A TIRE MARK LOCALIZATION METHOD FOR FORENSIC IMAGE ANALYSIS

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Abstract: An automated tire mark identification system includes functions of the mark localization, segmentation, feature extraction, tire-tread matching and identification. The tire mark localization is the first and most important step for the system development. The study proposed a new algorithm called rotation-projection method to solve the problem of the seed selection by using region growing algorithm for skid mark localization and expand the processing scope of the types of tire marks. This new algorithm has six steps including gradient direction angle detection, image rotation, image projection, calculating the coefficient of the variant, and detecting the tire mark area. This method combined with the gradient operator can effectively detect the area of the new or old tire marks. Its accuracy is similar to the original region growing algorithm in new tire mark localization. Nevertheless, the algorithm also can localize the old tire mark while the region growing method can not cope with.

Keywords*: tire mark, localization, region growing*

1. INTRODUCTION

Tire mark data is an important verification source in accident investigation. Its type/patterns, length and location at the scene area can be used to reproduce drivers' behavior, collision points, vehicles' heading, minimum speeds before collision, post collision trajectories, etc., in an accident reconstruction (Baker et al., 1986, Wang et al., 2003). In practice, this data was measured and provided by investigators/policemen at the scene area using tape and a simple (non-metric) camera. This data further can be used to identify its belonging of the tire of the vehicle at the accident scene or out of the scene by manual method. The time and cost needed to measure and identify the marks depend on the inspector's views, experiences and skills, and its accuracy is varied by investigators. Therefore, how to develop an automotive and non-destructive method to directly obtain the measurements or features of the tire marks such as tire width, striation width, number of striations, track pattern etc. to save operational time and cost is an important issue.

There are two types of tire marks-imprint and friction mark. Tire imprint retains the features of tire tread and can be used as an input to compare and match with tire-tread. On the contrary, friction mark includes skid mark, yaw mark and tire scrubs which don't have complete texture as tire-tread does. However, skid mark possesses a little outline characteristics as tire-tread does. It often has distinctive striations (streaks) that are parallel to the length of a skid mark. Contrarily, yaw mark and tire scrubs are quite different from tire-tread. Because skid mark and tire imprint are mostly captured at the accident scene, problems of the automatic skid mark and tire imprint measurements are the focus of this study.

In forensic image analysis, measurements taken from photographs (i.e., photogrammetry) usually used to capture data such as ratios, and scaling while performing any marks comparison. The introduction of digital imaging has not changed the nature of the comparison activity. However, it has enabled the scientist to extract information more easily including other sources of imagery, especially, the videotaping. The biggest progress in forensic image analysis in recent years has been the ability to visualize and extract image detail via three-dimensions (3D) (Bramble et al., 2001). However, due to its high cost to perform comparisons of 3D data model using a 3D laser or digitizer system (e.g., Rolleimetric and GOMATOSⅢ), the scope of its application is constrained and is only used at serious traffic accidents or crime scenes (Buck et al., 2006). Therefore, an economic and high accuracy method for tire mark analysis needs to develop in the near future. In general, an automatic tire mark measurement system must include functions of mark localization, segmentation, feature extraction, matching and tire identification. The localization of tire mark is the first and most important step to accomplish the development of an automatic mark measurement system. Thus, our goal is to develop a method to perform the localization of tire mark in an accident image.

Unlike standard object recognition, in real environment the marks are embedded in a complicated and irregular pavement texture and have to be detected in images presenting pavement texture. Typical objects in such images that are difficult to recognize are unconstrained illumination conditions, unknown position, orientation, size and pattern of the marks and irregular texture (background). However, the image segmentation methods for standard object recognition (on simple background) still can be used to localize marks after the image has been preprocessed appropriately. Image segmentation techniques can be roughly divided into three categories: measurement space guided spatial clustering, split and merge growing schemes, and region growing schemes (Revol et al., 1997). To find locations of the skid mark directly, Wang (2005) employed a region growing algorithm to localize skid marks after the image was binarized by using average gray-level value as the threshold. In this study, the maximum coefficient of variant (i.e., the average value divided by the standard deviation of the gray-level values) in a sub-region was used as a seed to grow the region. Its terminate condition is based on the threshold of the average coefficient of variants in every region. While all the coefficients of variants in neighboring regions were below the threshold, region growing will be stopped. Basically, this algorithm can detect the regions of skid mark correctly while the area of the mark has higher coefficients of variants than other regions. Due to the complexity of pavement texture, the original region to grow (i.e., region of the seed) was occasionally out of the area of skid mark even if the image was preprocessed and it results in actual regions of the marks can not be found. To solve this problem, a new algorithm is proposed in this study and a lot of skid mark images are used to compare the results of image segmentation with the above region growing method.

This study next introduces this new algorithm to localize the skid mark or imprint on hard surface (e.g., asphalt concrete pavement). Detailed description of each step in the procedure is followed and the algorithm is validated by using tire marks obtained from the car-braking test and roadway survey. Discussion of experiment results and conclusions are finally addressed.

2. ALGORITHM FOR THE TIRE MARK LOCALIZATION

The photographs or images of tire marks on roadway surface were collected by using a simple or non-metric camera. The appropriate vertical photographing distance from a mark is in a range of 100~200 cm. It can greatly decrease the effect of tire mark interweaved with pavement texture and capture clear marks. Further, while taking the picture, the photographer must stand straddling above a tire mark and keep the orientation of camera parallel approximately to the surface of roadway. Furthermore, while viewing through the viewfinder of camera, focus on tire mark and mark's longitudinal direction is perpendicular as far as possible to the picture area (frame). Therefore, tire mark generally locates in the central area of the picture. However, the new algorithm should possess the capability to localize the area of tire mark when the mark deviates slightly from the central position of picture.

2.1 Algorithm

Because tire mark area has higher contrast than other regions in image, it can be used to distinguish mark area from image. This idea has been used to develop a skid mark detection model (Wang et al., 2005) to see whether skid mark existing in the image. Basically, a picture with skid mark has higher contrast than without them. The contrast is represented by using the coefficient of variant (i.e., CV) on horizontal projections. That is the variance of the horizontal projections of dark points (greater than the threshold) in image plane after image was binarized by using average gray-level value as the threshold. When abnormal values of CVs, which greater than the upper bound or smaller than the lower bound, in the sequence of horizontal projections are detected, there is a skid mark existed in image. That is the moving range control chart method. This study directly employs the characteristics of distribution of horizontal projections of dark points to develop a new localization method to detect the possible range of tire marks. This algorithm which calls as rotation-projection method has following steps.

Step 1. Using gradient operator to detect the gradient direction angle (θ) of a tire mark.

Step 2. Rotating image from the minimum angle (θ - 90 - a) to the maximum angle (θ - 90 + a) via increment of 1 degree. a is a parameter e.g., 15 degree.
In each image rotation, performs steps 3, 4 and 5

Step 3. Binarizing image using the average gray-level as the threshold.

Step 4. Obtaining the horizontal projections of dark points

Step 5. Calculating values of the coefficient of variant.
While image rotation is terminated, performs the following steps.

Step 6. Selecting specific rotating angle with the maximum CV value

Step 7. Detecting the range of tire marks

2.2 Tire mark region detection

Due to a non-uniform distribution of the illumination in close-range photographing, the central area is brighter than the other regions in a picture. When image is binarized using an average gray-level value as the threshold, the phenomenon is much obvious. Figure 1 shows the horizontal projections of dark points of an image. Supposed that tire marks located at the central area, the two valleys can be found based on the average value of projections, as shown in Figure 1. We can detect the positions of intersection points between the horizontal line of average projection value and the curve line derived from horizontal projections in each valley. The probable region of tire marks can be obtained by comparing the intersection points. For example, points a and b are the left and right intersection ones in valley 1 and points a' and b' are the intersection ones in valley 2. We can compare the positions of points a with a'. If a' is greater than a in position or coordinate, it is the right boundary of the tire mark. The left boundary of tire marks can be determined by the comparison of points b and b'. That is b and a' is the left and right boundary of the tire mark, respectively.

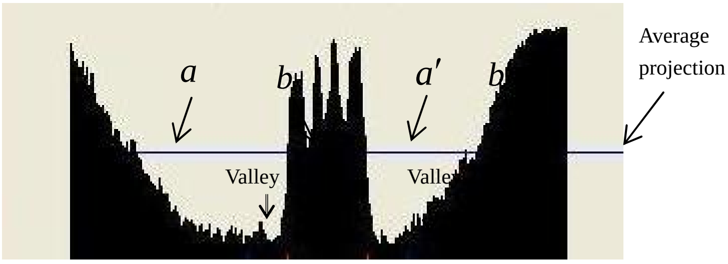


Figure 1 Horizontal projection of the dark points in an image

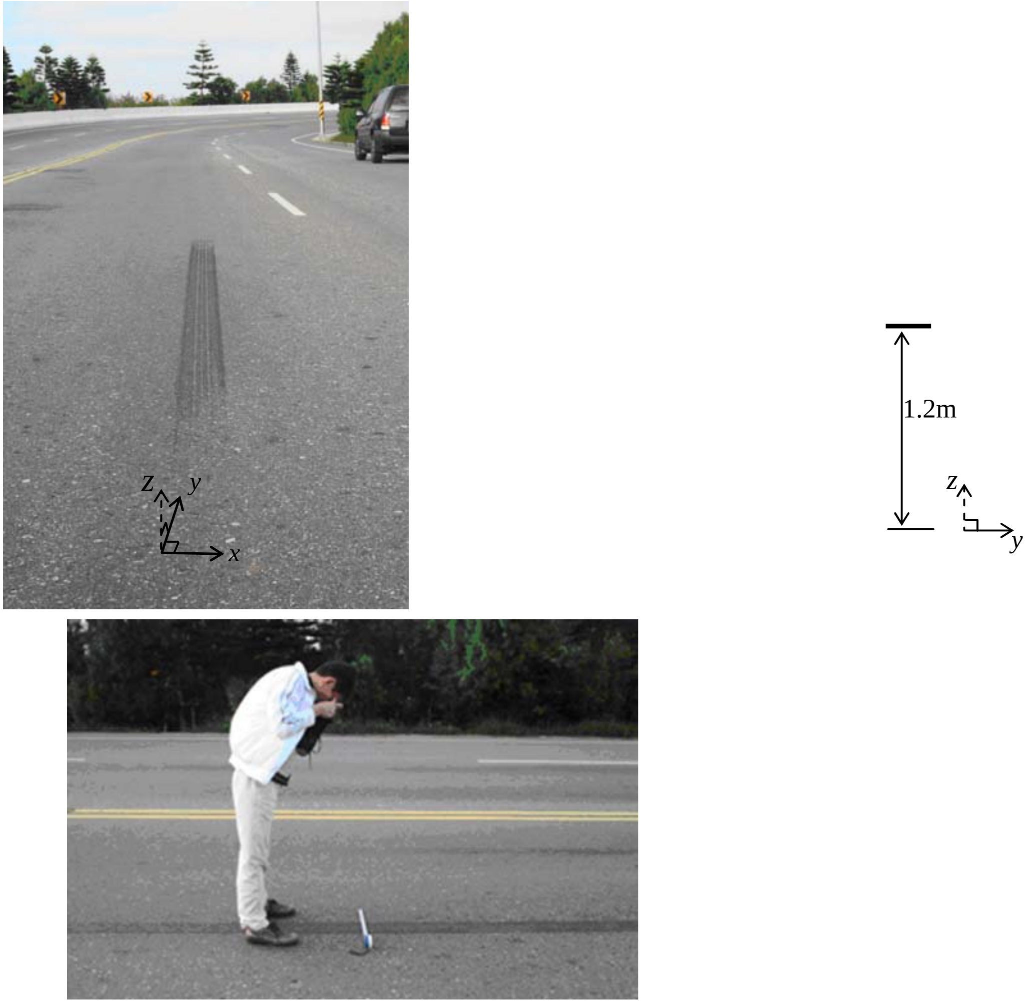
3. EXPERIMENT RESULTS AND DISCUSSION

To validate this new algorithm for localizing tire marks, this study employed empirical data (new skid marks from the car-braking test) and the survey data (new and old skid marks and tire imprints) on roadway surface. Further, an operational system was established by using Borland C++ program to demonstrate the results of tire mark localization.

3.1 Tire mark image acquisition

Tire marks data is obtained from an empirical car-braking test (Wang, 2003) and a roadway survey. This data from car-braking test is the new one while the data of roadway survey is the old one. However, the photographs of skid marks or tire imprints on the real roadway surface (asphalt concrete pavement) are collected by using a simple or non-metric camera which is similar to the ones used by the police investigators in Taiwan. A camera, PENTAX ESPIO 160 with 35mm fully automatic lens-shutter and built-in 200mm lens (38~160mm), auto focus, auto exposure control and auto flash, is used in our experiments. The available vertical photographing distance from a tire mark is in the range of 100~200cm.

There is no requirement of additional illumination to take picture unless in low light situations (auto illumination). Before taking the picture, photographer must stand straddling above a mark and keep the orientation of camera parallel approximately to the surface of roadway as shown in Figure 2. While viewing through the viewfinder of camera, focus on the mark and its longitudinal direction is perpendicular as far as possible to the picture area (frame). Photos are further scanned by using a scanner to acquire the digitized images of the marks.



(a) (b)

Figure 2 Skid mark image acquisition

(a) A skid mark on the roadway, (b) Vertically photographing the skid mark from a distance around 1.2 meters using a simple camera (PENTAX EPSIO 160)

3.2 Operational system

Based on this systematic framework of tire mark localization, we can obtain important temporary results such as the image size, rotation angle of tire mark, the coefficient of variant, the number of dark points in horizontal axis, the X-RM control chart, the detection of tire marks, the boundaries of tire marks etc. These items will be automatically calculated and recorded in data base and portray in working area on computer screen while tire mark localization system is operating. Figure 3 shows the operational environment of this proposed system and an example is demonstrated.

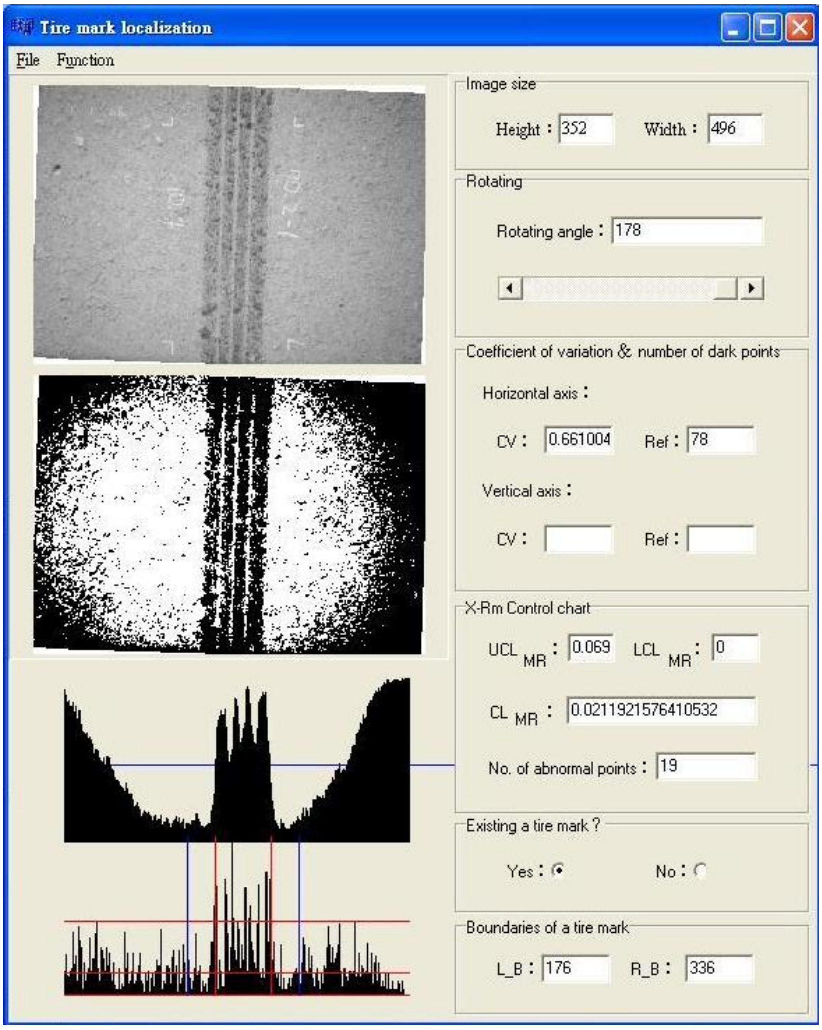


Figure 3 Operational characteristics of proposed system and example demonstrated

3.3 Results and discussions

To validate the accuracy of our proposed method, we employed 44 new tire marks images (22 skid marks and 7 tire imprints) and 23 old ones (9 skid mark and 14 tire imprints) as the inputs of operational system. Table 1 (a) and (b) shows the results of these marks' localization including the gradient direction angle, the scope of image rotated, the detected slope angle of a tire mark and the successful localization or not. Table 2 shows the part of results of before and after tire marks been localized using the proposed and original region growing method. None of the picture represents unsuccessful localization of tire mark image. From Table 1 and 2, we can see that six tire mark images, including photo no. 24, 25, 28, 34, 37, and 51, can not be localized successfully due to the wrong detection of gradient direction angle (for example, the 178 degree detected for the skid mark in the photo no. 24 image with its real gradient direction angle around 90). Furthermore, although photo no. 45 has the correct detected gradient direction angle, it still can not be localized correctly due to its wrong identification of the range of tire marks.

In Table 2 (a), we also learn that the results of skid marks localized by using the region growing algorithm with the seed of maximum coefficient of variant in sub-region. There are three error detections. The reason is that the seed region is out of the skid mark area. Furthermore, the region growing algorithm with the seed region of maximum CV is not appropriate for the localization detection of old tire marks. In other words, the seed selection must be based on other criteria if in case of using old tire mark image. However, the region growing algorithm has similar accuracy comparing to the proposed algorithm in new skid mark localization. From the Table 1 and 2, we obtain the following conclusions.

1. The proposed method can be used to localize tire marks in the images with high accuracy in normal conditions in spite of tire marks are new or old ones. Further, the gradient direction detection can effectively reduce the operational time of mark's slope angle detection, and then accelerate system operation.
2. The reasons for wrong localization of tire marks are mainly resulted from wrong detections of the gradient directions of marks in image. Although gradient direction detection can reduce operational time, the accuracy for tire mark localization would be impacted slightly. Contrarily, its accuracy can be ensured by detecting all angles of the images (rotating from 0 to 180 degrees). The other reason resulted in the wrong localization is from the determination or judgment of a tire mark region in image. In methodology, if the valleys formed by dark pixels horizontal projections are not obvious, the range of a tire mark can not be detected accurately or correctly. Therefore, the imaging process of tire marks on roadway surface is important and influential to the results of mark localization. Additional illumination to photograph tire mark (i.e., the imaging process) will improve the accuracy of tire mark range detection.
3. Region growing algorithm with the seed of the maximum CV in sub-region can localize the new tire marks effectively due to the high contrast in the images. Contrarily, the algorithm is not appropriate for an old tire mark because of the low contrast in an image. The other criteria for selecting the seed must be established while using the algorithm to localize the old tire marks. Nevertheless, we can directly employ the proposed method to perform the localization task of the old tire marks.

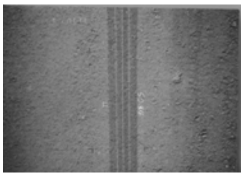
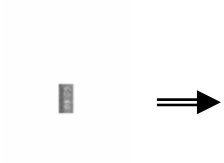
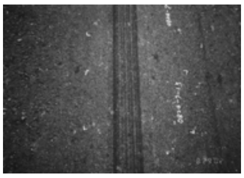
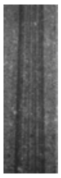
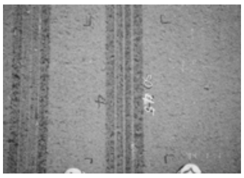
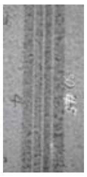
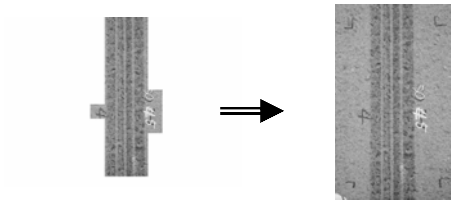
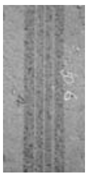
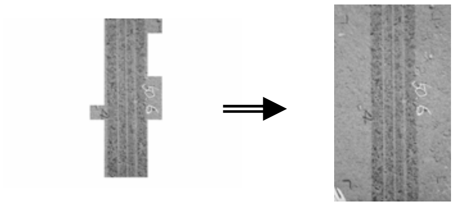
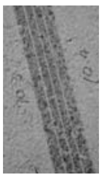
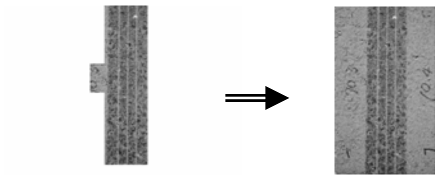
Table 1 Results of new tire marks localization (a)

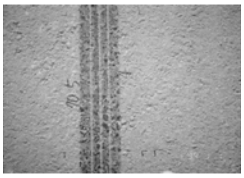
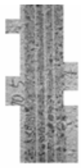
Photo no.	Gradient direction angle (degree)	Rotational scope (degree)	Detected slope angle (degree)	Localization successful or not?	
				by new algorithm	by region growing
1	91	-14~15	-1	Yes	Yes
2	83	-22~7	-1	Yes	Yes
3	93	-12~17	-1	Yes	Yes
4	83	-22~7	-1	Yes	Yes
5	92	-13~16	-3	Yes	Yes
6	95	-10~19	1	Yes	No
7	95	-10~19	1	Yes	No
8	90	-15~14	1	Yes	Yes
9	91	-14~15	-1	Yes	Yes
10	90	-15~14	1	Yes	Yes
11	91	-14~15	-1	Yes	Yes
12	86	-19~10	1	Yes	Yes
13	93	-12~17	-1	Yes	Yes
14	87	-18~11	-1	Yes	Yes
15	88	-17~12	-2	Yes	Yes
16	91	-14~15	-1	Yes	Yes
17	90	-15~14	-2	Yes	Yes
18	86	-19~10	-1	Yes	Yes
19	90	-15~14	1	Yes	Yes
20	91	-14~15	-1	Yes	Yes
21	88	-17~12	-2	Yes	No
22	89	-16~13	-1	Yes	Yes
23	98	-7~22	-1	Yes	Yes
24	178	73~103	18	No	Yes
25	178	73~103	-18	No	Yes
26	92	-13~16	-1	Yes	Yes
27	91	-14~15	1	Yes	Yes
28	168	63~83	18	No	Yes
29	94	-11~18	-1	Yes	Yes
30	92	-13~16	-1	Yes	Yes
31	94	-11~18	-1	Yes	Yes
32	90	-15~14	1	Yes	Yes
33	91	-14~15	-1	Yes	Yes
34	0	-105~-75	-	No	Yes
35	93	-12~17	-1	Yes	Yes
36	91	-14~15	-1	Yes	Yes
37	80	-97~-67	-18	No	Yes

Table 1 Results of old tire marks localization (b)

Photo no.	Gradient direction angle (degree)	Rotational scope (degree)	Detected rotated angle (degree)	Localization successful or not?	
				by new algorithm	by region growing
38	91	-14~15	1	Yes	No
39	108	3-33	3	Yes	No
40	92	-13~16	-1	Yes	No
41	97	-8~21	-1	Yes	No
42	94	-11~18	1	Yes	No
43	90	-15~14	-1	Yes	No
44	95	-10~19	1	Yes	No
45	88	-17~12	1	No	No
46	88	-17~12	1	Yes	No
47	87	-22~7	2	Yes	No
48	94	-11~18	1	Yes	No
49	105	0-29	1	Yes	No
50	85	-20~9	-1	Yes	No
51	72	-33~-3	-4	No	No
52	88	-17~12	2	Yes	No
53	96	-9~20	3	Yes	No
54	89	-16~13	1	Yes	No
55	92	-13~16	3	Yes	No
56	91	-14~15	2	Yes	No
57	92	-13~16	2	Yes	No
58	88	-17~12	-1	Yes	No
59	100	-5~24	1	Yes	No
60	85	-20~9	-1	Yes	No
61	91	-14~15	2	Yes	No
62	97	-8~21	1	Yes	No
63	85	-20~9	3	Yes	No
64	84	-21~8	1	Yes	No
65	95	-10~19	1	Yes	No
66	88	-17~12	1	Yes	No
67	85	-20~9	2	Yes	No

Table 2 Part of results of tire mark localization and segmentation

Photo no.	Original image	Localization	
		by new algorithm	by region growing
6		 (correct)	 (error)
21		 (correct)	 (error)
22		 (correct)	 (correct)
23		 (correct)	 (correct)
25		 (error)	 (correct)

26		 (error)	  (correct)

4. CONCLUSIONS

The study proposes a new algorithm, namely, rotation-projection method to localize the tire marks in the images for solving the problem of the seed selection with the region growing algorithm. Furthermore, the new method is also appropriate for the old tire marks' localizations in images with low contrast. Basically, the proposed method combined with gradient operator can localize the tire marks effectively in normal conditions, but its accuracy would be impacted slightly due to the possible wrong detection of the gradient direction angle. To ensure the accuracy of tire marks localization, the method can detect all angles of the image. Nevertheless, a major premise of the algorithm is the tire mark located in the central area of the image. When imaging conditions does not follow the premise, the proposed method possibly can not find out the real area of the tire mark. Therefore, the new algorithm still has a room to improve in the future and this issue is my next studies.

ACKNOWLEDGEMENT

The work described in this paper forms part of the research project, The study on establishing a automatic identification model of skid mark at accident scene, supported by the grant from the National Science Council of the Republic of China under grant number NSC 94-2211-E-346-002.

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Answer Sheet

Paper ID: 100462

Paper title: A TIRE MARK LOCALIZATION METHOD FOR FORENSIC IMAGE ANALYSIS

Contact author: Wang Ying-Wei

1. Preference to present at the "poster session"

a) If a poster session is held, I strongly prefer the poster presentation to the oral presentation.

b) If the 'Poster Session' is held, I do not mind to present at the poster session.

✓c) I strongly prefer the oral presentation to the poster presentation.

2. "International Research Groups (IRGs) relating session"

3. Revision report

No.	Requested revision level	Location		Reviewer's comment/request/question	Resulting revision
		Page no.	No. of line/ figure/table		
1	Required	1	9	Introduction automotive should be automated	The word was modified. (p1, line 9)
2	Required			Explain the limitations of the algorithm	The revision is as the descriptions of No. 7
3	Required	7	6-7	Correct the words photo no. 24 image.	The words were modified. (p7, lines 3, 5-6)
4	Required	11	11-12	Correct the project name (the Study of The study on, a automatic)	The project name was modified. (p11, line 14)
5	Required	11	30-31	Correct the reference format to follow the paper instruction	The reference format was corrected. (p11, lines 19-32)
6	Required	8-9		Table 1. Specify which photo is new or old mark	Table 1 had been specified the types of the tire marks. (p8-9)

7	Total comment			Good paper and interesting work. Some grammar needs fixing. Could do with some work to explain the limitations of the algorithm and scope of the application (eg who will use it and does the camera need to be set up in any special way?)	The grammar had been fixed. Some spelling errors had been revised. The algorithm is based on the valleys formed by pixel horizontal projection to distinguish the boundaries of a tire mark in an image. Suppose that the valleys are not significant or obvious in an image, the boundaries can not be discriminated accurately. Thus, a wrong localization of a tire mark is occurred. In other words, the imaging process for a tire mark is important and influential to the results of mark localization. In term of the scope of the application, the major application is for the investigators to compare and match the tire mark with the tire tread pattern and then indentify the tire marks belongings. The camera do not need to be set up in any special way. The investigator must note that the lens can't be zoom to capture the close-range picture of the tire mark which will have the vague boundaries problem. In addition, while photographing, the photographer must focus the tire marks from a distance within 100~200 centimeters and let the mark's longitudinal direction as far as perpendicular to the picture area (frame).
8	Total comment			Accept Paper: Paper is OK but needs thorough review of grammar to ensure correct technical information is relayed. The paper needs to be reviewed to correct contextual grammar. More discussion of limitations of the algorithm would be useful.	The revision is as the descriptions of No. 7