

System of Stereo-Footprint Data Acquisition-Recognition

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Abstract- Stereo-footprint is a vital trace evidence of criminal detection. Thus, it is important to make a high accuracy feature extraction of the stereo-footprint. In this paper, a system of stereo-footprint data acquisition-recognition is designed. In the system, feature extraction is completed through CP35MHT80 which offered by Wenglor, image extraction is gotten through C920 which is offered by Logitech and the software sections such as image acquisition, coordinate transformation, peripherals ranging module and feature data processing etc. are completed through Labview2011. At last, as the results shows, the system can make a speed stereo-footprint feature extraction and recognize based on the relative verification theory. After that, a high quality stereo-footprint recognition report will show up.

Index Terms- Stereo-footprint, Feature extraction, Footprint recognition

I. INTRODUCTION

In the crime scene, footprint is the most easily left traces. And China is also one of the first countries to regard footprint as a sort of criminal litigation evidences [1]. The footprint shape distribution characteristic depends on Human foot type bone and the individual specificity and relative stability, the foundation of the footprint for identification [2]. Footprint is under the effect of dynamic stereotype in the trace by the body, it contains both gait features and trace characteristics [3]. Gait features of continuous footprints is a reflection of the walking exercise habits such as length, width and angle of step. Traces of footprint features can reflect the age, gender, height, body and walking posture of the criminal. Feature data extraction of footprint is an important material evidence identification, and it is conducive to the criminal investigation process smoothly. Therefore, it is particularly important to analysis the footprints left over from the crime scene correctly and quickly.

As a kind of nondestructive testing method, optical technology plays an important role in the evidence's discovery, records, extraction, preservation and identification of the footprints [4]. At present, the technology of footprint examination is gradually mature, but most of the ways are dependent on the expert's experience. In order to complete feature extraction and feature recognition between the suspect and the crime scene quickly, many scholars have research results. In[5], a way of alignment of core point for shoeprint analysis and retrieval have been proposed; In [6], the retrieval of shoeprints images based on the integral histogram of the Gabor transform domain have been proposed; In[7], a examination system based on image processing of footprints be designed; In[8], an algorithm of image matching recognition for incomplete

footprints have been proposed; In [9,10], a recognize and retrieve approach based on scale-invariance feature transform have been proposed for incomplete footprint

At present, most of the footprint recognition systems adopt two-dimensional data processing based on image processing, but the acquisition and processing of the 3d data. In[11], the reliability of many two-dimensional measurement method of footprints is discussed; In[12], the accuracy about many the automatic identification system of footprint is discussed, the conclusion shows that the effect is not ideal. Therefore, it is the inevitable requirement of development to extract 3d data of the stereo-footprint quickly. In[3], a footprint alignment algorithm fusing texture features and depth information is proposed, but need to extract the 3d information of entire footprint.

The system of stereo-footprint data acquisition-recognition is designed based on the theory of trace examination and the expert's experience knowledge. Only few feature points data extracted can realize the stereo-footprint feature extraction quickly and accurately, then complete the footprints feature recognition between the suspect and the crime scene. Finally, system generate stereo-footprint examination conclusion.

II. SYSTEM STRUCTURE

The characteristics of legacy easily for footprint make it the key trace the scene of the most crime; individual characteristic of footprint makes it become the important material evidence in the process of criminal investigation. Not completely the same individuals in the world, apparently there are differences footprint between individuals. There exist certain differences between different footprint of the same person, but the differences between different individuals more apparent [1]. On this basis, combined with relevant theoretical basis and the expert's experience, the system be designed.

Schematic of system of stereo-footprint data acquisition-recognition is show in Figure 1. System mainly composed of feature data acquisition system and feature data recognition system. Feature data acquisition system is mainly composed of image acquisition and processing, stepper motor control and laser range. Firstly, the camera acquisition the graphic images of stereo-footprint, then the coordinate transformation between pixel and motor move, finally complete the feature data extraction by the laser range finder. Feature data acquisition system to complete the stereo-footprint data extraction, then

the feature data deposited in corresponding stereo-footprint database. Feature data recognition system mainly complete feature data recognition between stereo-footprint of suspect and the crime scene, then acquire reasonable conclusion by the theory of stereo-footprint examination.

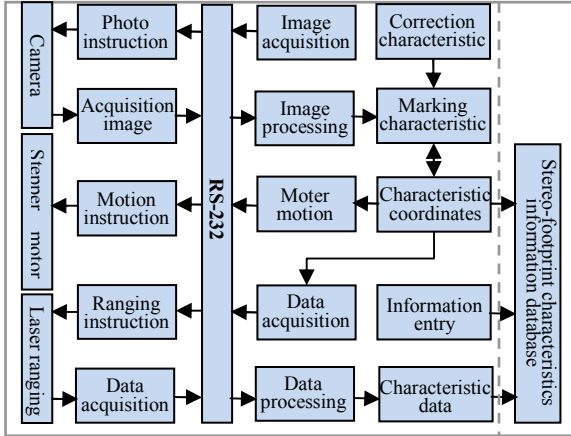


Fig.1 Schematic of system of stereo-footprint data acquisition-recognition

III. THE BASIC PRINCIPLE OF SYSTEM OPERATION

According to the existing trace examination theory, we need to determine the footprint coordinate system at the first step, then according to the coordinate system to find the footprint feature points and extracts the data of feature points.

Figure shows the process of building footprint coordinate system. Firstly, two tangent lines are made on the footprint contour A,B and C,D, then make the angle bisector of tangent AB,CD, cross footprint contour at point E, the point E be called heel point, the angle bisector is the longitudinal axis of the footprint coordinate system. E is the base point, take point O along the longitudinal direction Y at 75mm, through the point O make perpendicular of vertical axis, the line is the abscissa axis of the footprint coordinate system. From this, the coordinate system is completed.

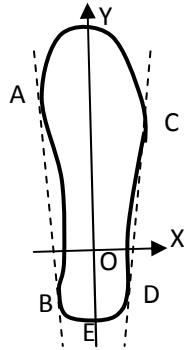


Fig.2 Footprint coordinate system

The forefoot area indentation is the indentation feature of the forefoot part in the footprint. The forefoot pressure are different, coupled with wide palm size, bone thickness, muscular extent, morphology and other features are different, that lead to the different of forefoot area indentation. This kind of difference not only reflected in the footprint surface but also trace depth^[1]. In order to obtain feature points, in the footprint coordinate system, selecting the center point H0 (0,120)(mm)

of the forefoot,(10,130),(10,110),(-10,110),(-10,130),(0,130), (10,120),(0,110),(-10,120), that's called the mountainside points of forefoot area. Similarly,(30,150),(30, 90),(-30,90), (-30,150),(0,150),(30,120),(0,90),(-30,120), that's called the foot points of forefoot area. In actual measurement, depending on the left or right feet, the (30,150),(-30,150) points are corrected to (20,140), (-20,140).

System using the elevation differences between the feature points to characterize the stereo-footprint's trace feature. If the i_{th} direction's elevation of the mountainside points and foot points respectively are h_{i0}, h_{i1} , the elevation of the H_0 is h_0 , then the i_{th} direction's the whole slope steepness g_{i0} and slope steepness g_{i1} can be obtained by "(1)" and "(2)":

$$g_{i0} = h_0 - h_{i0} \quad (1)$$

$$g_{i1} = h_0 - h_{i1} \quad (2)$$

For the above measurements, the crime scene stereo-footprint are expressed as: g_{Si0}, g_{Si1} , the suspect's stereo-footprint are expressed as: g_{si0}, g_{si1} . The whole-slope steepness's variation sum of squares A_1 and the half-slope steepness's variation sum of squares A_2 between the forefoot area indentation's of crime scene stereo-footprint and the suspect's stereo-footprint, the formula are shown in "(3)", "(4)":

$$A_1 = \sum_{i=1}^8 (g_{Si0} - g_{si0})^2 \quad (3)$$

$$A_2 = \sum_{i=1}^8 (g_{Si1} - g_{si1})^2 \quad (4)$$

Similarly, hallex area indentation also different. Selecting $(\pm 10, 170), (\pm 30, 170), (\pm 10, 150), (\pm 30, 150), (\pm 10, 130), (\pm 30, 130)$ as the indentation feature extraction point for left and right hallex. If the center point elevation of hallex $(\pm 30, 150)$ is h_0 , then the j_{th} direction's hallex steepness can be calculated by "(5)", the hallex steepness variation sum of squares A_3 between crime scene and suspect as shown in "(6)":

$$g_j = h_0 - h_j \quad (5)$$

$$A_3 = \sum_{i=1}^5 (g_{Sj} - g_{sj})^2 \quad (6)$$

Which h_j is the j_{th} direction elevation of hallex area indentation, g_{Sj} is the j_{th} direction elevation of crime scene stereo-footprint, g_{sj} is the j_{th} direction elevation of the suspect.

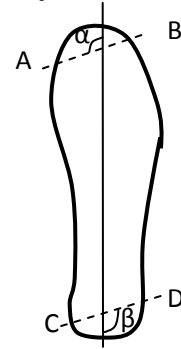


Fig.3 Angles schematic of foot lift-down

Gait direction is an important trace feature, the stereo-footprint lift angle and down angle can reflect this feature well. As shown in Figure 3, the angle of line segment AB with the footprint center line is α , the angle of line segment CD with the footprint center line is β , then lift angle variation A_4 and down angle variation A_5 between the crime scene stereo-footprint and the suspect is shown as "(7)", "(8)":

$$A_4 = |\alpha_s - \alpha_s| \quad (7)$$

$$A_5 = |\beta_s - \beta_s| \quad (8)$$

α_s, β_s are the lift angle and the down angle of crime scene, α_s, β_s are the lift angle and the down angle of suspect.

The length and width of the stereo-footprint are the important trace feature. The footprint length variation A_6 and the footprint width variation A_7 between the crime scene and the suspect is shown as“(9)”,“(10)”:

$$A_6 = |L_s - L_s| \quad (9)$$

$$A_7 = |W_s - W_s| \quad (10)$$

Which L_s, W_s are the footprint length and width of the crime scene, L_s, W_s are the footprint length and width of the suspect.

IV. ACQUISITION AND RECOGNITION OF FEATURE DATA

Features data acquisition and feature data recognition are the two main parts of the system. The accuracy of features data acquisition affects the system effectiveness directly, the rationality of feature data recognition related to the rationality of the footprint examination report.

A. Acquisition of Feature Data

Firstly, features data acquisition system get stereo-footprint image by the camera, and then the system control stepping motor move to the feature points extract feature data with laser range finder.

This system chooses two phase stepper motor SS1704A20A and SS2304A42A, which offered by Sanse Motor, with the MD-2522 and MD-2545 drives respectively, can realize eight kinds subdivision settings. The system chooses 25600 step/rev subdivision settings to ensure the accuracy, and the precision can reach 0.078 mm. Camera C920, can achieve 1080p video recording and 1920X1080 pixels, which offered by Logitech. Laser rangefinder is Wenglor's CP35MHT80 with working range 50-350 mm and resolution of 50 μ m, response time is less than 1.25 ms, spot size 0.6*1.5~1.5*4 mm. To make the motor find the stereo-footprint image feature points accurately, we have to make coordinate transformation of stepper motor motion coordinate, image pixel coordinates and footprint coordinate.

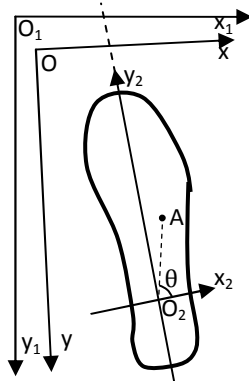


Fig.4 Schematic of coordinate systems

As shown in Figure 4, stepper motor motion coordinate xoy, image pixel coordinate $x_1O_1y_1$ and footprint coordinate $x_2O_2y_2$. Footprint coordinates feature point $A(x_{A0}, y_{A0})$, to make stepper motor can control the laser range finder to finish data extraction accurately, coordinate value of A must be

conversion into stepper motor motion coordinates. $O_2(x_2, y_2)$ is known, so, the coordinate of feature points A in image pixel coordinate (x_{A1}, y_{A1}) can be calculated by“(11)”:

$$\begin{cases} x_{A1} = x_2 + \sqrt{x_{A0}^2 + y_{A0}^2} \cos\left(\frac{\pi}{2} - |\arctan k_2| + \theta\right) \\ y_{A1} = y_2 - \sqrt{x_{A0}^2 + y_{A0}^2} \sin\left(\frac{\pi}{2} - |\arctan k_2| + \theta\right) \end{cases} \quad (11)$$

θ_0 is the included angle of footprint center line with the X-axis of image pixel coordinate system. The footprint center line is generated by the system automatically. k_2 is the gradient of center line in image pixel coordinate.

When the feature points A in image pixel coordinates is obtained, then need to convert stepper motor motion coordinate system coordinates(x_A, y_A), coordinate(x, y) is the O in the image pixel coordinates, as shown in“(12)”:

$$\begin{cases} x_A = \gamma \cdot (\sqrt{(x_{A1} - x)^2 + (y_{A1} - y)^2} \cdot \cos(\theta_1 + \theta_2)) \\ y_A = \gamma \cdot (\sqrt{(x_{A1} - x)^2 + (y_{A1} - y)^2} \cdot \sin(\theta_1 + \theta_2)) \end{cases} \quad (12)$$

γ is the ratio of motor motion coordinates and image pixel coordinates, which θ_1 and θ_2 as shown in“(13)”,“(14)”. Control single motor motion can obtain linear equation of X-axis in motor coordinate system, k_1 is the gradient for X-axis of the stepper motor coordinate system in the image pixel coordinate system.

$$\theta_1 = \arctan\left(\frac{y_{A1}}{x_{A1}}\right) \quad (13)$$

$$\theta_2 = \arctan k_1 \quad (14)$$

Obtained the coordinates of footprint feature points in the stepper motor coordinate realize stereo-footprint feature points, image pixel points and stepper motor points for laser ranging corresponding to each other. So, the system can extract the stereo-footprint feature point data accurately. Finally, system pushes the data into the database.

B. Recognition of Feature Data

Feature data acquisition is the foundation of system accuracy, and the feature data recognition is the foundation of system accurate judgment results. This system adopts the universal basis of stereo-footprint examination in criminal investigation process. The whole-slope steepness's variation sum of squares A_1 , the half-slope steepness's variation sum of squares A_2 , hallex steepness variation sum of squares A_3 , lift angle variation A_4 , down angle variation A_5 , footprint length variation A_6 and footprint width variation A_7 are identified as indexes, the index variation threshold as shown in table I.

TABLE I
THRESHOLD VALUES OF STEREO-FOOTPRINT FEATURES

Indexes	A_1	A_2	A_3	A_4	A_5	A_6	A_7
Threshold value	45	25	22	8	8	11	5.4

The system recognition stereo-footprint feature data between the scene crime and suspect. If the result of index is less than the index threshold, system receives the index's conclusion. System to make the suspect is the perpetrator, when the seven indexes are in a state of receiving.

Footprints can reflect individual features fully only walking naturally. Therefore, it is not very reliable determine with single footprint. If there are multiple traces, system can average value processing of feature data. The conclusion will be more reliable. Feature data recognition system also designs

the average value processing function.

C. Software Design

Image processing, feature data processing, feature data recognition and system operation interface are based on NI Labview2011 software implementation. Use the VISA (Virtual Instrument Software Architecture) function complete footprint image acquisition, using DCT (Database Connectivity Toolkit) complete the connection between feature data and stereo-footprint feature database which based on Access2010.

V. PERFORMANCE EVALUATION

To test the reliability of the system, we set up the feature recognition experiment of the same person with same shoes and different shoes.

There are 5 people participate in this experiment, including 2 women, 3 men, and 20 stereo-footprints are extracted. For the convenience of recognition, we extract stereo-footprints of left foot.

The experimental results are shown in the below table. In which the symbol "√" means that could satisfy the index, the symbol "X" means that could not satisfy the index. System determines the suspect is the perpetrator, when the seven indexes are in a state of receiving.

TABLE II
RECOGNITION RESULTS FROM ONE PERSON WITH SAME SHOES

Indexes	A ₁	A ₂	A ₃	A ₄	A ₅	A ₆	A ₇
Person A	√	√	√	√	√	√	√
Person B	√	√	√	√	√	√	√
Person C	√	√	√	√	√	√	√
Person D	√	√	√	√	√	√	√
Person E	√	√	√	√	√	√	√

In order to trace examination of stereo-footprints better, police officers extract stereo-footprints often ask the suspect to wear the shoes of crime scene. As show in Table II, the system can well meet the indexes for same person with same shoes.

TABLE III
RECOGNITION RESULTS FROM ONE PERSON WITH DIFFERENT SHOES

Indexes	A ₁	A ₂	A ₃	A ₄	A ₅	A ₆	A ₇
Person A	√	√	√	√	√	√	√
Person B	√	√	√	√	√	√	√
Person C	√	√	√	√	√	√	√
Person D	√	√	√	√	√	√	√
Person E	√	√	√	√	√	√	√

In the process of criminal investigation, we found that some cunning criminals to discard or destroy crime's shoes. In this case, the police officers often find similar to the shoes texture of crime scene to complete the stereo-footprints extraction. As show in Table III, the system can well meet the indexes for same person with different shoes.

The experimental results show that the system of stereo-footprint data acquisition-recognition can effectively recognize the stereo-footprint of the same person.

VI. CONCLUSION

The success of designing the system to make the extraction and recognition of stereo-footprint become more conveniently, and it don't need too much reliance on trace expert's experience knowledge. In the scope of the existing data sets, system comparative accuracy can reach 100%. The system can promote the widely used of stereo-footprint in the criminal investigation process effectively.

However, this system only chose the completed stereo-footprint with clear texture. In order to improve the reliability and the performance of the system, the future research work will consider incomplete stereo-footprint.

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