Pattern Recognition 42 (2009) 1308 – 1317

Contents lists available at ScienceDirect

Pattern Recognition

journal homepage: www.elsevier.com/locate/pr

Rotation and intensity invariant shoeprint matching using Gabor transform with application to forensic science

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ARTICLE INFO

Article history:
Received 13 November 2007
Received in revised form 14 October 2008
Accepted 5 November 2008

Keywords:
Forensic science
Shoeprint
Gabor feature map
Fourier transform
Power spectral density

ABSTRACT

Shoe marks at the place of crime provide valuable forensic evidence. This paper presents a technique for rotation and intensity invariant automatic shoeprint matching. Multiresolution features of a shoeprint have been extracted using Gabor transform. Rotation of the shoeprint image has been estimated using Radon transform and is compensated by rotating the features in opposite direction. The performance of the proposed algorithm has been compared with the technique in which the features have been determined using Fourier transform and its power spectral density. Shoeprint database has been generated by inviting participants to tread on an inkpad and then stamp on a piece of paper. Euclidian distance classifier has been used to find a suitable match. The performance of the proposed algorithm has been evaluated in terms of correct recognition rate computed using best match score at rank '1' and cumulative match score for the first four matches with rotation, intensity and/or mixed attacks. A good matching performance has been achieved with rotation attack; typically 91 percent at rank '1' and 100 percent at rank '2' for full prints. Performance of the proposed technique is better even for partial shoeprints. Experimentation has also been carried out by perturbing shoeprint images with Gaussian white noise, salt and pepper noise to evaluate the robustness of the proposed technique.

1. Introduction

Forensic science refers to the application of principles and methods of science and medicine to legal questions of a criminal or civil nature. Shoe impressions are the most common clues along with tyre print and some of the physiological biometric evidences (like odor, hair, blood etc.) found at the place of crime. Shoeprints found at the place of crime with great regularity; hence studied by police and crime laboratory personnel. These impressions carry substantial information and are useful in linking the crime scenes and trap the criminals.

Shoeprint is the mark made by outside surface of the sole of a shoe (consist of distinctive geometric patterns). Shoe marks can be broadly classified into two classes: (i) shoe impressions which contain 3-D information (shoeprints at the beach) and (ii) shoe impressions which contain 2-D information (shoeprints on a floor). Probability of occurrence of shoe marks at the place of crime is higher than that of fingerprints since a high proportion of burglars wear gloves [1]. In several jurisdictions of Switzerland it was revealed that 35 percent of the crime scenes had shoeprints usable in forensic science, and found that 30 percent of burglaries provide usable shoeprints [2]. It is common for burglars to commit a number of offences on the same day. As it would be unusual for offenders to discard their footwear between committing different crimes [3]; timely identification and matching of shoeprints helps in linking various crime scenes. The modus of operandi of the criminals helps the officer in the process of crime(s) investigation. In these cases it is possible to work back from suspect, using impressions from his/her shoes to see if a match can be found at the crime scene and thereby providing corroborative evidence. When the crime place is examined by the scenes of crime officers (SOCO), shoe impressions can be collected by way of either using photography, gel, electrostatic lifting or by making a cast when the impression is on soil. Shoeprints of the persons having legitimate access are then eliminated and the SOCO can be quite confident to say that left over shoeprints belong to the offenders.

Birkett system of coding shoeprint patterns was devised by John Birkett of the metropolitan police forensic science laboratory by allocating alphanumerical values to various pattern elements [4]. This system failed uniquely to identify a pattern because of the multitude of new patterns from manufacturers in the late 1980s. Further this problem was addressed by prefixing the coding elements with two numerical digits for the year and a three digit numerical suffix in 1993. A database was constructed using readily available software which allowed the images to be stored, displayed and

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doi:10.1016/j.patcog.2008.11.008

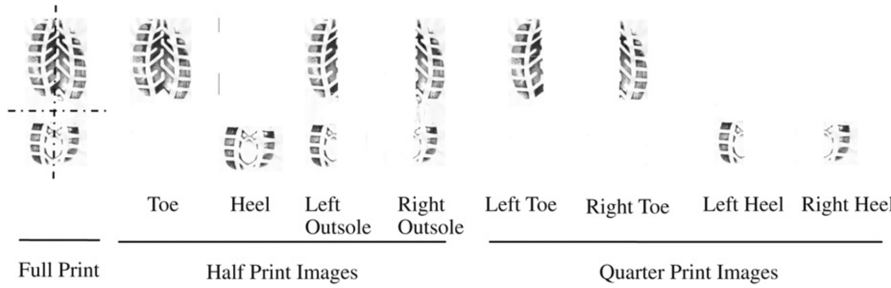

Fig. 1. Partial shoeprint images generated from full print image.

have text added which could be searched for keywords or specific codes. Matching of the impressions has been either carried out manually by searching through paper catalogs or more commonly semi-automatically using a computer database and a manual classification. Earlier contributions [4–7] have employed semi-automatic methods of manually annotated footwear print descriptions using a codebook of shape and pattern primitives. The problems associated with these methods were: (i) no attempt has been made to code the spatial information of the patterns (where the various patterns occur on the shoe); (ii) modern shoes tend to have more intricate patterns, difficult to describe with simple shapes; and (iii) they depend on subjective judgments and lead to difficulties in determining a match at a later stage.

Fully automatic shoeprint classification and retrieval is still relatively new and immature. Some work has recently been reported in Refs. [8–15]. These algorithms extract set of features from a shoeprint image using different descriptors like Fourier descriptors or fractals, and then sort a database of shoeprints in response to a sample shoeprint. Contributions in Refs. [8,9] make use of fractals to represent the footwear prints and a mean square noise error for classification. Classification accuracy of 88 percent reported for 145 full print images with no spatial or rotational variations. Alexander et al. [10] presented an automatic classification and recognition of shoeprints. A uniform method of recognition and classification for the shoeprint pattern to increase effectiveness and utilization of the system in investigation (as the same SOCO may not have attended all the scenes) is proposed in Ref. [11]. Fourier transform (FT) has been used for classification of full and partial prints of varying quality [12]. FT provides invariance to translation, rotation and encodes spatial frequency information. Classification of 65 percent at rank ‘1’and 87 percent at rank ‘5’ on full prints were reported. For partial prints, a performance of 55 percent at rank ‘1’ and 78 percent at rank ‘5’ has been achieved. The footwear prints were processed globally, but encoded in terms of local information in the print. The approach deals well with translation, rotation variations and for larger data set; however the query examples originate from the learning set and no performance statistics have been provided for partial prints. Pavlou et al. [13] presented an automated footwear classification system using local shape and pattern structure. The selected features and pattern descriptors are affine invariant and can cope with relative translation and rotation. The abundance and localized nature of these features permit good recognition performance for partial impressions. The features are transformed into robust scale invariant feature transform or gradient location and orientation histogram descriptors with the ranked correspondence between footwear patterns obtained through the use of constrained spectral correspondence method. Performance evaluation has been carried out in terms of correct recognition rate for full and partial prints. The matching performance of 85 percent at rank ‘1’ on full prints and 91 percent for the best six matches has been reported. The performance for partial prints reported as 84 percent, when matching ‘half top’ partial prints at rank ‘1’ and 90 percent at rank ‘6’. Su et al. [14] constructed the topological spectrum for each shoeprint image. Initially, Euler number for each structuring element was computed, which gives a series of Euler numbers (one set, or spectrum, for the positive image, and one for the negative). The normalized difference of this combined series gives the topological spectrum that represents the topological information about the distribution of set of objects and holes at different scales. Performance evaluation of information retrieval has been carried out with hybrid matching algorithm (precision vs. recall) based on combining the two distances of two spectra, suitable for data sets with more than one relevant record. Su et al. [16] devise a denoising technique, called non-local mean filtering. In this technique, the expected result of an operation on a pixel can be estimated by performing the same operation on all of its reference pixels in the same image. Similarity is based on the correlation between the local neighborhoods of the working pixel and the reference pixel. Visual and quantitative comparisons with two benchmarking techniques were conducted.

If the percentage of correctly identified prints is improved then the number of criminals caught and successfully prosecuted can be increased. However, several practical difficulties exist which hinder the effectiveness of real world shoeprint matching for both manual and automated: (i) shoeprints are inherently accompanied by some capture device-dependent noise (ripples when gel is lifted or fine grain noise in soil), (ii) distortions can be introduced when the shoeprint is actually being made (by non-uniform pressure of the sole, or blurring caused by foot slippage, or artifacts such as stones which interfere with the pattern), and (iii) partial or incomplete prints resulting from incomplete contact between the shoe sole and the surface. Hence, the performance of a system for partial prints and shoeprint with noise is of considerable interest and importance. Fig. 1 shows full print image and partial prints.

The proposed work presents an automated shoeprint matching technique for forensic investigation in crime scene linking. This paper is motivated towards deriving genuine textural features from full print and partial prints. Shoeprint features have been extracted using Gabor transform. The extracted features of the query and template have been used for matching. Similarity measure used for matching is Euclidian distance metric. Performance of the proposed algorithm and the algorithm stated in Ref. [12] has been compared. The proposed algorithm yields better result for both full print and partial print images with variations in rotation, intensity or both.

The paper has been organized as follows: Section 2 explains the proposed technique for shoeprint matching. It includes Gabor feature computation for shoeprint images along with the shoeprint rotation estimation using Radon transform. Section 3 deals with feature estimation of shoeprint image using FT and power spectral density (PSD). Section 4 describes experimental results and discussions followed by conclusions and references.