Development of Evaluation Method of Stripping Ratio of Road Markings Using Image Analysis

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ABSTRACT: In snowy areas, snow removal operations cause damage to road lane marking lines, so every year there is a considerable amount of money spent on re-applying these lines. At present, the decision on the need to re-apply the lane marking lines is made based on the amount of damage to the lines at points occurring every 2 to 5 km. However, there is large variation in the damage to lane marking lines caused by snow removal, and it is therefore necessary to evaluate the amount of damage not at points, but continuously as a line. In this research, image processing was applied to images of the road surface taken at 20-m intervals from a traveling vehicle using a digital camera, and a method of continuously obtaining the rate of peeling of the road lane marking lines was developed. In addition, this method was applied to a national two-lane road within Sapporo City, and the results showed that it is possible to continuously evaluate the lane marking lines before and after re-application as well as to identify in detail the areas where the lane marking lines need to be re-applied using the criteria for re-application.

KEY WORDS: Road markings, image analysis, stripping ratio, template matching method, Hough transform.

1 INTRODUCTION

Road markings provide motorists with information such as directions and rules concerning road traffic. The Road Act states that “road markings shall be provided at the necessary locations to ensure the integrity of the road structure and the safety of traffic”. The main types of road markings are centerlines, lane division lines, and roadway edge markings; these are continuously drawn in white either as continuous lines or as broken lines, parallel to the direction of the road. The paint for road markings is broadly divided into liquid paint (JIS K-5665, type 1 or 2) and powder paint (JIS K-5665, type 3), and factors such as the amount of traffic, weather conditions, durability, and economics are taken into account to determine the type of paint that is used.

Damage to road markings, such as soiling, wear, and stripping, normally occurs due to the passage of vehicles. In particular, in snowy regions road markings are stripped by surface levelling and snow removal operations and their visibility is greatly reduced; therefore, it is necessary to periodically inspect and repaint the road markings. In Hokkaido, road markings are repainted every year after the snow melts, and the annual cost of repainting national roads, prefectural roads, and municipal roads amounts to about 3 billion yen. Because of the severe fiscal situation in Japan in recent years, public works expenditures are being continuously cut, and road maintenance and management costs are also being cut. Against this background, it is necessary to evaluate the damage to road markings more precisely in order to more efficiently repaint road markings.

The Road Sign Handbook published by the Japan Contractors Association of Traffic Signs and Lane Markings specifies a method whereby the damage to road markings is evaluated in accordance with the following three criteria: night visibility, appearance, and stripping (Figure 1). The main method for evaluating night visibility is to measure the night retro-reflection of glass beads dispersed on the surface of the road marking. Appearance and stripping are evaluated visually or from photographs based on daytime visibility without using measuring equipment. To evaluate the appearance, five or more people observe the road markings from a distance of about 3 m, and the appearance is evaluated based on the first impression of the road marking. To evaluate stripping, the proportion of the stripped area, that is, the stripping ratio, is obtained using enlarged photographs taken on site directly above the road marking. In the handbook, if the overall evaluation score calculated based on the abovementioned three criteria is less than 3, it is concluded that the road markings need to be repainted.

Evaluation criteria

Evaluation rank	Night visibility evaluation (night reflectivity ($mcd/m^2 \cdot lx$))	Appearance evaluation (first impression)	Stripping evaluation (stripping ratio(%))
5	≧ 274	Good, unchanged from initial construction	< 3
4	186 - 274	Some discoloration, but function of the sign is sufficient	3 - 8
3	126 - 186	Soiling, yellowing, bleeding, etc., can be seen	8 - 23
2	65 - 126	Soiling, yellowing, etc., is remarkable	23 - 40
1	< 65	Original form lost, flowing and soiling, visibility is poor	≧ 40

Overall evaluation

Overall evaluation＝0.3A+0.3D+0.4N

A：Night visibility evaluation rank
D：Appearance evaluation rank
N：Stripping evaluation rank

It is desirable that the overall evaluation is 3 or higher

Figure 1: Method for evaluating road markings (The Japan Contractors Association of Traffic Signs and Lane Markings, 1998).

Normally, road marking evaluation is carried out at points located every 2-5 km. However, in snowy regions the damage to road markings due to snow removal varies greatly, so a continuous damage evaluation is necessary, rather than a coarse evaluation every 2-5 km.

In recent years, with the remarkable increase in the performance of computers, advanced image processing technology has begun to be used for road maintenance and management. Abe and Ogawa have applied fractal analysis to the evaluation of cracking in pavements (Abe and Ogawa, 1992). Moreover, in recent years, Takeichi and Hirakouchi have carried out research into the evaluation of road surfaces in winter using wavelet analysis (Takeichi and Hirakouchi, 2001), and Tanaka has investigated the identification of cracks by applying binarization to road images (Tanaka, 2006). If it becomes possible to continuously evaluate damage to road markings by image analysis, such as the techniques in the above research examples, it will be possible to rationally and efficiently repaint road markings.

In the present research, image analysis was applied to road surface images taken at 20 m intervals using a digital camera mounted on a traveling vehicle on normal roads within Sapporo City, with the objective of developing a method for continuously obtaining the stripping ratio of road markings. In addition, the method was applied to national roads within Sapporo City to evaluate the effectiveness of the method.

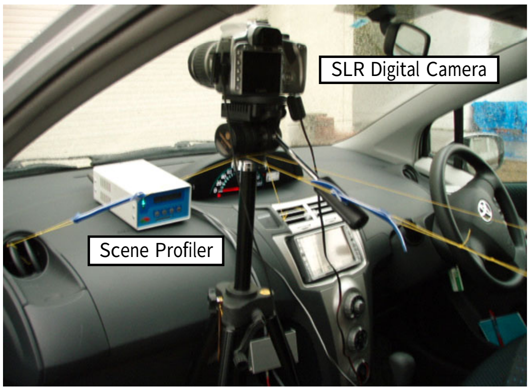
2 OUTLINE OF THE SURVEY

In this research, roadway edge markings (hereinafter, edge markings) painted in a solid white line on the edge of the roadway were evaluated over almost the entire length of the examined road, except at crossroads. Route 36 (9.7km) and Route 12 (13.3km) on national roads within Sapporo were surveyed.

The road surface in front of a vehicle traveling in the left-hand lane was photographed from the passenger seat at 20 m intervals. Photographs were taken using a single lens reflex camera (Canon EOS Kiss Digital X).

As shown in Photograph 1, the camera was mounted in the passenger seat at a height of 1.3 m from the road surface, with a dip angle of 2°. The recorded image size was 2816×1880 pixels (vertical angular field of view = 35°, horizontal angular field of view = 52°), with the shutter speed set to 1/320 second. Photographs were taken traveling at speeds less than the legal speed limit, using a control device (scene profiler) that converted the speed pulse obtained from the vehicle control unit into the distance traveled; the control device transmitted a shutter signal to the camera at the set distance intervals.

The survey was carried out twice: in the spring (May 2008) prior to repainting the edge markings and in the autumn (October 2008) after repainting. In all cases photography was carried out when the road surface was dry, between 9:00 am and 4:00 pm, to account for reflections from the road surface and sunlight.



Photograph 1: Road marking measurement equipment.

3 EXTRACTION OF THE EVALUATION AREA

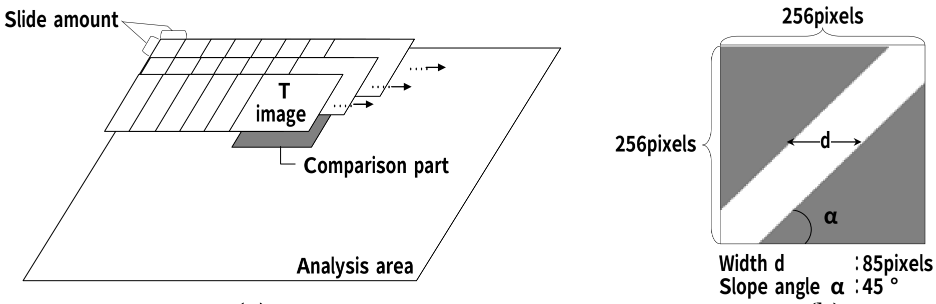
As shown in Figure 2 (a), the edge markings were in the bottom left area of the photographic image of the road surface. In this research, an area that included 20 m of the edge markings, the same distance as the photographing interval, was selected for analysis (hereinafter, referred to as the analysis area). At crossroads and bus lanes, there are no edge markings; therefore, the road surface images for these locations were excluded from the subsequent analysis. The edge markings in the analysis area could not be seen in some places due to factors such as obstruction by other vehicles, and thus it was difficult to evaluate the all edge markings. Therefore, a sub-area (hereinafter, evaluation area) was identified in the analysis area, as shown in Figure 2 (a). The procedure used to identify the evaluation area is presented in Figure 2 (b).

First, the road surface image (color image) was converted to a grayscale image and then cropped to extract the analysis area. Next, the evaluation area was extracted from the analysis area using the template matching (TM) method.

(a) (b)

Figure 2: Extraction of the evaluation area: (a) Analysis area and evaluation area and (b) Evaluation area extraction procedure.

TM is a method in which a template image (hereinafter, T image) is slid over the whole analysis area, and a comparison is carried out to identify the area that most resembles the T image, as shown in Figure 3 (a). In this research, the T image was 256×256 pixels, the angle of inclination of the edge markings was 45°, the width of the edge marking was 85 pixels, and the amount it was slid was 32 pixels (Figure 3 (b)). The T image represents the state in which there is no stripping in the road markings, and thus the area within the analysis area with the least amount of damage to the road markings was identified by TM.



(a) (b)

Figure 3: Template matching method: (a) Slide a template image and (b) Template image.

Various indices have been proposed for the degree of similarity, such as the correlation coefficient or the residual error between the T image and the comparison area, but normally it is determined based on the pattern of the analysis image or the detection accuracy. In this research, the correlation coefficient was adopted as the degree of similarity, as its detection accuracy is comparatively high. Accordingly, the area for which C is a maximum is extracted from the analysis area and taken as the evaluation area.

The correlation coefficient C is obtained from Equation (1).

$$C = \frac{\sum_{j=1}^{N}\sum_{i=1}^{M}\left(I(i,j)-\bar{I}\right)\left(T(i,j)-\bar{T}\right)}{\sqrt{\sum_{j=1}^{N}\sum_{i=1}^{M}\left(I(i,j)-\bar{I}\right)^2\sum_{j=1}^{N}\sum_{i=1}^{M}\left(T(i,j)-\bar{T}\right)^2}} \quad (1)$$

$$(i = 0,1,2,\cdots,M-1,\quad j = 0,1,2,\cdots,N-1)$$

$I(i,j)$: Grayscale value at coordinates (i, j) in comparison area

$T(i,j)$: Grayscale value at coordinates (i, j) in T image
M : Number of vertical pixels in image
N : Number of horizontal pixels in image

In Equation (1), $\bar{I}$ and $\bar{T}$ are the average grayscale values in the comparison area and the T image, respectively, and are expressed by Equations (2) and (3).

$$\bar{I} = \left(\sum_{j=1}^{N} \sum_{i=1}^{M} I(i,j) \right) \Big/ MN \tag{2}$$

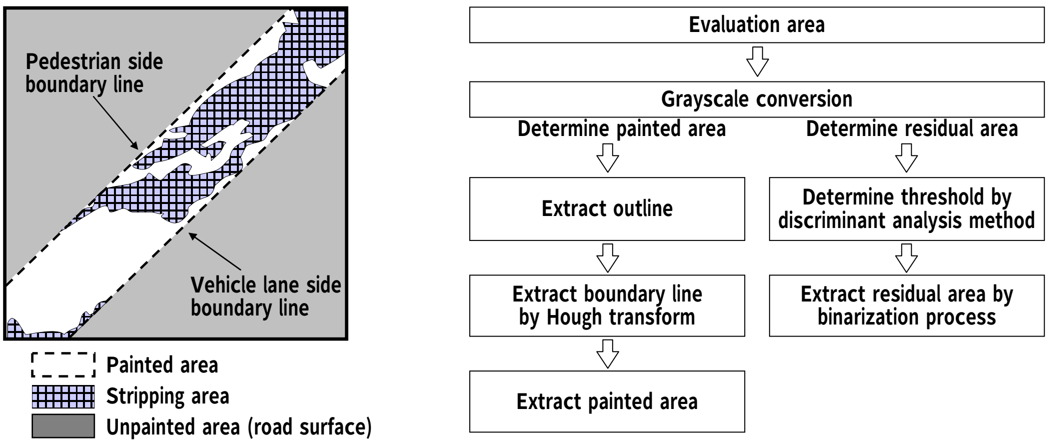
$$\bar{T} = \left(\sum_{j=1}^{N} \sum_{i=1}^{M} T(i,j) \right) \Big/ MN \tag{3}$$

4 CALCULATION OF THE STRIPPING RATIO

A road marking on which stripping has occurred can be divided into a painted area and a stripped area, as shown in Figure 4 (a). The stripped area is the area obtained by subtracting the area on which the paint remains (hereinafter, the residual area) from the painted area, and the stripping ratio can be obtained from Equation (4).

$$Stripping\ ratio(\%) = \frac{Painted\ area - Residual\ area}{Painted\ area} \times 100 \tag{4}$$

In this research, image analysis (Figure 4 (b)) was applied to the evaluation area extracted by TM, the painted area and the residual area were determined, and the stripping ratio was calculated using Equation (4). Since variation occurs in the brightness of the evaluation area, grayscale modification was carried out so that the density area of the evaluation area was a maximum (0-255).



(a) (b)

Figure 4: Extracting painted area and residual area: (a) Painted area and stripped area (b) Procedure of image analysis.

4.1 Determination Painted Area

The painted area is enclosed by the boundary lines of the road marking (the boundary lines on the pedestrian side and vehicle lane side), as shown in Figure 4 (a). Various image processing methods can be used to determine the boundary lines, such as affine transforms. In this research, based on the shape of the road markings (straight lines), the Hough transform was used as it is excellent for detecting straight lines. The Hough transform is a straight line detection method used in various image analysis systems such as image-based authentication of mechanical components. The Hough transform has the advantage that it is capable of stable detection even when there is noise or discontinuous straight lines in the image.

The evaluation area in this research was a grayscale image, and thus it is not possible to directly apply the Hough transform. Therefore, the Hough transform is applied after extracting the outlines of the boundary lines by the following method.

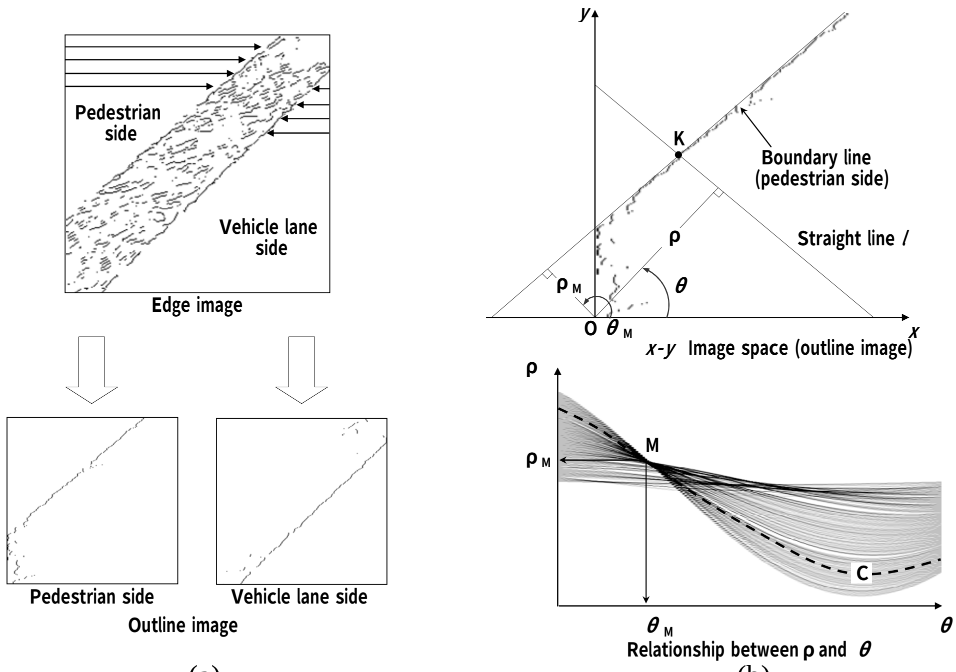
First, edge detection is carried out using the Sobel method to generate line images as shown in Figure 5 (a). Then, the first point at which the density changes from 255 to 0 (white to black) from the left side of the line image was detected, to generate an outline image of the pedestrian side. The same detection is carried out from the right side of the line image, to generate an outline image of the vehicle lane side.

Next, the Hough transform is applied to the obtained pedestrian side outline image to determine the boundary line of the road marking and the road surface. The boundary line is determined using the Hough transform by the following procedure.

As shown in Figure 5 (b), a straight line that is present in the outline image (x-y image space) can be expressed by Equation (5).

$$\rho = x\cos\theta + y\sin\theta \tag{5}$$

ρ : Length of the line normal to the straight line l that passes through the origin O
θ : Angle between the normal line and the x-axis



(a) (b)

Figure 5: Extraction of boundary lines: (a) Extraction of outline images (b) The Hough transform.

By rotating the straight line l around the point K in the outline image, the parameters θ and ρ can be obtained, and the relationship between the two is drawn (curve C). This is carried out for all lines on the outline image, to obtain the point through which the most curves pass (point M). The straight line represented by the parameters (ρ_M, θ_M) corresponding to point M is taken as the boundary line.

This is also applied to the outline image on the vehicle lane side, and the area enclosed by the 2 straight lines on the pedestrian side and the vehicle lane side was taken to be the painted area.

4.2 Determination of the Residual Area

From the density histogram of the evaluation area, binarization was carried out on the density values of the evaluation area to extract the residual area using a threshold calculated by the discriminant analysis method. The discriminant analysis method is typically used to determine the threshold for binarization of images.

As shown in Figure 6, it is assumed that the point at which the density values (1, 2, . . . , 255) are divided into two classes is t. Density values less than t are taken as class C_1, while those equal to or greater than t are taken as C_2. The total number of class C_i (i=1, 2) pixels ω_i, the average density value M_i, and the variance σ_i are obtained, and the variance within the class $\sigma\omega^2$ and the variance between the classes σ_B^2 is calculated using Equations (6) and (7).

$$\sigma_W^2 = \frac{\omega_1\sigma_1^2 + \omega_2\sigma_2^2}{\omega_1 + \omega_2} \tag{6}$$

$$\sigma_B^2 = \frac{\omega_1\omega_2(M_1 - M_2)^2}{(\omega_1 + \omega_2)^2} \tag{7}$$

The dividing point t is varied, σ_B^2 and σ_W^2 are calculated, and the ratio between the discriminant ratio (σ_B^2/σ_W^2) and t is obtained. The value of t that maximizes the discriminant ratio is taken to be the threshold value used in the binarization process.

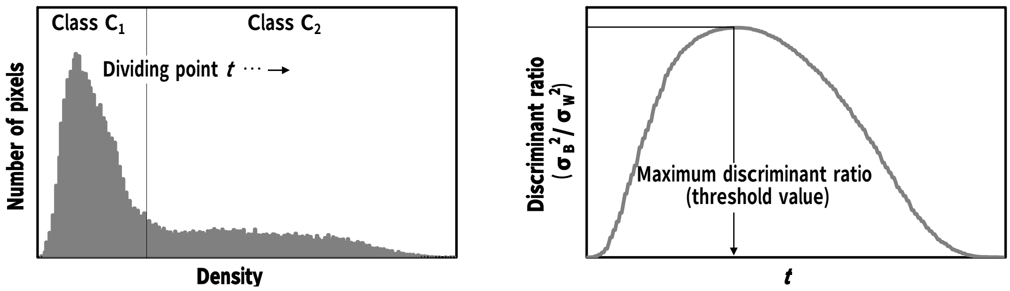


Figure 6: Determination of threshold by discriminant analysis method.

4.3 Results of the Stripping Ratio Calculation

An example of the stripping ratio calculated by the above method is shown in Figure 7. It can be seen that as the stripping ratio increases as the damage to the road markings increases. When the stripping ratio is 5% or less almost no damage to the road markings can be seen, but when the stripping ratio is 5-30%, crack-shaped or hole-shaped stripping can be seen near the boundary line (between the road surface and the road marking). Furthermore, when the stripping ratio is 30% or more, the stripping proceeds into the interior of the road marking, and when it exceeds 60%, the outline of the road marking becomes unclear.

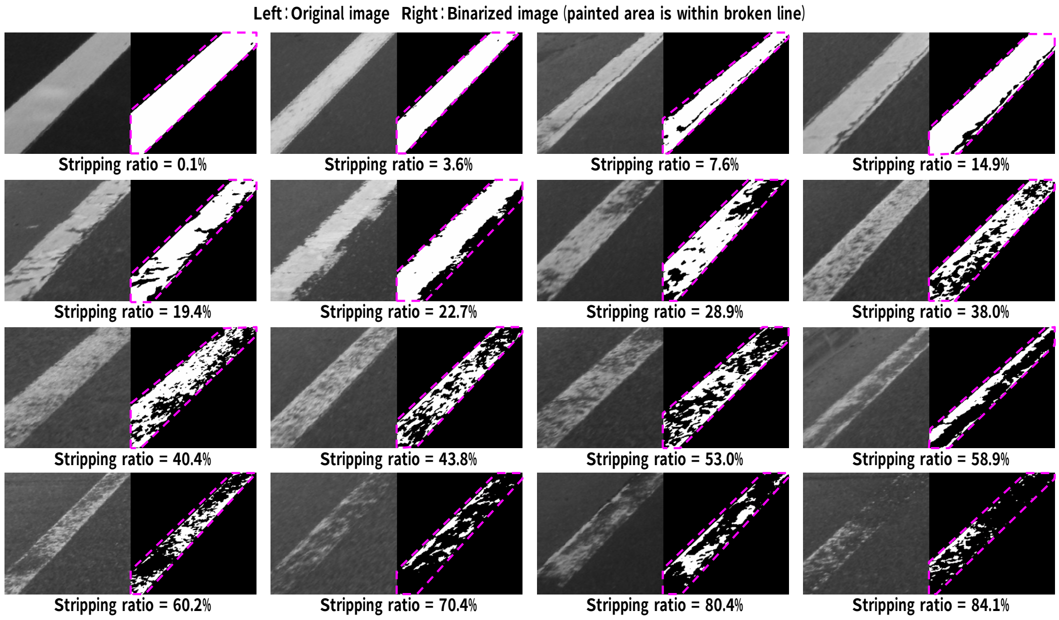


Figure 7: Example of calculating stripping ratio.

In order to verify the validity of the image analysis method used in this research, the painted areas and the residual areas for the 16 evaluation areas shown in Figure 7 were determined by the visual method described below to obtain the visual stripping ratio. To determine the painted area, the boundary lines between the road markings and the road surface were determined visually, in reference to the overall road markings of the analysis area. To determine the residual area, the threshold was adjusted and the binarization process was carried out in reference to the original images. Figure 8 shows the relationship between the stripping ratios from the image analysis and the visual stripping ratios. The relationship between the two was nearly 1 to 1; therefore, the accuracy of the proposed method is sufficiently high.

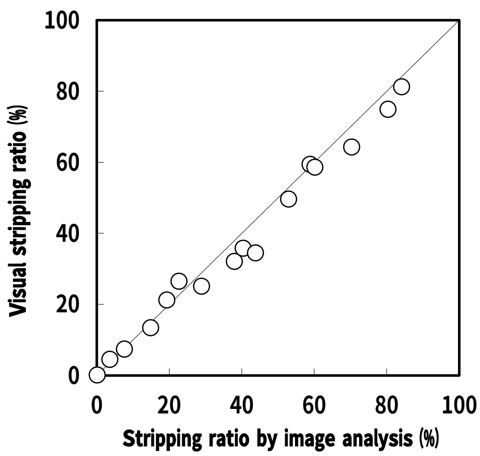


Figure 8: Relationship between stripping ratio from image analysis and visual stripping ratio.

5 STRIPPING RATIO PROFILE OF THE SURVEY ROUTE

The variation in the stripping ratio (the stripping ratio profile) for R36 and R12 obtained by this method is shown in Figure 9. In the spring prior to repainting, the stripping ratio varied greatly from 0 to 80% along both routes, but in the autumn after repainting, the values of both the stripping ratios and their variation were small. Furthermore, in the four areas denoted by A–D in the figure, the repainting operation was completed before the survey in spring. Therefore, although the difference in stripping ratio between spring and autumn was small, the difference in stripping ratio in the other areas was large; thus, it can be seen that over virtually the entire route, the damage to the road markings was repaired to a considerable extent.

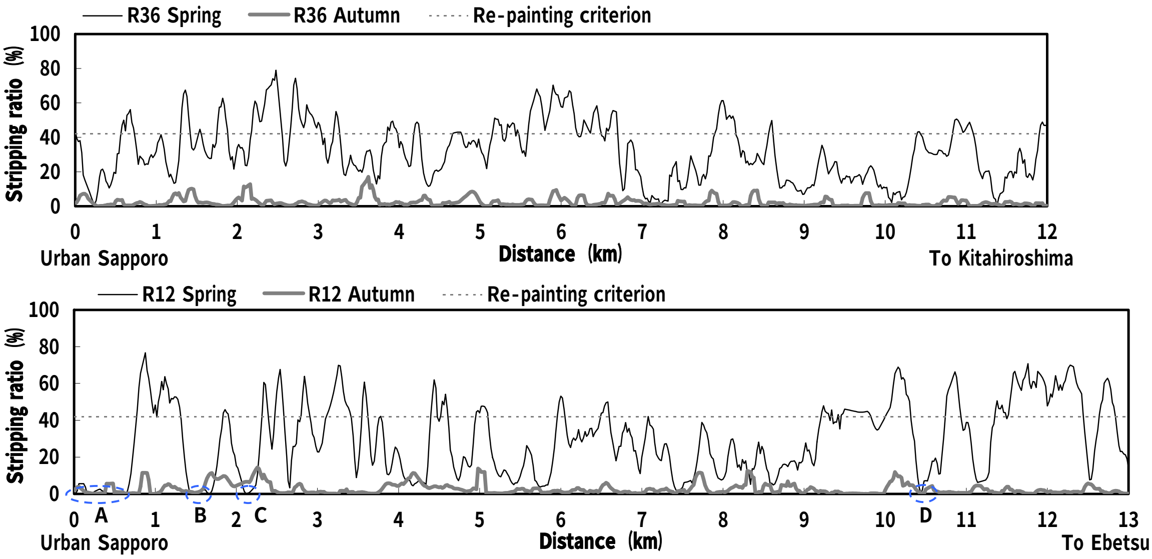


Figure 9: Stripping ratio profile on survey route.

The Road Signs and Traffic Safety published by the Japan Contractors Association of Traffic Signs and Lane Markings contains road marking images as a standard for deciding whether repainting is necessary (The Japan Contractors Association of Traffic Signs and Lane Markings, 2008). When the proposed method was applied to these images, a stripping ratio of 42% was obtained. Therefore, in this work, a stripping ratio of 42% was regarded as the criterion for repainting the road markings and applied to the spring stripping ratio profile shown in Figure 9. As a result, it was deemed necessary to repaint the areas above the dotted line in this figure. For R36 and R12, respectively, it was found that 30.7% and 31.1% of the routes exceeded the criterion for repainting.

By using the proposed method, it was possible to identify in precise detail the areas in which repainting was necessary. However, carrying out repainting work in only small areas while skipping others is inefficient and the appearance is undesirable. Therefore, in practice, the length of the area to be repainted is frequently set to 1 km. By assuming this repainting length, the average stripping ratio over 1 km intervals was obtained. Figure 10 shows the average stripping ratio prior to repainting (spring) along the survey routes. The area in which the repainting criterion based on the average stripping ratio (42%) was exceeded, that is, the area in which repainting was deemed necessary, constituted 25% of R36 (3 areas out of 12) and 15.4% of R12 (2 areas out of 12). Considering that road markings are currently repainted along almost the entire survey route each year, adopting the proposed method would enable the areas that require repainting to be specifically identified, which could lead to reduced road maintenance costs.

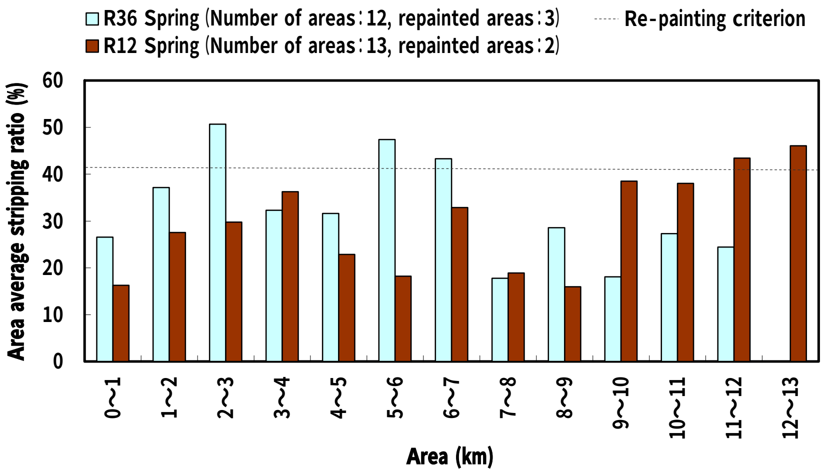


Figure10: Area average stripping ratio on survey route (spring).

6 CONCLUSIONS

The conclusions of this research are as follows.

- A method for continuously obtaining the stripping ratio of road markings by applying image analysis to road surface images photographed at 20 m intervals by a digital camera installed in the passenger seat of a traveling vehicle has been developed. Moreover, it has been demonstrated that the stripping ratios calculated by this method are virtually identical to the stripping ratios calculated by the visual method.
- When the stripping ratio profiles of R36 and R12 were obtained using this method, it was found that the stripping ratios in autumn after repainting were low at less than 10%. In contrast, the stripping ratios in spring before repainting were large, and the variation within the route was also large. Furthermore, it was possible to identify in detail the areas in which repainting was necessary by applying a repainting criterion to the obtained stripping ratio profile.
- Assuming repainting work is carried out in 1-km intervals, the average value of the stripping ratio in each area was obtained. The results showed that 25% of R36 and 15.4% of R12 required repainting.

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