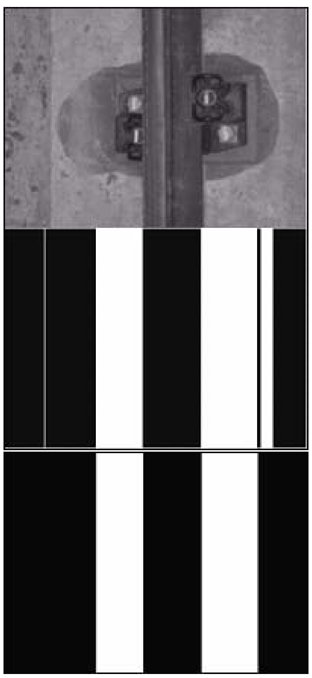

Fig 3(a). Candidate rail region of a concrete track

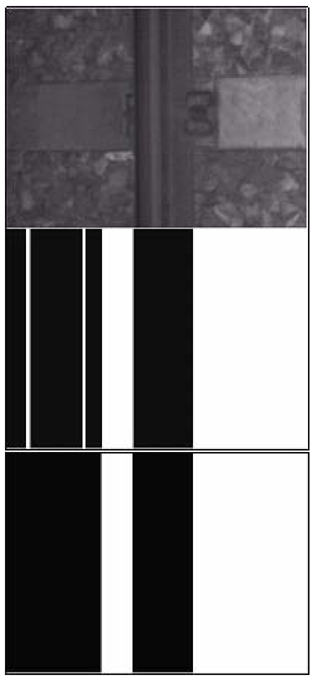

Fig 3(b). Candidate rail region of a ballast track

THE ELASTIC RAIL CLIP REGION SEARCH

Wavelet transformation [2] is used to search for the vertical edge of the base plate and the vertical edge of the wooden sleeper. The elastic rail clip regions is then identified. Wavelet theorem is used to transform images from spatial domain into frequency domain for later recognition of the edge. The Laplacian method [3] and other method of edge detection are not used because a threshold value is required by these methods and a reasonable threshold is not easy to obtain. However, with wavelet transformation, no specified threshold value is required to detect the vertical edge of base plate and the vertical edge of wooden sleeper. Moreover, wavelet transformation can be applied to all kinds of environments. Using wavelet transformation can obtain edge information at the low frequency (LL) as well as at the high frequency, including the horizontal edge information (LH), the vertical edge information (HL), and the intersect edge information (HH). Wavelet transformation of a concrete track is shown in figure 4(a), and wavelet transformation of a ballast track is shown in figure 4(b).

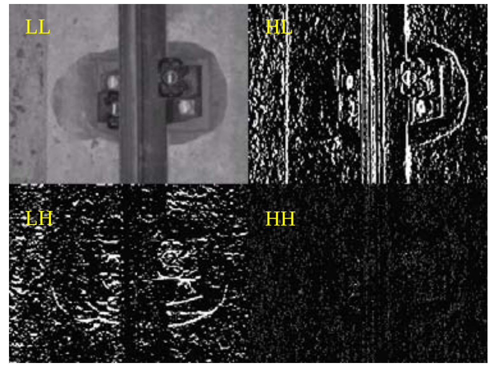

Fig 4(a). Wavelet transformation of a concrete track

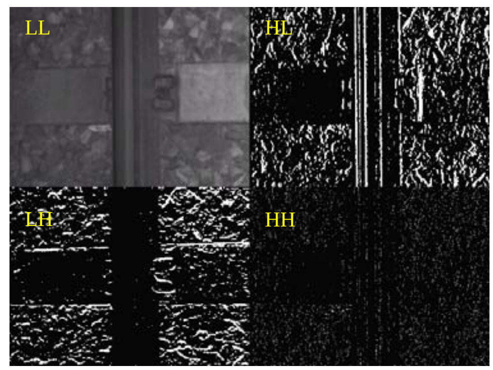

Fig 4(b). Wavelet transformation of a ballast track

After wavelet transformation, unnecessary regions of frequency band (LL, LH, HH) are deleted while the frequency band of vertical edge (HL) is retained. Then, images are transformed back into the spatial domain by means of inverse wavelet transformation with black and white color. In this way, the vertical edge from the image can be found. By using vertical scan, the possible vertical edge of the base plate is retained in a concrete track and vertical edges that are either too long or too short are deleted. The threshold of vertical scan is the width of the correct rail multiplied by 4/5. If the length of a vertical edge is larger than this threshold value and smaller than the image width multiplied by 1/2, it is possible that it is the vertical edge of the base plate, as shown in figure 5(a) or the vertical edge of the concrete sleeper in a ballast track as shown in figure 5(b).

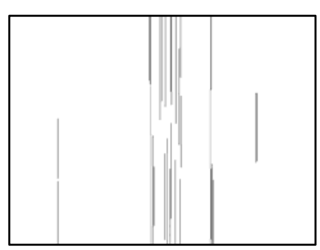

Fig 5(a). Vertical edge of the base plate

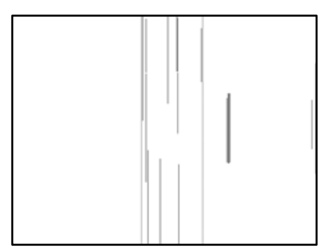

Fig 5(b). Vertical edge of the concrete sleeper

After accomplishing the vertical edge image, the correct vertical edge of the base plate must be identified. A starting position is found from the rail edge position moving rightward. This move distance is the rail width. Then, from this starting position search inward to a vertical edge image. When the first position of vertical edge is reached, it is the correct vertical edge of base plate. For the concrete sleeper, the starting position is found from the rail edge position moving rightward to a move distance of 3/5 times of the width of the rail. Then, from this starting position search inward to a vertical edge image. When the first position of vertical edge is reached, it is the correct vertical edge of concrete sleeper. This process speeds up search of the base plate with the correct vertical edge position and the concrete sleeper with the correct vertical edge position.

The following steps are used to identify the elastic rail clip region of a concrete track :

(1) Move upward from the starting point of the vertical edge of the base plate by a distance of 1/6 times of the length of the vertical edge of the base plate. Then, set coordinates y of this point as coordinates of edges, y1 and y2, of the elastic rail clip region.

(2) Move upward from the terminal point of the vertical edge of the base plate by a distance of 2/6 times of the length of the vertical edge of the base plate. Then, set coordinates y of this point as coordinates of edges, y3 and y4, of the elastic rail clip region.

(3) Move leftward from the starting point of the vertical edge of the base plate by a distance of 1/2 times of the width from the start point of the vertical edge of the base plate to the position of the rail edge. Then, set coordinates x of this point as coordinates of edges, x2 and x4, of the elastic rail clip region.

(4) Move leftward from the rail edge by a distance of 3/5 times of the width from point x2 to the position of the rail edge. Then, set coordinates x of this point as coordinates of edges, x1 and x3, of the elastic rail clip region.

The following steps are used to identify the elastic rail clip region of a ballast track:

(1) Move upward from the starting point of the vertical edge of the concrete sleeper by a distance of 1/10 times of the length of the vertical edge of concrete sleeper. Then, set coordinates y of this point as coordinates of edges, y1 and y2, of the elastic rail clip region.

(2) Move upward from the terminal point of the vertical edge of the concrete sleeper by a distance of 1/10 times of the length of the vertical edge of concrete sleeper. Then, set coordinates y of this point as coordinates of edges, y3 and y4, of the elastic rail clip region.

(3) Set coordinates x of the vertical edge of the concrete sleeper as coordinates of edges, x2 and x4, of the elastic rail clip region.

(4) Move leftward from the rail edge by a distance of 3/5 times of the width from point x2 to the position of the rail edge. Then, set coordinates x of this point as coordinates of edges, x1 and x3, of the elastic rail clip region.

The elastic rail clip region of a concrete track is shown in figure 6(a), and the elastic rail clip region of a ballast track is shown in figure 6(b). If the ratio of the rail and the vertical edge is estimated correctly, the elastic rail clip region is obtained quickly and correctly.

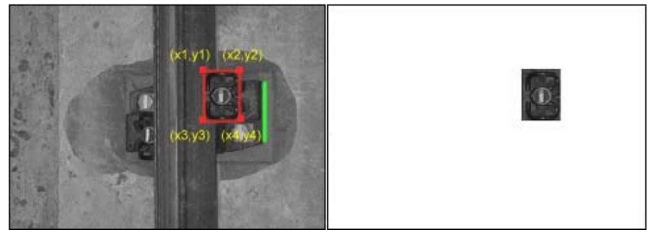

Fig 6(a). The elastic rail clip region of a concrete track

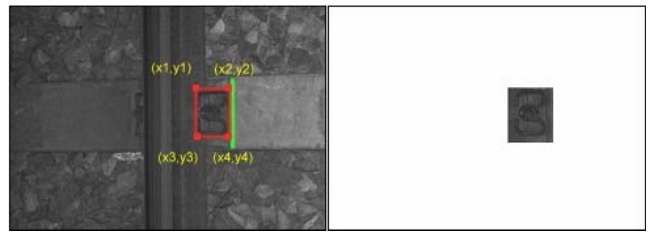

Fig 6(b). The elastic rail clip region of a ballast track

THE ELASTIC RAIL CLIP SELECTION

This section introduces the subsystem of elastic rail clip selection. Because the background environment of the elastic rail clips differs, thresholds of the binary used to separate the image from the background are different. Therefore, methods to automatically determine thresholds must be designed. The pixel at the edge of the image usually appears in the high frequency region. This is because pixels of this region has the characteristic of rapid variation. This characteristic can be used to distinguish the foreground (the elastic rail clip region) from the background (the environment) in the image. Then, the values of pixels at the edge of the image are averaged. By taking the averaged value as the threshold for the binary image, the preliminary elastic rail clip image is selected. The detection of edges is performed with the Sobel Operation and a threshold value of 45. This threshold value is applicable for all kinds of tracks. Figure 7(a) and figure 7(b) show the preliminary binary image from elastic rail clip of a concrete track and from a ballast track after applying the Sobel Operation respectively.

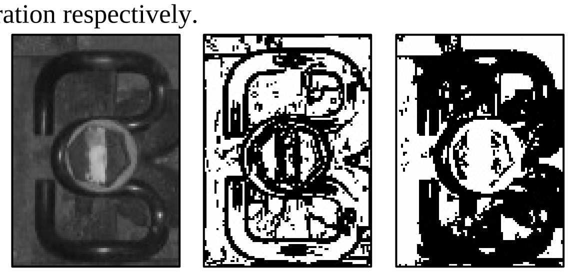

Fig 7(a). The preliminary binary image from the elastic rail clip of a concrete track

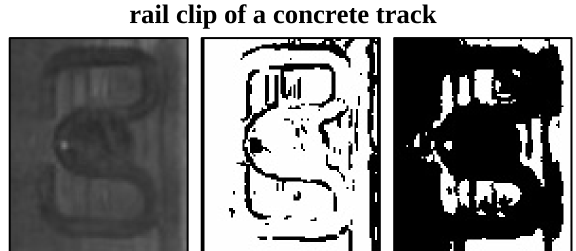

Fig 7(b). The preliminary binary image from the elastic rail clip of a ballast track

The binarized images include not only the elastic rail clip but also some background noises. Therefore, further elimination of non-elastic rail clip region is necessary. This process is called detailed selection of the elastic rail clip. At this step, pixel binary value of 0 is converted back to its original grey-level pixel value. In this way, the grey-level histogram is obtained by which the elastic rail clip and the background image can be divided into two regions. The Otsu method [4] is applied to searching for the best threshold value for detailed selection of elastic rail clips. This method selects the maximum value of variances within these two regions. This maximum value is then taken as the best threshold value. The detailed binary image of an elastic rail clip from a concrete track is shown in figure 8(a) while the detailed binary image of an elastic rail clip from a ballast track is shown in figure 8(b). Although some pixels of the elastic rail clip are filtered out, elastic rail clips still appear to be distinct in the images.

Fig 8(a). The detailed binary image of an elastic rail clip of a concrete track

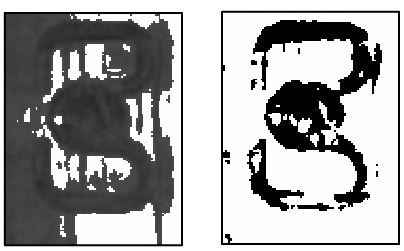

Fig 8(b). The detailed binary image of an elastic rail clip of a ballast track

Some pixels of the elastic rail clip can be eliminated if the value of the pixels is close to the background pixels. This maybe due to a broken elastic rail clip. Therefore, the image of the broken elastic rail clip must be repaired, but avoid over-repairing the broken elastic rail clip so that it cannot be distinguished from a normal elastic rail clip. The Morphology method is used here. This is because the dilation operation can easily over-repairing the broken elastic rail clip so that it cannot be distinguished from a normal elastic rail clip. However, the close operation fills in the holes without changing structures of the elastic rail clip image. Therefore, the dilation operation is used as the initial process, and then process it with the close operation. After processed by the morphology method as shown in the right of figure 9(a) and the right of figure 9(b), the elastic rail clip image is almost complete. However, small noises that are not in the elastic rail clip image still need to be removed. The object search algorithm [5] is used to construct objects with connected neighboring pixels. Then, the area and the position of the object is computed, select the biggest area, and extract it as the elastic rail clip. A complete elastic rail clip image of a concrete track is shown in the left of figure 9(a), and a complete elastic rail clip image of a ballast track in the left of figure 9(b) .

From some of the tracks, the elastic rail clip color appears to be red. The pixels of the elastic rail clip turns to be very striking in the image. Therefore, the RGB color model is converted into the HSV for the elastic rail clip selection. The scope of hue, saturation, and value of pixels are set. If some pixels conform with the scope, they are retained. Then conversion of the grey-level, image binarized, morphology and object search are performed for elastic rail clip recognition.

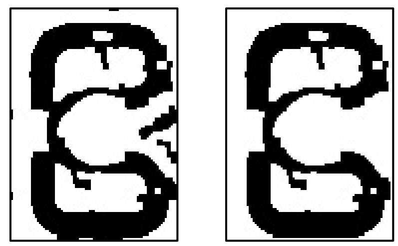

Fig 9(a). The complete elastic rail clip of a concrete track

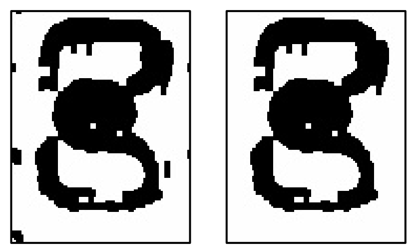

Fig 9(b).The complete elastic rail clip of a ballast track

THE ELASTIC RAIL CLIP RECOGNITION

To recognize whether the elastic rail clip image is normal or broken, the characteristic structure of the elastic rail clip is recognized, characteristic point search is performed and characteristic values are computed. Seven characteristic points are obtained as shown in figure 10(b). The elastic rail clip image is equally split by three horizontal lines and one vertical line. Therefore, intersections of the lines and the elastic rail clip image produce characteristic points which are used for characteristic value calculation.

Steps to search for characteristic points are as follows：

(1) Determine whether all of the 7 characteristic points exist.
(2) If one of the characteristic points is missing, it suggests that the elastic rail clip under examination is broken.
(3) If all of the 7 characteristic points exists, the characteristic value calculation can be proceed.
(4) Define the formula for each characteristic points.

Steps to calculate characteristic value are as follows：

(1) The image at characteristic point 1 is scanned to find the horizontal width with a grey-level value of 0. This width must be smaller than a half of the width of line A.

(2) x_1 of characteristic point 1(x_1, y_1) must be smaller than the midpoint x_A of line A (x_A, y_A).

(3) The image at characteristic point 2 is scanned to find the vertical length with a grey-level value of 0. This length must be smaller than a half of the length of line B.

(4) y_2 of characteristic point 2(x_2, y_2) must be smaller than the midpoint y_B of line B (x_B, y_B).

(5) The image at characteristic point 3 is scanned to find the horizontal width with a grey-level value of 0. This width must be smaller than a half of the width of line C.

(6) x_3 of characteristic point 3(x_3, y_3) must be greater than the midpoint x_C of line C (x_C, y_C).

(7) x_4 of characteristic point 4(x_4, y_4) on the line D must be greater than x_1 and x_5 .

(8) The image at characteristic point 5 is scanned to find the horizontal width with a grey-level value of 0. This width must be smaller than a half of the width of line E.

(9) x_5 of characteristic point 5(x_5, y_5) must be smaller than the midpoint x_E of line E (x_E, y_E).

(10) The image at characteristic point 6 is scanned to find the vertical length with a grey-level value of 0. This length must be smaller than a half of the length of line F.

(11) y_6 of characteristic point 6(x_6, y_6) must be greater than the midpoint y_F of line F (x_F, y_F).

(12) The image at characteristic point 7 is scanned to find the vertical length with a grey-level value of 0. This width must be smaller than a half of the width of line G.

(13) x_7 of characteristic point 7(x_7, y_7) must be greater than the midpoint x_G of line G (x_G, y_G).

As long as characteristic values of one of the characteristic points do not conform to the above steps, the elastic rail clip is considered broken. Otherwise, it is an intact and complete elastic rail clip.

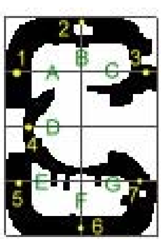

Fig 10. The characteristic points Image

RESULTS AND DISCUSSION

Current study tests the elastic rail clip image recognition system with Taipei rapid transit system in Taiwan. Three routes are chosen: Bannan Line, Xindian Line, and Danshui Line. The test system consists of four parts: identification of rail position, search of elastic rail clip regions, selection of the elastic rail clip, and recognition of an elastic rail clip. Each of these subsystems is directly related to the success of the final recognition result. Therefore, individual test on each of the four parts and a complete test on the whole system are performed to obtain the recognition rate.

Table 1. The recognition rate from the Bannan Line

Test scope	Test images	Success	Fail	Recognize rate
First subsystem	30	27	3	90%
Second subsystem	30	28	2	93%
Third subsystem	30	27	3	90%
Fourth subsystem	30	26	4	86%
Complete test	30	21	9	70%

Table 1 shows the recognition rate of Bannan Line. Bannan Line uses concrete tracks with VOSSLOH elastic rail clips. First, from observation, reasons for failures in identification of the rail position from this test include the dirtiness at the rail position. Besides, slope of the camera position could also cause the grey-level of column vectors to variation. Second, the failure of search of elastic rail clip regions could be caused by weak lighting condition which affects the edge information. In this case, the system fails to detect the vertical edge of base plate during wavelet transformation. Third, the weak illuminating condition can also contribute to failure in detection of the elastic rail clip. Weak lighting causes pixels of the elastic rail clip and pixels of background to be too similar to be distinguished apart. In this case, the system cannot select the elastic rail clip pixels. Fourth, failure in recognition of elastic rail clip can be attributed to the preceding step of elastic rail clip selection. As long as the elastic rail clip pixels and the background pixels can be separated, the success of recognition can be achieved.

Table 2. The recognition rate from the Xindian Line

Test scope	Test images	Success	Fail	Recognize rate
First subsystem	30	30	0	100%
Second subsystem	30	27	3	90%
Third subsystem	30	30	0	100%
Fourth subsystem	30	30	0	100%
Complete test	30	27	3	90%

Table 2 shows the recognition rate of Xindian Line. Xindian Line uses ballast tracks with the same elastic rail clips as Bannan Line. Additionally, Xindian Line uses red elastic rail clips. Therefore, 30 images of red elastic rail clips are used for examination. Failures in testing could be due to weak lighting and the dirtiness of neighboring vertical edges of base plate environment.

Table 3. The recognition rate from the Danshui Line

Test scope	Test images	Success	Fail	Recognize rate
First subsystem	15	15	0	100%
Second subsystem	15	15	0	100%
Third subsystem	15	11	4	73%
Fourth subsystem	15	10	5	67%
Complete test	15	10	5	67%

Table 3 shows the recognition rate of Danshui Line. Danshui Line uses ballast tracks with the same elastic rail clips as Bannan Line. In addition, 15 elastic rail clips of ballast tracks are used. Potential causes for failure of testing include the severe rust and erosion of some tracks caused by rains. This causes pixels of the elastic rail clip and pixels of the concrete sleeper to be the same. In this case, the edge information of the elastic rail clip structure and the signal become less discriminable and lead to failures in the elastic rail clip selection and recognition.

Table 4. The recognition rate from all of the above three Lines

Test scope	Test images	Success	Fail	Recognize rate
First subsystem	75	73	2	97%
Second subsystem	75	70	5	93%
Third subsystem	75	68	7	90%
Fourth subsystem	75	66	9	88%
Complete test	75	58	17	77%

In summary, recognizing rates of all three lines of Taipei rapid transit system are listed in Table 4, This paper use 75 intermixed images of elastic rail clips and obtains a recognition rate of 77% with the current system.

CONCLUSIONS

Quality of photography images has a great impact on the recognition rate of the system. If the light source can be reinforced while photographs are taken, the contrast of images could be enhanced. This research used the grey-level equalization algorithm to improve contrast in the images but the effect is limited. Therefore, better algorithm could be helpful, such as homomorphic processing algorithm it will be investigated later. Moreover, the method of the elastic rail clip recognition is greatly influenced by the background noise in the environment, especially when it causes the elastic rail clip pixels to resemble the background pixels. Therefore, image processing methods used in the elastic rail clip selection subsystem has to be improved. More effective algorithm is required to reduce effects imposed on the system from the complex environment. Further research should be done to investigate methods for the broken bolt detection to make the recognition system of the elastic rail clip more comprehensive and complete.

ACKNOWLEDGEMENT

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REFERENCES

[1] I. H. Witten, A. Moffat, and T. C. Bell, Managing Gigabytes: Compressing and Indexing Documents and Image, Van Nostrand Reinhold, 1994.

[2] S. G. Mallat, “A Theory for Multiresolution Signal Decomposition: The Wavelet Representation,” IEEE Trans. on Pattern Analysis and Machine Intelligence, Vol.11, No.7, pp. 674-693, July 1989.

[3] D. H. Ballard and C. M. Brown, Computer Vision, Prentice-Hall, New York, 1982.

[4] R. C. Gonzalez, and R. E. Wood, Digital Image Processing, Addison-Wesley, New York, 1992.

[5] D. Vernon, Machine Vision, Prentice-Hall, 1991, pp 34 - 36.