Automatic Recognition of Patterns and Words Road Markings based on Laser Reflectance Information

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ABSTRACT

Road surface markings provide guidance and information to drivers, promote road safety, and ensure the smooth flow of traffic. Most previous studies in this area focused on the detection and recognition of lane lines with very limited prior work on the recognition of lane center road markings. This paper focuses on the development of an algorithm for automatically detecting and recognizing road markings of patterns and word messages at traffic lane center. Road markings of Chinese characters are first studied. In addition, a method for identifying the completeness of road markings is also presented. Authors propose an approach to extract road marking features based on the derivation of a binary matrix image transformed from laser reflectance collected from a top down roadway view laser scanner. The results of case studies on asphalt pavement (city streets) show that the approach can detect and recognize lane center road markings with a significant success rate. The average successful detection rate is 96.06%, including 94.05% success of Chinese character road markings and 97.73% success of direction arrows and others. From the case studies, it was also noted that a significant portion of road markings have relatively low completeness. Further studies will focus on increasing survey speed, detecting other highway classes containing different Chinese characters and road markings such as icon, increasing detection rate, conducting study on various pavement condition, and developing a decision making strategy for road marking maintenance.

INTRODUCTION

Road markings are a special traffic signs which are commonly marked on the surface of paved roadways to provide guidance, warning, or information to drivers and pedestrians. Sometimes, road markings are used to supplement the message of road signs and other devices. Road markings include lane lines (single, double, solid, and broken), lane arrows (straight, right, left, and combined), numbers, letters, and figures. It is very important to keep the uniformity of the markings in minimizing confusion and uncertainty about the meaning; however, countries and areas usually categorize and specify road markings in different ways. Nevertheless, to maintain the clearness and completeness of road markings above an acceptable level is always an important but challenging task for roadway authorities. Some but limited previous research works were concentrated on road marking automatic detection and recognition.

From literature reviews, it was found that lane lines were studied the most out from all kinds of road markings, and the difference in image brightness between pavement and lane lines was the key element used for the detective method. Broggi [1] has developed a massively parallel approach that can successfully detect the lane line from the pavement, even under the shadow condition. Charbonnier, et al, [2] adopted the image process method to detect the lane lines. Brightness was also the main factor that was utilized to differentiate between lane lines from pavement. The developed algorithm provided very promising results. However, researchers claimed that lane line colors do not give significant difference in brightness; therefore, there was no good outcome of classifying white lane lines from yellow ones. Additionally, Frank [3] studied the vertical projection of lane line brightness and derived an algorithm to detect the location of land lines with great success. In 2007,
Li [4] presented a shape-based road markers detection and recognition method employing moment invariants for integrating the research works of intelligent vehicles and driver assistance systems. The experiment results show that lane lines and arrows were detected and recognized effectively through the method.

In 2008, Lee [5] conducted research study to detect road markings marked at the intersection area. Image brightness was again selected as the key element to identify road markings from pavement. He also adopted methodologies of feature detection and template matching in that study. Crosswalk road marking was a typical example used, and the features of repeated and fixed amount of horizontal projection of image brightness provide a great success to identify the cross road markings.

It is clearly observed that conducting image process on differential brightness of road markings and pavement has been used for lane line detection in most of the related researches. Maier, et al [6] presented a general geometric approach using curve-based prototype fitting to detect arrow markings. The authors focused on the usage of a monocular gray value camera. Regions of interest are determined based on some preliminary knowledge in order to reduce the search space. Prototypes encoded as arc splines were used for the comparison with the extracted contours of object candidates, which enables both detection and classification. Another methodology for the automatic recognition of on road markings was presented by Kheyrollahi and Breckon [7]. The authors proposed an approach based on the extraction of robust road marking features through inverse perspective mapping and multi-level binarization. This is the first time that recognition of on-road textual words, including numbers, lane arrows, words (in English), were carried out. Raw data were collected under varying test conditions, and the success rate is approximately 81% for lane arrows and 85% for words.

It was noted that most of the prior studies were concentrated on lane line detection and recognition, and only one paper studied the textual words (in English) painted on traffic lane center. Furthermore, none of the prior research mentioned above includes the analysis of the road markings completeness which is not only important to drivers for safety sake but also to roadway engineers for scheduling maintenance. Therefore, in this study research work will focus on the detection, recognition, and completeness identification of four types of road markings painted at traffic lane center, namely Chinese characters, numbers, signs, and lane arrows markings. It should be mentioned that the official language used in Taiwan is Chinese; therefore, the textual words are all written in Chinese characters. This is typically the same in China, although it is traditional rather than simplified Chinese characters used in Taiwan roadway network.

### DATA COLLECTION

Researchers utilize a pavement survey device equipped with laser scanner, distance measurement instrument (DMI), and accelerometer (as shown in Figure 1) to collect two major data of pavement surface, profile (mm) and laser reflectance in terms of millivolt (mv). A polygonal scan mirror is functioned with the laser and the laser’s frequency is 1000 scan/sec and 943 points per scan. The
pavement survey device is mounted at 2.1 meter (7 feet) above ground which allows a horizontal measurement width of 4.2 meter (14 feet). This will ensure the scanning line coverage is wider than one traffic lane which is usually 3.5 to 3.6 meter (11.7 to 12 feet) in Taiwan. Point spacing along the 4.2 meter horizontal scanning line is between 3.8mm to 7.6mm with an average of 4.8mm. General speaking, the points at the lane center are more dense than that at both sides, so the point spacing at the center is much closer than that of outer part. The vertical (along driving direction) point spacing is dependent on the survey speed. The higher the speed is, the larger the spacing is. The average vertical point spacing is 13.8 mm at a driving speed 50 km/hr conducted in this research work. More detailed descriptions of this pavement survey device and its functions are given in Tsai’s dissertation [8].

FIGURE 1. Pavement laser scanning device used by National Taiwan University research team.

In Taiwan, both traffic paints and thermoplastic strips are commonly used for road markings. No matter which material is used, road markings usually have 2 to 5 mm thicknesses above the pavement surface. In addition, the received laser reflectance from road markings is much higher than pavement materials, particular asphalt pavement. These two features, profile elevation and laser reflectance, are captured by the selected pavement survey device; however, only the information of laser reflectance is used for developing the analysis algorithm in this study [9]. This study chose Taipei city streets as the major survey fields because of the wide varieties of road markings. The survey experiment was conducted between 11 PM and 5 AM in order to have less traffic interference. Some examples of road markings are displayed in Figure 2.
FIGURE 2. Some examples of road markings at traffic lane center in Taiwan’s city streets

ANALYSIS METHODOLOGIES

Data Reduction

The data reduction process was first applied to the collected raw data of laser reflectance for removing the unwanted part, such as lane lines, stop lines, and crosswalk road markings. Algorithm of these procedures was also developed [9]; however, it is not included in this paper. Figure 3 illustrates a laser reflectance binary matrix image of one traffic lane which includes left lane lines, cat’s eyes (repeated black dots on the double left lane lines), right broken lane lines, the Chinese characters of road markings in the middle, 禁 (Jin) 行 (Xing) 機 (Ji) 車 (Che), which means “No Motorcycle Allowed”, and a straight lane arrow. Although in this study researchers have worked on the development of comprehensive algorithm to detect all kinds of lane lines, cat’s eyes, and center lane road markings, this paper will only focus on the center lane road markings because of its complexity compared with others. More detailed description of other road markings detection algorithm is presented in Hsu’s thesis [9].

FIGURE 3. An example of reflectance binary matrix image of surveyed traffic lane

Reflectance Threshold Selection for Binary Matrix Invention

The survey device captures the laser reflective intensity (reflectance) of measured traffic lane. Although the reflectance within individual paving or painting material is not very uniform, the difference of that between material types is significantly enough to differentiate the material types. In general, the reflectance of road markings made by traffic paints and thermoplastic strips has a range between 420 mv and 600 mv which is much higher than that of pavement materials, typically ranged from 180 mv to 280 mv. Owing to the facts that environmental factors, such as time of day, sun light, and moisture, may affect the measurement, survey data were collected in various environmental conditions for testing the variation of reflectance. In this study, trial and error method was adopted to find the appropriate threshold of reflectance which can give a clear cut between road markings and pavement materials. Ranges of reflective intensity from 240 mv to 440 mv were selected in the trial and error process with an increment of 20 mv. Once a threshold is applied to the reflective intensity...
image, pixel with intensity higher than the threshold will be assigned as 1, and pixel that has 
intensity lower than or equal to the threshold will be assigned as 0. A binary matrix is established 
through this process. The next step is to mark all pixels of number 1 as white color and that of 
number 0 as black color. This will convert the reflective intensity image into a binary matrix image 
as shown in Figure 4. In this figure, three binary matrix images of road marking character 機(Ji) 
are displayed. They are screened by intensity threshold of (a) 240 mv , (b) 380 mv, and (c) 440 mv, 
respectively. It is observed that by using threshold 240 mv will cause some spotted pavement pixels 
marked as white color which will interfere with the road markings detection. However, the image 
(c) of using threshold 440 mv turns some pixels of character 機 (Ji) into black color which will be 
misjudged as blurs of road markings. As a result, the reflective intensity 380 mv was finally selected, 
because it gives the best differentiation. Because laser reflectance of asphalt pavement typically 
ranged from 180 mv to 280 mv, any value between 300 mv and 400 mv can give a great result of 
pavement and road markings differentiation. The threshold derivation is not as complicated as those 
for segmentation of color images such as foreground-background separation. The selected iterative 
approach suited the needs for the application. However, this study only focused on asphalt 
pavement, and it needs further study to select the suitable reflectance threshold for rigid pavement 
due to its relatively higher reflectance than that of asphalt pavement.

(a) Threshold 240               (b) Threshold 380   (c) Threshold 440

FIGURE 4. Binary matrix images of Chinese character 機(Ji) screened by various threshold values 
of reflectance.

Identify Boundaries of Each Individual Road Marking

After completing the previous steps, a good and clear binary matrix image is converted and saved. 
The next step is to detect the exact location of each individual road marking of Chinese character, 
number, arrow, or figure, by cutting the image’s vertical and horizontal boundaries.

(A) Horizontal Projection

Horizontal projection is defined as the horizontal sum of pixel numbers with white color (or with 
value 1) in a single horizontal line. Based on the regulations of Taiwan Roadway Traffic Road 
Markings Specification [10], the width of every single stroke is 10 cm which is about 20 pixels in 
this study. Chinese character, lane arrow, or other road markings with more than one stroke in 
the same horizontal line will accumulate the horizontal projection to a large number of pixels. 
Figure 5 illustrates (a) road marking’s binary matrix image, (b) the original horizontal projection, 
and (c) the corrected horizontal projection of Chinese characters 禁(Jin) 行(Xing) 機(Ji) 車
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(Che), while Figure 6 provides the similar information of straight lane arrow road marking.

**FIGURE 5.** The binary matrix image, original horizontal projection, and corrected horizontal projection of Chinese character road markings of 禁(Jin) 行(Xing) 機(Ji) 車(Che).

**FIGURE 6.** The binary matrix image, original horizontal projection, and corrected horizontal projection of a straight lane arrow road marking.

The corrected horizontal projection was modified from the original horizontal projection by
choosing 10 pixels as cutting number. Any horizontal projection line has an original sum of white pixel number smaller than 10 will be reassigned its projection number to 0 and marked in the corrected horizontal projection. On the contrary, if a horizontal projection line has an original sum of white pixel number larger than or equal to 10, its projection pixel is then reassigned to 100. Through this modification, the corrected horizontal projection can provide very clear boundary of almost all the road markings at traffic center lane. It should be mentioned that many Chinese characters have gap(s) within one word, such as shown in Figure 7. This Chinese character was horizontally divided into three parts based on the given analysis method, and it can be easily mistreated as three characters. In order to integrate the top, middle, and bottom parts into one word, calculation of gap width is added into the calculation algorithm. Based on the regulations of [10], the gap between any two consecutive Chinese characters or other road markings must be larger than 100 cm. Therefore, researchers selected a spacing 50 cm as the conservative judging threshold. For every gap appears on the corrected horizontal projection, the gap width is also calculated. If it is smaller than 50 cm, the adjacent two parts of this specific gap will be integrated and considered as one Chinese character. The same procedure was repeated for the continuous binary matrix image obtained from the previous steps. By conducting this operation, parts of a single character can be integrated as a whole no matter how many gaps within one character.

![FIGURE 7. An example of a Chinese character composed of three parts with two horizontal projection gaps](image)

(B) Vertical Projection

Likewise, the vertical projection is defined as the vertical sum of white color pixel numbers along the vertical lines of binary matrix image. The similar operation procedure was then applied to the binary matrix image after step (A) to find the horizontal boundary of each single character and other types of road markings. Figure 8 illustrates 12 examples resulted from the completion of step (B). These final binary matrix image (hereinafter FBMI) examples, including Chinese characters 禁(Jin),行(Xing),機(Ji),車(Che) (No Motorcycle Allowed), 慢(Man) (Slow),公 (Gong),車(Che),專(Zhuan),用(Yong) (Bus Exclusive Lane), high occupancy vehicle (HOV) lane sign, speed limit number 50 (km/hr), and directional arrow, all have clear cut at four boundaries. These final binary matrix images (white=1, black=0) will provide good bases for the next step of
image classification.

FIGURE 8. Examples of boundary-clear-cut FBMI of “No Motorcycle Allowed”, “Slow”, “Bus Exclusive Lane”, “50 km/hr” and “Left turn only” markings.

**Image Classification**

As mentioned that the objective of this study is to detect road markings at center traffic lane and to clarify their completeness. Therefore, the next step is to identify what they are by using the templates. Researchers designed the template images based on the instructions offered by Taiwan Roadway Traffic Road Markings Specification [11]. A total number of 33 template images were designed for this city street project. These include 22 Chinese characters, 4 speed limits (40, 50, 60, and 70), 6 different types of lane arrows, and a HOV sign. Each template image is a binary matrix having four sides clear cut. Pixels with 1 indicate the road marking itself and pixels with 0 represent the background. The following sections describe the developed algorithm used to classify the identity of each road markings.

(A) Enlarge or reduce the size of each FBMI to match the standard size of template

All templates have a standard image size, i.e. 200 pixels by 500 pixels, but the FBMI of road markings may not have uniform image size due to the variation of road construction. Therefore, the first step of the image classification is to enlarge or reduce the FBMI size to match the template standard size.

(B) Multiply the analyzed sample’s FBMI pixels by template images

This step is to multiply the image pixels (1 and 0) of any given sample’s FBMI by that of each template’s image for obtaining an index namely road marking judgment index (RODI). In other words, RODI is the dot summation of sample FBMI and template inverse matrix. The following equation shows the mathematic calculation of the RODI.

\[
\text{RODI}_{ij} = \sum_{x=1}^{m} \sum_{y=1}^{n} S_{xy} \times T_{xy}
\]  

(Eq. 1)

Where:

- RODI<sub>ij</sub>: road marking judgment index of sample i to template j
- S<sub>i</sub>: Sample i’s binary matrix of m times n pixels
- T<sub>j</sub>: Template j’s binary matrix of m times n pixels, j is the template number 33

The purpose of this operation is to search the best matching template image for each sample. Therefore, each sample has to repeat the same calculation procedure 33 times over all the template images. Remember that sample’s FBMI includes pixels 1(road marking) and pixels 0 (pavement background), so as each template. When a sample’s FBMI pixels are multiplied...
by its corresponding (correct) template; theoretically, the RODI will receive the highest value from the 33 trials, and this value equals to the total number of pixels 1 of that given sample. This is because when sample’s FBMI matches its correct template, all the sample’s pixels 1 will be multiplied by pixels 1 of the template due to their matching position in both matrices, and this will result in a sum equals to the number of pixel 1 of either matrix. Likewise, the pixel 0 of sample’s FBMI will be multiplied by pixel 0 of the template which will result in a sum of 0. When we add these two parts together for obtaining RODI, the sum will remain the same as the first part. Under this condition, the RODI value calculated from Eq. 1 is the maximum and it equals to the number of pixels 1 of the given specific sample. All the other 32 trials will result in smaller RODI values compared to that obtained from the correct template. This is because some, if not all, sample’s pixels 1 may be multiplied by pixels 0 of those incorrect templates; thus turn out a small RODI value. It shall be noted that the maximum RODI is not always obtained, because the road markings at the traffic lane center are easily worn out with time. If a road marking is severely worn out, a clear peak value of RODI may not be obtained from the 33 trials. Instead, several RODI values within a small range may be obtained. Although these values are still relatively higher than that calculated by other templates, it is difficult to identify which one is the correct template from the group. Figure 9 demos a typical case that a sample is heavily worn out. By using the current calculation procedure, the correct template image 禁(Ji) can hardly be identifies. Therefore, the image classification algorithm is further modified in step (c).

![Figure 9](image_url)

FIGURE 9. A sample of road marking that is severely worn out

(C) Multiple template image pixels value by 3

In this study, it is suggested to modify the template binary matrix pixel value by a multiplier 3, i.e. pixel of road marking is 3 and pixel of background stays as 0. This will lower the weight of the worn out portion and increase the weight of the remaining portion. By doing so, the RODI value obtained from the correct template will be 3 times larger than it was before, while the RODI values of the other 32 trials may only slightly increased. Through the case studies presented below, it is concluded that the RODI value calculated from the modified step (C) is a great indicator for matching the sample with the correct template.
DETECTION OF ROAD MARKINGS COMPLETENESS

Road surface markings provide guidance and information to drivers. Markings “No motorcycle allowed” prevent the mix of vehicles/trucks with motorcycles on the same traffic lane which play a major part in reducing motorcycle accidents. Lane arrows are used on approaches to traffic lights to show which lane the driver should move into if he/she wants to turn or carry on straight. “SLOW” markings are often used on the approach to a hazard. Therefore, it is extremely important to maintain the road markings as clear and complete as possible. It is regulated by Taiwan Traffic Control Facility Planning and Design Handbook [10] that “road markings must be maintained at a clear standard at all time, and re-paint treatment shall be taken if markings are worn out or dirtied.” Although this regulation states the importance of road markings, it does not give a quantitative statement about how to decide the level of “worn out” and to define the quality of remaining completeness of road markings. Different from the traffic lane lines, road markings painted at the traffic lane center are much easily to be worn out by wheels or dirtied by dripping motor oil. Figure 10 shows the road markings “公(Gong)車(Che)專(Zhuan)用(Yong)” and the left broken lane line are severely dirtied or worn out. Therefore, this study also concentrates on algorithm development of detecting the completeness of road markings.

For each sample’s FBMI, the road marking completeness factor (CF) is calculated by Equation 2.

\[ CF_i = \frac{\text{total no. of pixels 1 of sample i’s FBMI}}{\text{total no. of pixels of sample i’s FBMI}} \times \frac{\text{total no. of pixels of correct template for sample i}}{\text{total no. of pixels of correct template for sample i}} \]

(Eq. 2)

Where:
CFi: the road marking completeness factor (CF) (%) of sample i

Since each sample’s FBMI has been sized down or up to match the standard scale of template, the total number of pixels of samples’ FBMI is same as the total number of pixels of correct template for that sample. Therefore Equation 2 can be simplified as Equation 3.

\[
   CFi = \frac{\text{total no. of pixels of sample } i \text{’s FBMI}}{\text{total no. of pixels of correct template for sample } i}
\]

(Eq. 3)

Figure 11 illustrates a comparison of some road markings at relatively good and bad conditions. The first two rows give 10 samples’ FBMIs and their corresponding CFs, while the third and fourth rows displays the information of another set of FBMIs of the same 10 road markings. It is clearly observed that the developed algorithm can provide very promising results in terms of determine road marking completeness.

![Figure 11](image)

**CASE STUDIES**

In this paper, four sections of Taipei city streets, including two regular traffic lanes and two bus exclusive lanes, were surveyed by the pavement laser scanner device at speed 50 km/ hr. The developed analyzed algorithm was applied to the measured raw data step by step. Table 1 gives the analyzed results. The total length of four sections of city streets is 7,144 meter which includes 4,409 meter regular traffic lanes and 2,735 meter exclusive bus lanes. The average accuracy rate of automatically detecting Chinese character markings is 94.05%, while that of detecting lane arrows, speed limits numbers, and HOV sign is 97.76%. This is of the similarity of some Chinese characters, such as 車 (Che) and 専 (Zhaun), particularly when both of them have low completeness factors. Nevertheless, both accuracy rates are well above 90% which indicates that the analysis algorithm...
CONCLUSIONS

Road surface markings provide guidance and information to drivers, promote road safety, and ensure smooth flow of traffic. Sometimes, road markings are used to supplement the message of road signs and other devices. This study focuses on the algorithm development for automatically detecting and recognizing road markings at traffic lane center. Laser reflectance of the pavement surface was collected by pavement survey device equipped with laser scanner. Because of the significant difference of reflectance between road marking (both traffic paints and thermoplastic strips) and paving materials, road markings binary matrix image was extracted from the scanned traffic lane surface image. Different from most English spoken countries, road markings analyzed in this study include many Chinese characters in addition to speed limit numbers, lane arrows, and HOV sign. Analysis algorithm was successfully developed for road markings’ binary matrix image extraction, image classification, and the completeness factor calculation. Case studies of city asphalt pavement traffic lanes show that the average accurate rate of road markings detection is 96.09%. A total number of 245 road markings are correctly detected from the population of 256. General speaking, markings of Chinese characters have a relatively low successful detection rate (94.05%) due to the similarity of some characters, particularly when markings are severely worn out or dirtied. From the case studies, it was also noted that a significant portion of road markings have relative low completeness. Further studies will focus on increasing survey speed, detecting other highway classes containing different Chinese characters and road markings such as icon, increasing detection rate, conducting study on various pavement condition, and developing a decision making strategy for road marking maintenance.

REFERENCES


