A REVIEW: ANALYSIS OF FOOTWEAR IMPRESSION EVIDENCE COLLECTION & DETECTION

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Abstract- Impressions of footwear are commonly found in crime scenes. The quality and wide variability of these impressions makes their analysis is very difficult. This research will develop new computational methods to assist the forensic footwear examiner in the U.S. In this research work involves developing a database of representative footwear print images so that appropriate algorithms can be developed and their error rates can be determined. Algorithms for identifying special features such as wear marks and embedded pebbles will be developed. Matching algorithms to be developed will be for both the tasks of verification, where the goal is to determine whether the footwear evidence is from a particular suspect’s shoe, or that of identification, where the goal is to determine the brand of the shoe from a known set of brands. In each case a quantitative measure of the result of matching will be provided. In the identification mode, the tools will allow the narrowing down of possibilities in a database of known prints. Another goal this work is to assist the U.S. footwear examiner is homicides and assaults where there are no known prints to match. For this purpose a classification tool is to be developed, where the objective is to generate from the evidence a set of characteristics, e.g., gender, texture, shape, size and brand. This work will be extended by following guidelines of SWGTREAD and in close consultation with forensic footwear and/or tire tread examiners.

Key words- footwear matching, morphology, enhancement, indexing clustering & classification, etc.

Introduction
Shoe marks- the mark made by the outside surface of the sole of a shoe (the outsole)- are distinctive patterns that are often found at crime scenes. Shoe marks can be broadly broken into two classes:
1. Shoe impressions which contain 3-dimensional information (e.g., shoe impression at the beach) and
2. Shoeprints which contain 2-dimensional information (e.g., shoeprint on a floor).

Shoe marks are common at crime scenes and are believed to be present more frequently than fingerprints [1]. A study of several jurisdictions in Switzerland revealed that 35 percent of crime scenes had shoeprints usable in forensic investigation, while in [2], Girod found that 30 percent of all burglaries provide usable shoeprints.

More generally, footwear impressions are created when footwear is pressed or stamped against a surface such as a floor or furniture in which process the characteristics of the shoe is transferred to the surface. The tasks for the forensic footwear examiner are:
• verification: where an impression is to be matched against a suspect's print,
• identification: matching the print evidence against a possibly
large set of known prints, and
- classification: determining the generic characteristics of the
  footwear, such as brand, gender and size.

The variability of prints comes about because of the variety of
surfaces on which the impressions are made (Fig.1). Footwear
marks provide valuable forensic evidence. In many instances,
shoe marks can be positively identified as having been made by a
specific shoe to the exclusion of all other shoes. Identification is
based on the physical match of random individual characteristics
the shoe has acquired during its life. Evidence provided by a posi-
tively identified shoe mark is as strong as the evidence from fin-
gerprints, tool marks and typewritten impressions [1]. In other
instances, detail retained in a shoe mark may be insufficient to
uniquely identify an individual shoe but is still very valuable. Due
to the wide variety of shoes available on the market, with most
having distinctive outsole patterns, this implies that any specific
model of shoe will be owned by a very small fraction of the gen-
eral population. If the model of a shoe can be determined from its
mark, then this can significantly narrow the search for a particular
suspect. An image of a shoe mark can be obtained using photog-
raphy, gel, or electrostatic lifting or by making a cast when the
impression is in soil. Subsequently, in the forensic laboratory, the
image of the shoe mark is compared with the shoeprints and shoe
impressions of known shoe samples. A process of detection and
recovery of footwear impression evidence and of comparison of
the impressions with suspect shoes is described in [1].

The photograph of the impression or of the lifted impression or
cast can be subsequently scanned and a digital image produced.
Forensic analysis requires comparison of this image against spe-
cific databases. These databases include: (i) marks made by
shoes currently and previously available on the market and (ii)
marks found at other crime scenes. Comparing crime scene shoe
mark images to databases is currently a laborious task and it is
commonly manually conducted by searching paper catalogues or
computer databases. Due to its time consuming nature, shoe
mark evidence is not used as frequently as it could be. For exam-
ple, in 1993, only 500 of 14,000 recovered prints in the Nether-
lands were identified [3]. Thus, computer-based methods that
reduce the operator effort for this task offer great benefit to foren-
sic scientists. Forensic examiners of shoeprints and tire marks are
a community of about 200 professionals in the United States.
Shoepints constitute about 80-90% of the case-work of the tread
examiner who deals with both footwear and tire-marks. Guidelines
for the profession are given on the IAI website dealing with the
Scientific Working Group on Shoepint and Tire Tread Evidence
(SWGTR). The forensic footwear and/or tire tread examiner collects
and preserves footwear and tire tread evidence, makes scientific examinations, comparisons and analyses of footwear
and/or tire tread impression evidence in order to:
- include, identify, or eliminate a shoe or tire as the source of an
  impression;
- determine the brand or manufacturer of a shoe or tire;
- link scenes of crime;
- write reports and provide testimony as needed.

There has been significant research conducted in shoeprint analy-
sis in Europe focusing on the needs of the European forensic
community. There are important differences for the task in the US.
Homicides and assaults are paid more attention to than burglaries

in the U.S. In such cases, shoe prints have a very low likelihood of
appearing in other cases. Due to this reason the classification
 task, i.e., determining brand, style, size, gender etc., is of im-
portance. Through such classification, even if the person could not
be identified, the search could be narrowed down to a smaller set
of suspects. The goal of this research will be to develop several
computational tools to assist the U. S. forensic community in deal-
ing with footwear impressions. Some of the tasks are: rectification
of the shoe-prints before they are analyzed, extraction of classifi-
catory features for the purpose of identification or elimination,
obtaining the strength of evidence (match score) based on the
features extracted from the evidence and known prints and effi-
cient search through a database of prints.

Automatic Footwear Matching

In an automatic footwear identification system, firstly, known shoe-
prints are scanned, processed and indexed into a database (Fig.
2). An automatic footwear identification system accepts as input
shoeprint evidence and retrieves the most likely matching prints.
Automatic matching of footwear patterns has been little explored.
Early work [2,4-7] involves semi-automatic methods of manually
annotated footwear print descriptions using a codebook of shape
primitives, e.g., wavy patterns, geometric shapes and logos. The
process is laborious and the source of poor performance due to
inconsistent user encoding [17].

In known footwear prints are scanned in different angles, like +30,
-30, +60, -60, +90, -90, are scanned & indexed into a database
(Fig. 3).

The approach of [3] employs shapes generated from footwear
prints using image morphology operators. Spatial positioning
and frequencies of shapes are used for classification with a neural
network. No performance measures are reported [8, 9] uses frac-
tals to represent prints and mean square noise error classification.
Fourier Transforms (FT) have been used for classification of full
and partial prints [10,11].

Most recently [13] invariant local feature descriptors and spectral
matching has been used previous techniques of automatic foot-
wear matching can be characterized along four dimensions as
follows:

1. Features Used
- fractal patterns [8,9],
- 2-D Discrete Fourier Transforms (DFT) [10,11] and
- local invariant descriptors [12,13]

2. Feature Similarity/Matching Algorithms Used
- Mean Square Noise Error method [8,9],
- DFT coefficients [10,11] and
- spectral correspondence matching method [13] for local invari-
ant descriptor matching

3. Databases Tested are
- Database I [8,9]: 145 full-print images with no spatial or rota-
tional variations,
- Database II [10]: 503 shoepint images belonging to 139 pat-
tern groups with each group containing 2 or more examples,
- Database III [11]: 476 complete images belonging to 140 pat-
tern groups with each group containing two or more examples.
and

- Database IV [13]: a subset of 368 different patterns [14]

4. Footwear Prints Used in Experiments are

- real footwear prints and
- generated partials [11] (Fig. 2.1).

Various Techniques

Content-based Image Retrieval

There is a significant-sized literature on content-based image retrieval (CBIR). This is due to the fact that large volumes of images are being produced, e.g., by NASA and DoD and it is expensive or impossible to annotate each of them by type. Thus it is a challenge to find images similar to the one at hand.

Digital Image Enhancement

Interactive image enhancement operations are available in Photoshop and other image processing software that are available to the footwear examiner. This effort will be to perform such operations automatically so that searching can be done efficiently.

Footwear Print Detection

Debris and shadows and other artifacts in the crime scene impressions will interfere with true shoe prints. So, the proposed task of "shoe print detection" is to automatically label a print to be a shoe print or not. For this task, not only shoe print images are needed, but also other types of prints encountered in crime scenes.

Region Classification

Debris and shadows and other artifacts in the crime scene impressions are difficult to filter out from footwear impressions. They have interfered with attempts to store and search in the database. Therefore, after digital image enhancement, some algorithms are desired to be able to classify different regions of footwear impression to be one of two types: useful regions (impressed by footwear) and discardable regions (impressed by other artifacts (noise) such as debris).

Robust Matching Algorithms

To cope with poor image quality robust matching algorithms, that possibly emulate human expert comparisons, should be designed to make accurate and fast decisions. A comprehensive system needs to integrate three levels of analysis: (i) global shoe properties: heavily worn or brand new, shape, size etc., (ii) shoe classification: brand, style, belongs to male or female (iii) shoe recognition: Detailed and distinctive local features should be utilized to increase the discriminative power in order to confirm a match between a shoeprint recovered from the scene of crime and a suspect’s property.

Partial Print Matching

In some crime scenes, only partial shoeprints (termed as “half prints” and “quarter prints”) are available, e.g., the right column of Fig. 2.1. When information available in partial prints is limited, effective utilization of the little information available is a challenge.

Indexing

In a large shoeprint database, the efficiency (speed) of retrieving a query print may also be important. Effective indexing techniques should be designed for such requirement. Indexing method to enter standard shoeprint prototypes should also be developed.

Clustering

Clustering of footwear prints into those of similar type can yield not only faster retrieval but also provide taxonomy of footwear print types. Clustering will involve extracting discriminating features from footwear prints and determining their proximity in feature space.

Retrieval

The system should be flexible to allow for possibly different types of retrieval. For instance, the task can be that to retrieve all shoeprints in the database that match a particular region of the shoeprint.

Classification

There are several potential classification tasks, e.g., determining brand or manufacturer, determining gender, etc. Even if a perfect match does not exist in the template database, a variety of classification algorithms could be relied upon to provide useful information such as gender, age and shoe size.

Footwear Evidence Samples

It is proposed to create a data set of foot-wear outer sole impression samples. They are necessary for developing algorithms for this research as well as for testing. At present such databases are not publicly available.

Synergy with other forensic domains

This project has commonalities with other projects in the analysis of impression evidence, specifically questioned document examination and friction ridge analysis. However there are also major differences. [17,18]

Shoe-print Extraction

A critical step in shoe-print identification is shoe-print extraction—this is the task of extracting the foreground from the background surface. The problem is formulated as a machine learning task which is approached using a probabilistic model, i.e. Conditional Random Fields (CRFs). Since the model exploits the inherent long range dependencies that exist in the shoe-print it is more robust than other approaches, i.e. neural networks & adaptive thresholding of grayscale images into binary [18].

Conclusion and Future Work

In this paper we observe & studied various techniques for identification, classification & verification for shoe-print evidence collection and detection. Most of researchers are used enhancement, morphological & segmentation techniques, but the given results are not satisfied. In future we used the various image processing techniques such as segmentation is very useful to extracting the foreground from the background. Specifically mathematical morphology & another edge based algorithms is very better to extract the shapes of various types of shoe-patterns such as noise, robust, full-prints, partial prints, etc. datasets.
Fig. 1 - Example of five shoeprint pattern categories. The left two columns show examples of images of full-prints and the right column shows examples of images of partial-prints.

Fig. 2 - Indexing: Known footwear prints are scanned, processed and indexed into a database.

Fig. 3 - Indexing: Known footwear prints are scanned in different angles.

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