Segmentation of the Wear Area of Planar Shoeprint Using Mean Shift

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Abstract. In the field of forensic science, the wear area of planar shoeprint is a useful information for analysis of criminal suspects. However, the identification of shoeprint wear areas is often subjective to the expert's personal experience. In this paper, considering the characteristics of planar shoeprint images, a segmentation algorithm based on mean-shift is proposed to process planar shoeprint image to get the wear area. Firstly, the multiplicative intrinsic component optimization method(MICO) is employed to pre-segment the image. This method combines the level set with the offset field correction method to segment the outline of the unevenly printed shoeprint image. Secondly, we use mean shift to segment the image. Finally, we compare the actual wear area with the segmented wear area. It is found that the segmentation effect is good. By pattern recognition method, the wear area of the shoeprint is segmented to provide more objective technical support for detecting cases.

1. Introduction
The shoeprint is an important trace left by the crime scene. The shoeprint and other physical evidence are often used by the criminal investigators to narrow the scope of the investigation. In the later stages of litigation, criminal suspects were sued through a chain of evidence including the shoeprint. Shoeprint is a very important trace test for forensic science. Wear is one of the most important features in the shoeprint image. During walking, the force is transmitted to the ground through the sole of the shoe and is formed into a shoeprint in contact with the marking object, which can also reflect the wearing characteristics of the shoes worn by the pedestrian [1]. The wear characteristics of the sole refer to the traces caused by the shedding of the sole material due to the high frequency wear between the sole and the subject [2]. The wear characteristics can reflect the structural characteristics of the wearer's bare feet and changes in the structural characteristics of the sole, and also reflect the wearer's walking habits and exercise patterns [3, 4]. We outline the wear area on the shoeprint with a green line, as shown below
Figure 1. scratched sole wear area

For a long time, wear inspection is mostly based on the professional judgment of the criminal investigation expert, this is very subjective and there are individual differences. In order to carry out the quantitative comparison of the foot prints, mathematical statistics and fuzzy mathematics were used to digitize the wear characteristics and use the calculation or quantitative data given by the computer to determine [5,6].

One of the key technologies for shoeprint image segmentation is Mean Shift. Mean shift is currently mainly used in clustering [10,11], image segmentation, contour detection [12,13] and object tracking[14]. In image segmentation, the image pixels are first converted into sampling points in the feature space; then, mean shift clustering is performed on the sampling points, and clustering in the feature space corresponds to the segmentation of the image space. The second key technology of shoeprint image segmentation is the multiplicative intrinsic component optimization method (MICO). The MICO method was originally proposed to solve the segmentation of medical magnetic resonance images. It is based on a level set method of nonlinear prior shapes.

There are two innovation points in this paper. First, the method of computer vision is used to segment the shoe print, and the pattern and wear area of the shoeprint are obtained. This result is objective and repeatable, which is crucial to the incorporation of the shoeprint as part of the evidence chain during the litigation process. Secondly, with the passage of time, even if the suspect wears the same pair of shoes, the geometric shape of the wear area is also expanding, that is, we do not aim for high segmentation accuracy but focus on finding the wear area and observing the geometry of all wear areas on the same shoeprint by computer. Thanks to the mean shift, we can make fuzzy marks on the center of gravity of all wear areas on the shoe print.

2. Proposed Technology
In this context, we propose the following techniques to process image

![Flow Chart](image-url)

**2.1 Multiplicative Intrinsic Component Optimization**
The Multiplicative Intrinsic Component Optimization (MICO) method is a kind of Level Set method. It was proposed by Prof. Li in 2014[15]. It divides the picture into offset field and correction field, then, the image can be formulated as,
\[ I(x) = b(x)I(x) + n(x) \]  \hspace{1cm} (1)

2.2 Mean Shift

Mean Shift was first proposed by Fukunaga and Hostetler in a paper on probability density gradient function estimation in 1975\[16\]. It is weighted by a kernel function,

\[ y_{j+1} = \frac{\sum_{i=1}^{n} K(y_j - x_i) x_i}{\sum_{i=1}^{n} K(y_j - x_i)} \]  \hspace{1cm} (2)

Many scholars popularize the basic mean shift\[17,18,19,20,21,22\]. This article takes full account of the spatial information and range information of the pixel values, which together constitute a joint feature space \[X,Y,L,U,V]\[23,24\]. The Mean Shift algorithm is divided into rough segmentation and fine segmentation. First, the Mean Shift iteration process is used to calculate the probability density extreme point for each pixel. Points of the same class converge to the same extreme point. The color of each point in the class is replaced by the color of the center point of the class, and the rough segmentation is completed; after the rough segmentation is completed, too many extremum points are generated due to the over-segmentation, and some smaller regions appear, so some classes must be merged.

3. Experiments and Analysis

This experiment is on Windows Server 2008 R2 Enterprise, 64 bit operating system, the memory environment is 32GB, the processor is Inter (R) Xeon (R) CPU E5-2620 v2@2.10GHz, the program is realized by matlab R2013a. There are three Experimental parameters, hs, hr and convergence. The hs is the spatial space bandwidth, hr is the range space bandwidth and the convergence is the convergence threshold. In the experiment, the parameters of the first group are set as follows hs=16, hr=15, convergence =0.25

3.1 Data preparation

We let the volunteers have the ink on their feet, walk in one direction on a white scroll whose size is about 600 cm * 45 cm, and use the scene detail photography method to take pictures of the left planar shoeprint (310 volunteers, about 7,100 shoeprints). The image shown here is the shoeprint of our volunteers, numbered 15D-1-24. fig. 3 is our original image.

![Figure 3. original image](image)

3.2 Experimental results and analysis

3.2.1 Pre-segmentation effect of MICO

We are going to use the pattern recognition method to identify the wear area of the shoe print. First, we pre-segment the image using the MICO algorithm, the result can be seen as fig. 4.
3.2.2 Comparison between manual annotation and mean shift segmentation

We manually annotated the sample with past evaluation experience. Experience shows that this is a left foot shoeprint, and its wear area should be mainly distributed on the inside of the palm area and outside the heel area we manually noted 10 wear areas. As shown in fig. 5 (a). We use the mean shift to segment the fig. 4 and the result is shown in fig. 5 (b), in which the colorful point is the center of gravity of the same color area. Combining the knowledge of shoeprint knowledge to compare two images.

The 10 wears are formed in the three stages of people's walking, landing, vertical support (standing), and kicking. The wear part of the landing stage is mainly in the heel, reflected in the back edge of the heel and heavy pressure surface. The No. 8 wear area we marked is the partial wear of the heel. The wear area on the outside of the heel in fig. 5 (b) corresponds to the wear area No. 8 in fig. 5 (a).

The wear in the vertical support stage is due to the inlaid wear caused by the human body's gravity. Those wear patterns are found throughout the heel, arches, forefoot, and toes. The wear in the vertical phase is mainly the No. 9 wear area that we marked, and the wear group No. 1 to No. 7 marked on the outside of the foot. These wear areas in fig. 5 (a) are shown in fig. 5 (b).

At the kick-off stage, the wear of the forefoot area is formed when the foot metatarsophalangeal joints collapse. The soles are subjected to strong forces in this area and are often bent. The worn parts are related to the age of pedestrian. Observing the marked wear area No.10, it can be seen that the subject was a young man who used his thumb and ankle to kick his feet. Like the NO.9, the wear area No. 10 in fig. 5(b) are more discrete points than the labeled area in fig. 5(a), cause pattern recognition is more accurate than manual marking.
We note that in fig. 5(b), a large red dot is the center of gravity of the iteration, and of course it is also the center of gravity of the wear area. This is very important for studying the geometry of the wear areas of the same person. With the passage of time, the wearing area of the shoes worn by pedestrians is continuously expanding, and simply dividing the wear area of the shoes currently worn by the criminal suspects will have certain application limitations. However, if you find the center of gravity of a person's wear areas, its geometric position has a certain degree of stability. By comparing with the manual labeling, it can be found that the Mean Shift method can be used to segment the wear area and the desired effect can be expected.

3.2.3 Segmentation effect of FCM and K-means

In order to verify the effectiveness of the Mean shift algorithm, we also use the fuzzy C-means method and K-Means method to segment the shoeprint image. The parameters are set as follows. In FCM, we set sigma=2, in K-means, we set the parameters as follows, sigma=2, k=4. In order to facilitate detailed observation, we intercept the shoe heel and compare observations.

![Figure 6 (a). fcm segmentation](image)

![Figure 6 (b) k-means segmentation](image)

In fig. 6 (a) and fig.6 (b), we use white thin lines to depict the wear area in the shoe print image. From the above figures, it can be seen that the wear area depicted by the FCM is significantly larger than the wear area of the K-Means. Many small wear areas are reflected in the fig. 6(a), but they are missing in the fig. 6(b). This is related to the choice of the k’s value.

3.2.4 Comparative analysis of discrete graphs of segmentation effects

We compare the image processing results of MICO + Mean Shift algorithm in this paper with the image processing results of FCM and K-Means algorithm. The following figures shows the scatter plots of the three image processing results. Obviously, the treatment effect of this article is more tidy, and the shoeprint segmentation effect is obvious.

![Figure 7 (a). original image scatter](image)

![Figure 7 (b). mean shift image scatter](image)
At present, most of the clustering algorithms rely on the prior knowledge of the number of clusters, and artificial assumptions are added in the analysis of the feature space. For example, the K-means clustering algorithm needs to specify the number of clusters, fuzzy C-means needs to define the fuzzy membership function in advance once cluster the class, yet the mean shift algorithm does not require any prior condition.

4. CONCLUSION

In the field of forensic medicine, the identification of shoeprints is part of the chain of evidence that prosecutes suspects. In shoeprint identification, the results of the segmentation of the wear area are derived by experts based on years of experience, and these conclusions are highly subjective. This paper attempts to segment the wear area with shoeprint images using a pattern recognition algorithm to make the identification conclusion more objective. In this paper, we first use the MICO algorithm to pre-segment the shoeprint image, and then map the pre-segmented image into L, U, V format images. Next we use the Mean Shift algorithm to segment the image and finally get the wear area and its center of gravity. The image segmented by this method is compared with the manually labeled image. We find each corresponding wear feature point. Last, the fuzzy C-means method and the K-Means method are used to segment the image, and the scatter plots of the three segmented effect graphs are compared. Obviously, our algorithm performs better here. In future, our work includes thinking about how to eliminate the interference of the complex environment of crime scenes on shoeprints.

Acknowledgments

This work is supported by the Fundamental Research Funds for the Central Universities of China (Grant No.2018JKF217), the National Natural Science Foundation of China (Grant No. 61503387), National Key Research and Development Program (Grant No.2017YFC0803506, 2017YFC0822003).

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