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A TIRE-MARK IDENTIFICATION SCHEME FOR SUSPECTED VEHICLE DETECTION IN HIT AND RUN ACCIDENT

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Abstract：This study employs Visual dBASE to establish a systematic tire-marks matching database to increase the correctness and efficiency of tire-marks identification executed by investigators at accident scene. The database includes tire manufactures, vehicle type/model, and tire specifications. In addition, it encompasses a tire-marks matching function. It can be more conveniently used to identify the tire pattern and catch tire-treads by inputting the actual widths of light and heavy streaks on the tire-marks. From this systematic system, we can find out the probably involved tire size and vehicle geometric properties and infer from them with the front/rear track and wheelbase to determine the tire-marks' belonging. In its empirical case validation, this system shows that it does increase the operational effectiveness of tire-marks identification and reduce the scope of investigation, especially in hit and run accidents. Furthermore, it does improve the quality of accident investigation and identification.

Key Words: accident scene, tire-marks matching, database, accident investigation

1. INTRODUCTION

The tire marks data collected by the policemen/investigators at accident scene is the important items/evidences (Baker et al. 1986). It might encompass the imprints and tires' friction marks. These data can be used to identify the pre-collision drivers' behaviors, vehicles' traveling directions and minimum speeds, and to estimate the during-impact positions on roadway and their post-impact trajectories, etc., after the marks belongingness had been justified. In practice, tire-marks can be simply recognized by investigators/policemen from driver's statement, relative tire distance/orientation between the stopped vehicles and tire-marks, etc. The judgment based on drivers' statements and investigators' experience/knowledge frequently resulted in argumentation when drivers had inconsistent statements or investigator faced a highly complicated accident scene. Nevertheless, the outline characteristics of tire-marks are seldom employed by investigators to differentiate or classify tire-marks and their tires' belongingness. Therefore, tire-marks identification is an important issue in accident investigation.

In seeing this, Wang (2003) proposed a distance-base matching model to classify tire marks (skid-mark or imprint) and it was validated by an empirical car-braking test. His results show that the widths of heavy and light streaks on tire-marks can be used to catch the widths of ribs and grooves on tire-tread and reach much higher accuracy for inferring the involved tires. This method can be directly applied to simple car accidents where geometric data on tire-marks and tire-treads could be obtained from the at-scene or out-of-scene measurements.

In case of hit and run accidents, its operation must be integrated with a tire-tread database to effectively perform the iterative pair-matching task in order to obtain the probably produced tires. It then can greatly reduce the vehicle investigation scope. The purpose of this research is therefore to establish a tire-tread related database system to effectively perform tire-marks (skid-mark or imprint) matching task, especially for the empirical application in hit and run accidents.

This study first describes the geometric relationship between tire-tread and corresponding tire-mark. Next, the structures and contents of a database system are proposed according to the required data/items in tire-mark matching. After that, a database prototype system is established by using a database management system-Visual dBASE. A case study demonstrates operational process and temporary results of this system is followed. Finally, conclusions and suggestions are addressed.

2. GEOMETRIC RELATIONSHIP BETWEEN TIRE-TREAD AND TIRE-MARK

The geometric mapping-relationship between tire-tread and corresponding tire-mark is quite stable. Although the relationship is influenced by many factors such as vehicles' load, speed, tires' pressures and structure, pavement condition, etc., the variety of geometric properties on tire-mark such as deviation between widths on tire-marks and tire-tread is low. It means that tire-marks (skid-marks and imprints) still have the outline characteristics as tire-tread does.

Therefore, tire-marks matching can be based on the deviation between widths on tire-mark and tire-tread. After the tire-marks belongingness is identified, the involved vehicles at or not at scene can then be determined based on matched tire model and specification with vehicle-related data, such as the wheelbase and front or rear wheel-distance.

2.1 Matching Logic

The matching logic between tire-tread and corresponding tire-mark is shown in Figure 1. The key data of tires and tire-marks collected at scene includes marks' types, gap in double-side tire-marks, distances between front- and rear-wheel tire-marks, tires models, and tire-treads.

Contrarily, some important elements on vehicle such as wheelbase, front and rear tracks or treads, and tires' brand, model and specification must be collected/measured beforehand. The gaps in double-side tire-marks and distances between front- and rear-wheel tire-marks can be used to estimate the wheelbases and front or rear track on vehicles. In addition, the widths on tire-marks can be estimated by using a simple method (Wang, 2003) to match the widths on tire-treads. The tire-marks belongingness can then be identified by using the results of tire-treads matching. Furthermore, based on knowing the tyre types likely to have been involved in the accident it is possible to determine the vehicle likely to have been involved.

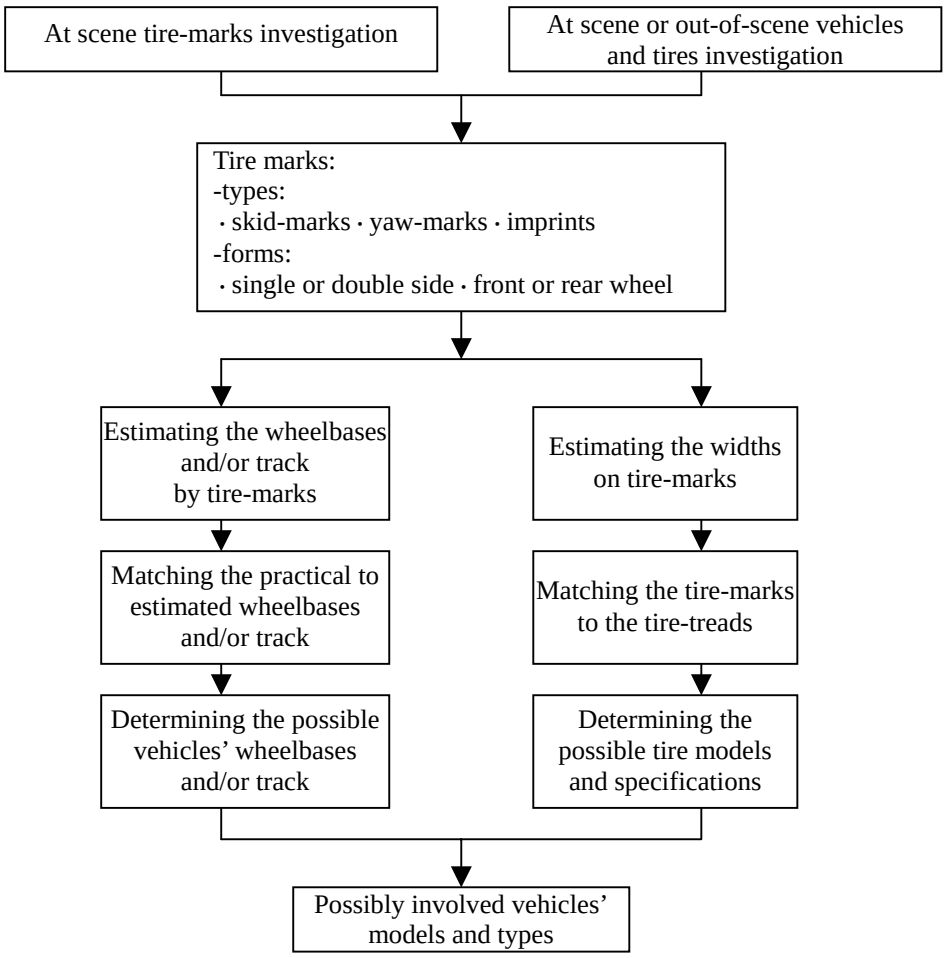


Figure 1 Matching Logic Flowchart

2.2 Matching Model

Although the mapping relationship between tire-tread and tire-mark is influenced by many factors such as vehicle's load, tire's pressure and structure, pavement condition, climate (temperature) etc., the variety of the texture geometries on tire-mark is within tolerance level. It means that tire-mark can be matched by using the similarity or dissimilarity between the widths of heavy and light streaks on tire-mark and the widths of ribs and grooves on tire-tread as shown in Figure 2.

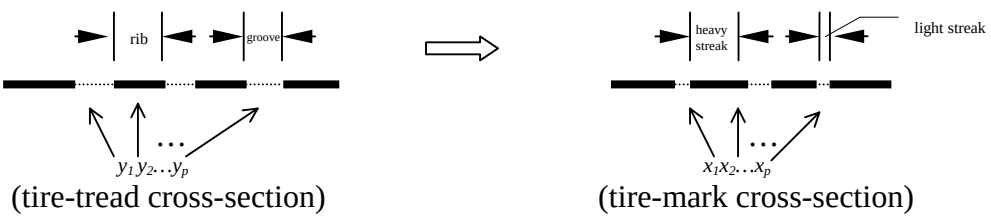


Figure 2 P-dimensional Tire-tread and Corresponding Tire-mark

Because tire-tread (rubber compound) is hyper-viscoelastic, the widths on ribs and grooves resulting from the non-uniform distributional effect of contact pressure will be variable. In practical, the lateral deformations of the ribs on tire-tread are within ± 0.1mm while wheel

rolling or skidding over dry asphalt surface [Brandt et al., 1998]. If the interaction between the widths on ribs and grooves is not considered, the deviation or similarity coefficient ($\mathbf{r_i}$) between width on tire-tread and corresponding width on tire-mark can be measured by Euclidean distance. Furthermore, the similarity coefficient can be represented by a normal density function based on the exponential transform of the Euclidean distance. Therefore, the total similarity coefficient between tire-tread and tire-mark can be represented by $\prod_{i=1}^{P} \mathbf{r_i}$ as shown in Formula (1).

$$\begin{aligned} \mathbf{r(x,y)} &= e^{-k(x_1-(y_1+y_{01}))^2} e^{-k(x_2-(y_2+y_{02}))^2} \cdots e^{-k\left(x_p-\left(y_p+y_{0p}\right)\right)^2} \\ &= e^{-k(\mathbf{x}-\mathbf{y})'(\mathbf{x}-\mathbf{y})} \\ &= \prod_{i=1}^{P} \mathbf{r_i} \end{aligned} \tag{1}$$

where,

$\mathbf{r(x,y)}$: total similarity coefficient between tire-mark ($\mathbf{x}$) and tire-tread ($\mathbf{y}$).

$\mathbf{r_i}$: similarity coefficient of i_{th} element between x_i and y_i.

$\mathbf{k}$: positive real number.

$\mathbf{x}$: $[x_1, x_2, \ldots, x_p]'$: vector of p-dimensional widths on tire-mark.

$\mathbf{y}$: $[y_1 + y_0, y_2 + y_0, \ldots, y_p + y_0]'$: vector of p-dimensional widths on tire-tread while contacting roadway surface.

$\mathbf{y_{0i}}$: the change of i_{th} width on tire-tread while contacting roadway surface, i=1,2,⋯ p.

In addition, the similarity coefficient between the empirical and estimated wheelbase and/or track (treads) also can be measured by Equation (1). Where $\mathbf{x}$ is substituted by estimated wheelbase and/or track and $\mathbf{y}$ substituted by the practical wheelbase and/or track and y_{0i}= 0 (no deformation).

3. STRUCTURE AND CONTENT IN THE DATABASE SYSTEM

From section 2, the widths on tire-marks can be matched to widths on tire-tread based on a stable tire-tread and formed tire-mark geometric relationship. In practice, the category of tire brands and types of tire-models are very large and having many specifications. A manual tire-mark matching will be a time-consuming and high-cost task. But its accuracy is still in question. Therefore, it is necessary to establish a database system of tire-mark matching to decrease investigation time/cost and increase matching accuracy. In the following paragraphs, description of the structure and content in tire-mark matching database-system is addressed.

3.1 The Contents of Databases

The purpose of tire-marks matching/classification is to obtain the probably involved tire-tread model (tread-pattern), specification, brand, etc., and infer the probably involved vehicles based on these observations. Therefore, the key data shall include tire' brand, model and size (specification) that can be directly used in matching. Furthermore, concerning that same tire

model (tread pattern) might be used in different tire specification, ribs' or grooves' widths, numbers of grooves, depths of the grooves, and width of tire-tread are also collected. On the other hand, the wheelbase and front/rear track (tread) on vehicle are directly related to tire-mark forms (single-sided or double-sided). These items are key matching elements in vehicle database. Other items such as vehicle type, model, length, width, weight, year, etc., are auxiliary/referenced items in vehicle database. The necessary items in tire-tread database are shown in Table 1.

Table 1 Key and Referenced Data/Items in Tire and Vehicle Databases

database type	matching items	reference items
tire	ribs and grooves width, no. s of grooves, tread-width	brand, function model, specification etc.
vehicle	wheelbase, track	Type, model, length, width, weight, year, ABS, exhaust-volume etc.

3.2 Structure in Database System

According to the matching logic described in Figure 1, we have learned that tire-mark matching goal is to find the possible tire's model and specification, and integrated them with estimated wheelbase and track to determine the probably involved vehicle's type and model. Therefore, we need three basic databases to perform tire-marks matching; first is a tire database, second the vehicle database, and third the basic information database such as producer or agents, address, telephone, etc. Besides, a matching function is needed to set up matching condition, input data and display results. The structure built in database system is shown in Figure 2.

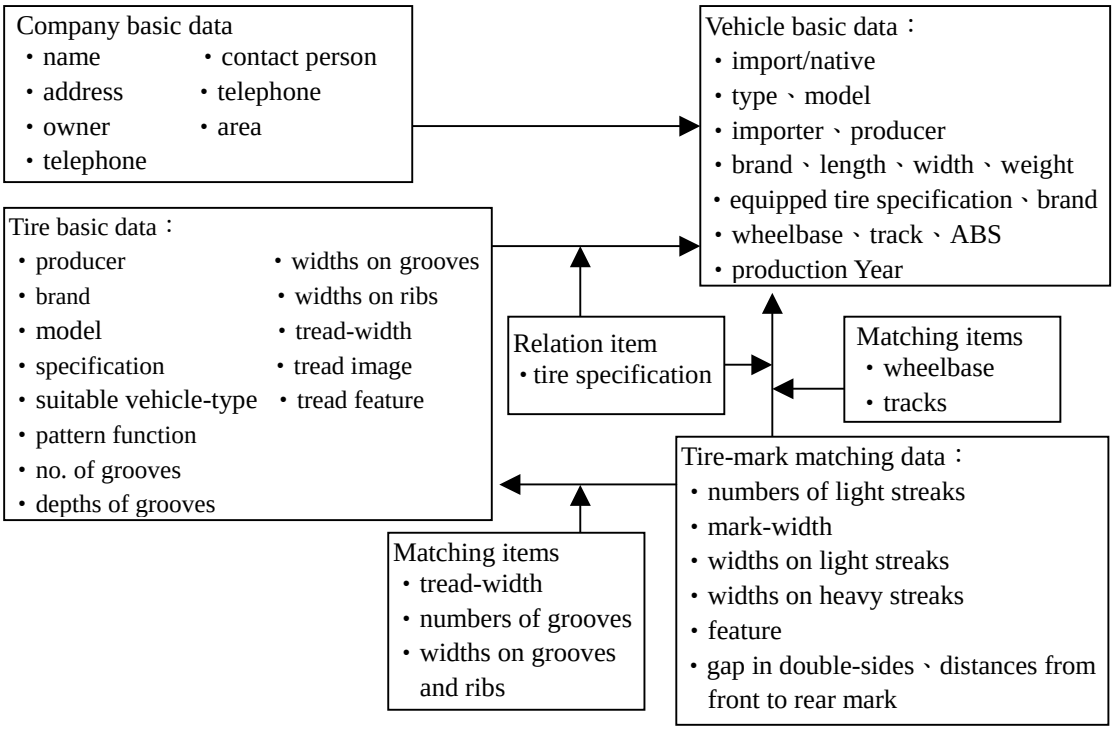


Figure 2 Structure and Content in Database System

Figure 2 shows us that the probably involved tire-model and specification can be obtained by employing tire-marks matching function followed by the matching items input, and the probably involved vehicle type and model can be determined based on its relevant item - tire specification, which relates tire database to vehicle database. In addition, the probably involved vehicle type and model can also be inferred based only on empirical and estimated wheelbase and/or track matching results, or combined with the probably involved tire specification.

3.3 Database System Establishment

There are about 80 brands in Taiwan's tire market. About 40 brands are having significant market share which includes BRIDGESTONE, MICHELIN, YOKOHAMA, GOODYEAR, DUNLOP, PIRELLI, GADJAH TUNGGAL, HANKOOK, CONTINENTAL, KUMHO, FALKEN, FEDERAL, TOYO, RIKEN, BFGoodrich, CHENG SHING, MAXXIS, NANKANG, SONAR, etc. To simply estimate total tire-treads in Taiwan, BRIDGESTONE tire is selected as a benchmark tire. This is based on an estimate of Bridgestone having 60% of the market share, with 70 tire models averaging 15 different specifications. Thus, total numbers of tire-treads in the form of brand types * tire-models * tire-specifications will be over 80,000. Furthermore, the total number of vehicle-models in the form of brand types * models are less than 20,000 in the past twenty years. Therefore, a database system with data entries less than 100,000 can be developed by a small-scale database management system, such as Access, Visual FoxPro, Visual dBASE etc.

In this study, Visual dBASE is employed to establish the system. Visual dBASE supports WINDOWS operational system and can be used in Delphi programming. It can easily be integrated into network application software and expended to Internet for public use.

3.3.1 System Demonstration

To concretely describe/demonstrate the database system prototype developed in this study, tire and vehicle data at Penghu-county were collected and used. Total tire brands are 22 and there are 165 specifications. The number of composite tire-treads is 331. The vehicle types including auto and light truck were collected and there are 31 brands and 132 models.

The developed system has three databases which are company basic information, tire-tread and vehicle, and a combination with tire-mark matching function, as shown in Figure 3、4、5、6、7 and 8.

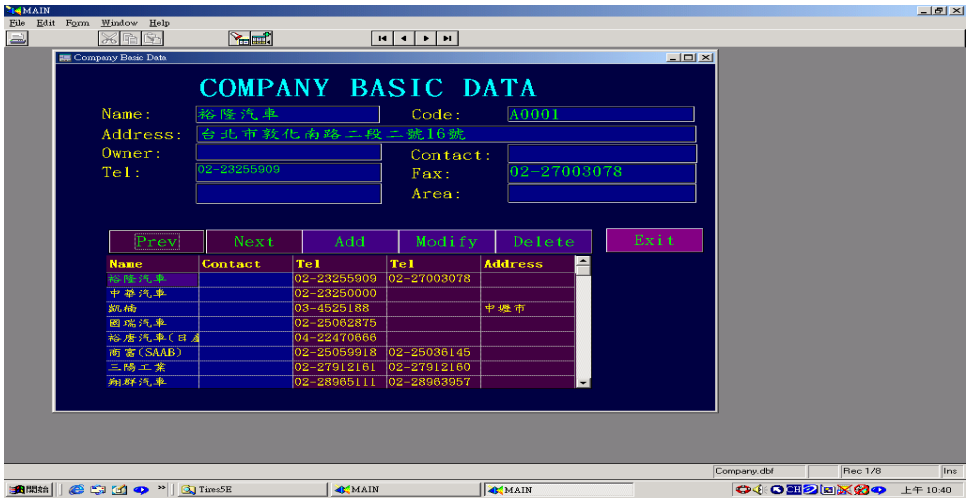


Figure 3 Company Basic Data

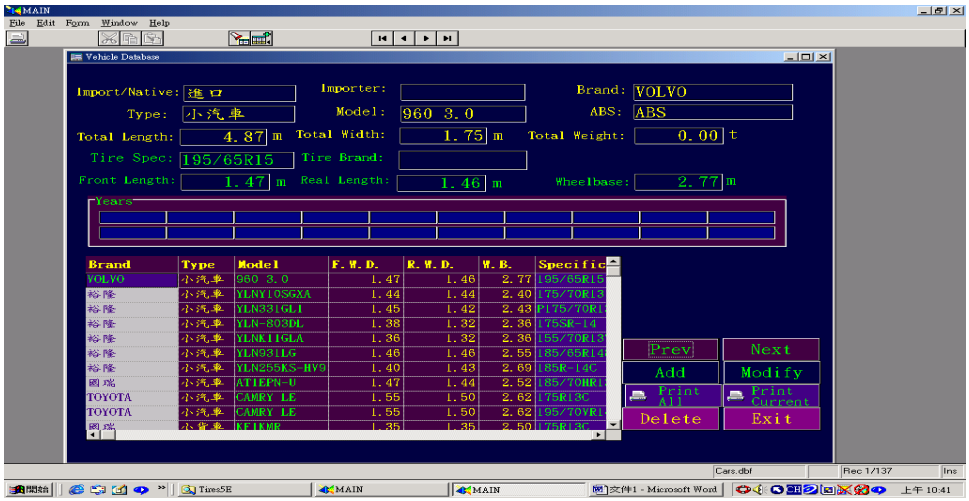


Figure 4 Vehicle Database

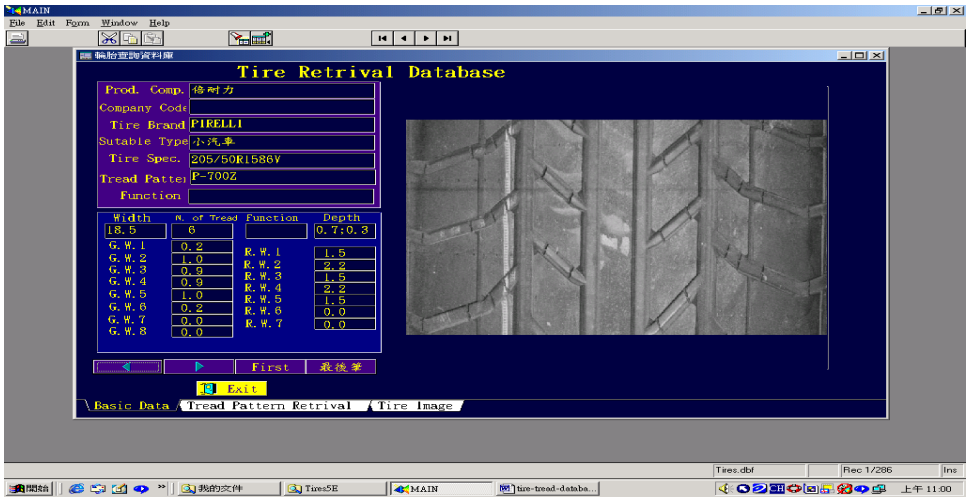


Figure 5 Tire Database

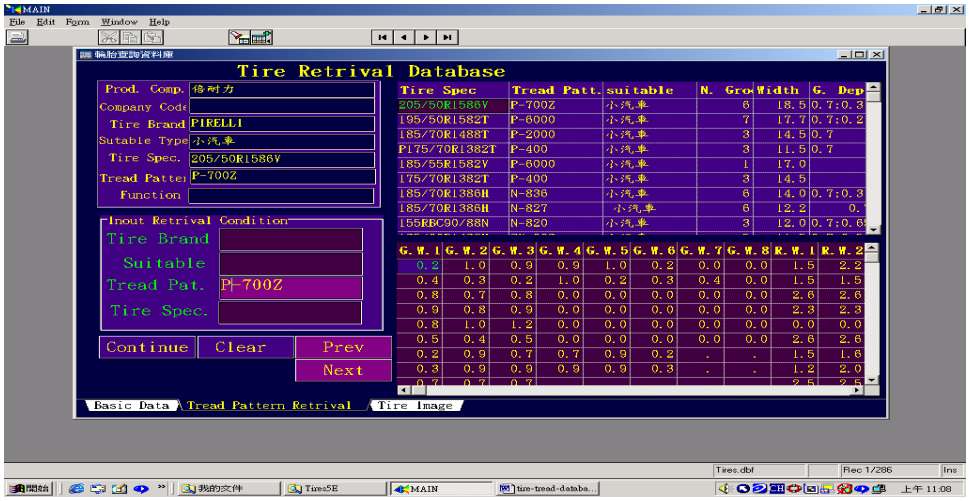


Figure 6 Tire-tread Retrieved by Model

Figure 7 Retrieved Tire-tread

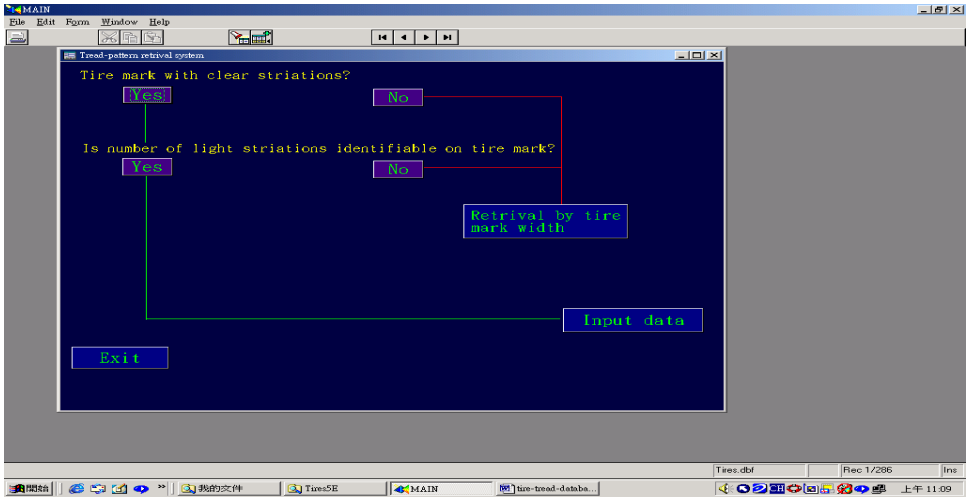


Figure 8 Tire-mark Matching Function

4. CASE TESING

To validate the tire-marks matching function of our database system, a case from empirical car braking test was employed to perform operation procedure and demonstrate its temporary and final results which are derived from matching methods and the relations between the databases.

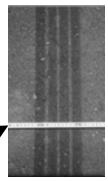
4.1 Case Description

To effectively obtain data used in matching model, an empirical car-braking test was undertaken. The date of this experiment was in August 24, 2002 and the location was on the Hsin-Ying road close to the Third fishing harbor in Penghu County. The test was performed by a car accelerating to 50km/hr and then pressed pedal to brake the vehicle until its fully stop.

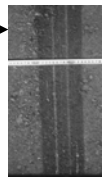
The test results show a double-side tire-marks printed on roadway surface as shown in Figure 9. Car's brand is YouLoong and the model is YLNYIOSGXA. Its wheelbase and front/rear track is 2.4, 1.44 and 1.44m, respectively. GoodYear tires with models of EAGLE GA + (left-front) and GPS2 (right-front) were used by this testing car. The specifications of lateral-section widths on tire-treads (175/70R1382H and 165/70R1379H) used by the EAGLE GA + and GPS2 models are 3.2, 1.2, 2.4, 0.9, 2.4, 1.2, 3.2 and 3.45, 0.7, 3.2, 0.7, 3.45m, respectively.

Because the widths on tire-marks are difficult to obtain by manual measurement, the marks, together with a scale were photographed from above. The obtained widths on tire-marks were measured by using the method developed by Wang (2003). The widths of the light and heavy streaks on left-and right tire-mark are 3.1, 1, 2.33, 0.67, 2.33, 1, 3.2m and 3.2, 0.65, 3.1, 0.6, 3.25m, respectively. The gap in the double-sides tire-mark is 1.45m obtained from at-scene measurement. These data can be used as inputs of tire-mark matching.

Figure 9 Skid-marks on the Roadway



(Left Skid-mark)



(Right Skid-mark)

4.2 Validating Matching Operations

This section demonstrates the matching operations based on the widths on tire-marks obtained above. First, we press the tire-matching function in the menu page. Figure 8 shows the conditional items for proceeding marks' matching. After tire-mark with clear texture and identifiable numbers of light streaks were selected, we used Figure 10 to present the data input items such as required matching degree (M. D.), numbers of light streaks, widths on light and heavy streaks, tread-deformation, control parameter, matching degree, wheelbase, track, etc. In this case, we assume that tread-deformation and control parameter are -0.05 and 0.5m, respectively. After data being input, we can press the button **Inquiry of possible tire-treads**, the system then will present the numbers of tire-treads being found. Thereafter, one can press the button **Finding the possible belonging tires**. The searching results will find out the probably involved tires' brands, specifications and models (as shown in the top of Figure 11) and their corresponding M. D. and the actual widths on tire-treads (as shown in the bottom of Figure 11). In this case eleven probably involved tires were found at 95% M. D. Furthermore, there are six probably involved vehicle types and models inferred after pressing the button Finding the possible vehicle (as shown in Figures 12 and 13). Their total M. D. is shown in the lower part of Figures 12 and 13. One vehicle-Ford LANSER-8 was found by using Goodyear tire with specification 175/70R1382H and the other six vehicles with specification-175/70R13 (as shown in Table 2). The vehicles with highest M. D. are YouLoong (YLNYISGXA) 0.99 and SANYANG (CV15-MLSX) 0.99.

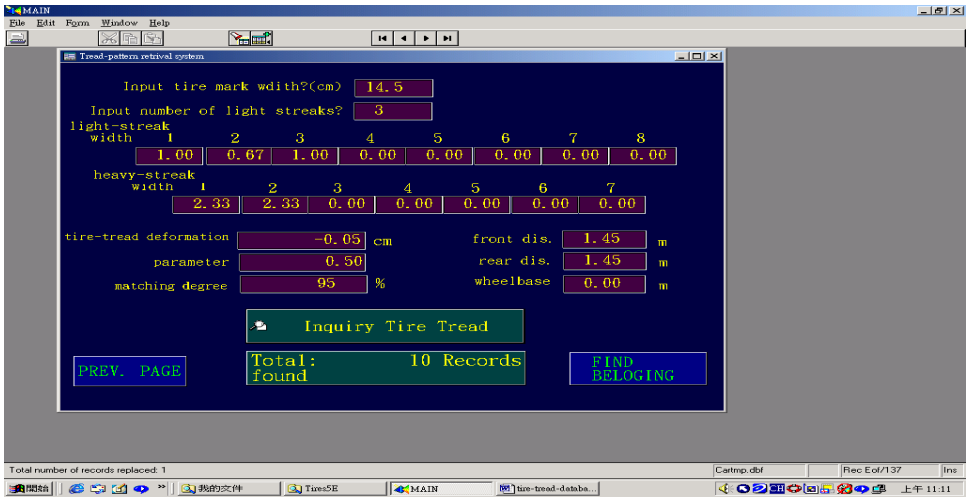


Figure 10 Tire-mark Data Input

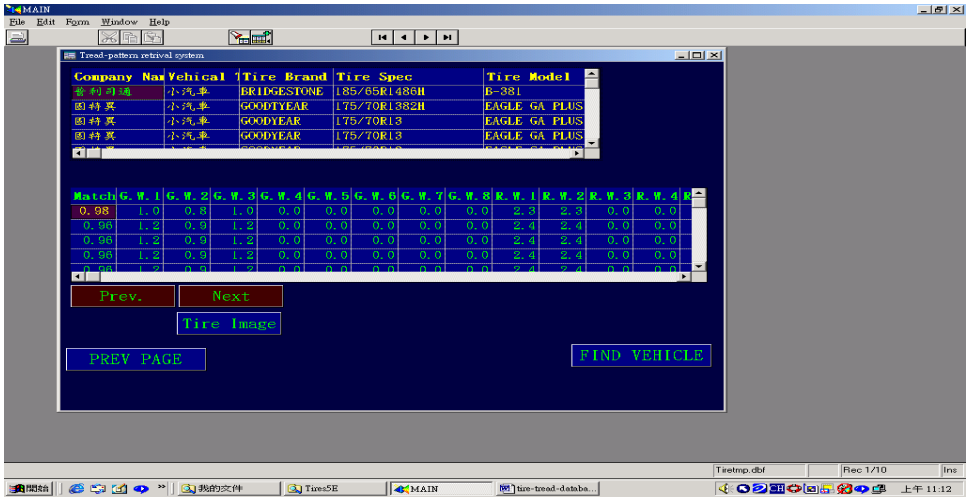


Figure 11 Probably Involved Tires and Corresponding M. D.

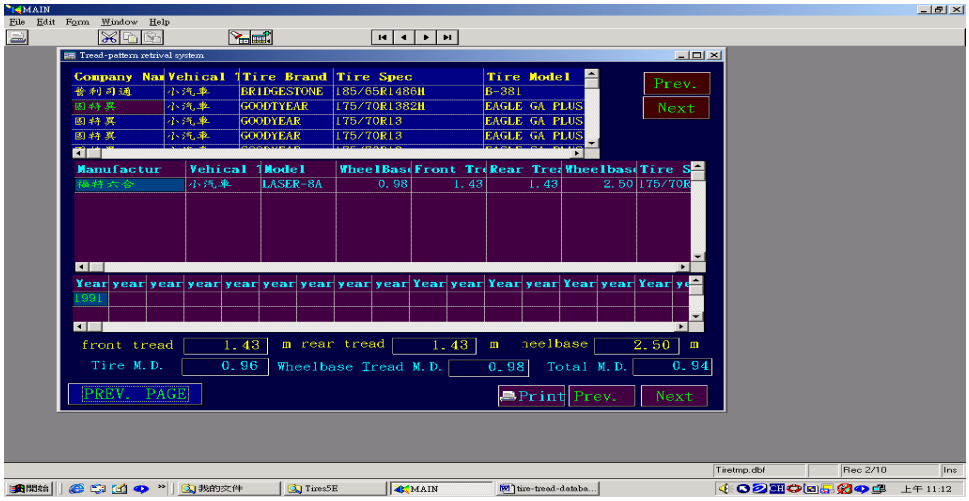


Figure 12 Probably Involved Vehicles and M. D. by Left Skid-mark

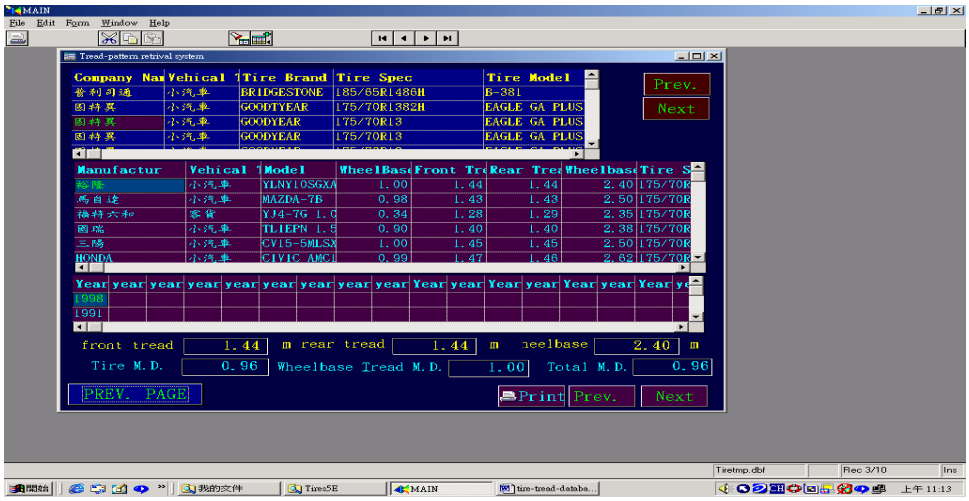


Figure 13 Probably Involved Vehicles and M. D. by Right Skid-mark

Table 2 Probably Involved Vehicles' Brands and Models and Their Matching Degrees

Vehicle brand	Vehicle model	type	Wheel M. D	Tire M. D.[2]	Total M. D.[1]
FORD	LANSER-8A	Car	0.98	0.96	0.94
YOULOONG	YLNY10SGXA	Car	1.0	0.96	0.96
MAZDA	MAZDA-7B	Car	0.98	0.96	0.94
FORD	YJ4-7G	Car	0.34	0.96	0.33
TOYOTA	TLIEPN1.5	Car	0.9	0.96	0.86
SANYANG	CV15-5MLSX	Car	1	0.96	0.96
HONDA	CIVIC AMC1.5	Car	0.99	0.96	0.95

Note：1.Total M. D. = Wheel M. D. * Tire M. D.
2.Weel M. D. determined by the wheelbase and/or front and rear wheel-distance.

5. CONCLUSIONS AND SUGGESTIONS

This study established a prototype database system to perform tire-mark matching and to improve the accuracy and efficiency in tire-mark classification. This system includes three key databases: company basic information, tire and vehicle, and functions of tire-mark matching and tire-tread retrieval. One can employ tire-mark elements such as widths, gap in double-side marks, distances from the front to rear mark, etc. to find out the probably involved tires' models and specifications in tire database. It can be integrated with the matching result of estimated and real world wheel base and treads in vehicle database to determine the probably involved vehicles types and models. The matching results on tire-mark can then be referred by policemen/investigators to identify involved vehicle or decrease investigation scope of suspected vehicles in hit and run accidents. The system was validated by a case study from empirical car braking test. A step by step matching procedure is demonstrated. The probably involved vehicles in this empirical case can be accurately found just in ten seconds. Nevertheless, this system still needs to be refined in terms of the following issues and directions.

(1) To enhance contents in tire and vehicle databases, it needs to expand the observation sample on tire and vehicle in Penghu County and then gradually extends to all counties in

Taiwan.

(2) To improve the completeness of our modules in database system and correctly facilitate tire-tread retrieval and tire-mark matching, a retrieval/matching function based on tire-tread and tire-mark image features should be developed.
Although the software is still under developed, other users can use it while the one has been installed in personal computer. Certainly, it is not available nowadays for the use via internet until the refined web version has been established.

ACKNOWLEDGEMENTS

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