



Crime scene reconstruction—Sex prediction from blood stained foot sole impressions



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ABSTRACT

It is often difficult to predict the sex of an individual based on bloody incomplete footprints. However, such prints/impressions are particularly common in a crime scene. Again variability in the texture, color of the target surface has an impact on the bloodstained impression formed. The study of bare foot, footprint, footwear (i.e. shoe, canvas etc.) within the legal context is referred to as forensic podiatry. Based on the fact that it is possible to predict the sex of an individual from footprint impressions, an automated model has been proposed in this paper for analyzing the sex of an individual from his/her broken/incomplete footprint impressions based on morphological features alone. Five male and female volunteers aged between 20 to 65 years participated in dataset development. Keeping the blood volume constant and having stepped on differently shaped porcine blood pools, the individuals were asked to walk on herbarium sheets. The footprints were recorded and documented in accordance with the guidelines in place for physical evidence documentation within the forensic domain. The morphological features that were extracted from each of the footprint impressions are footprint length, footprint breadth, angle of walking, approximated heel radius etc. Using exhaustive cross validation technique, the dataset was divided into training and test set. Non-redundant, relevant features that are particularly effective at sex prediction were marked out using the relief algorithm in coherence with the correlation metric. Supervised learning techniques were used on the dataset to predict the sex of the owner of an unknown footprint. The study concentrates on morphological features in order to deal with bloodstain footprint transfer stains formed on any non-porous/non-absorbent surfaces such as cemented floor, glass, mosaic floor space, colored and designed tiled floor spaces. Features such as the angle of walking and foot breadth were found to be particularly influential in sex prediction from incomplete bloodstained foot sole impressions. In comparison to a system for sex prediction from complete footprint impressions (82.2%), the automated system developed on incomplete foot impressions recorded an accuracy level of 83.47%.

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1. Introduction

The study and reconstruction of crime scene has always intrigued common man. Determination of the identity of individuals relevant to a crime scene plays an integral role in forensic investigation and the associated medico-legal practices [1]. Forensic anthropology particularly deals with the building of an antemortem profile of an individual from skeletal as also other remains left by the body of an individual in a crime scene. The body remains which are often left at a crime scene range from footprint

marks to hair strands etc. Luikkonen et al. in their work highlighted the contribution of shoeprint/footprint and toolmark examiners in the forensic reconstruction of a crime scene [2]. Use of clinical podiatric knowledge (i.e. bare foot, footwear anatomy, morphology etc.) for person identification within a legal context is commonly referred to as forensic podiatry [3].

While the domain of fingerprint identification stands vastly tread by computer and forensic scientists alike, the study of crime scene footprint impressions still stands limited. In this regard, the contributions of Dr. John DiMaggio, Wesley Vernon and Dr. Nirenberg deserve special mention [4,5]. The book “Forensic Podiatry—Principles and Methods” by DiMaggio and Vernon provides an overview of the methods followed for collection, documentation and analysis of pedal evidence, footwear evidence obtained from a crime scene in coherence with real world case

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study [5]. Krishan et al. undertook a study to analyze the sex differences in the foot length ratios of North Indian adolescent population aged 13–18 years. The study consisted of 303 adolescents (149 females, 154 males). Foot length ratio was found to exhibit sex differences in the given population [6]. Study conducted on the same population revealed that though women had larger mean heel ball index in both foot, statistically significant sex differences were only recorded for the right foot [7]. Research conducted on the Rajput population aged between 17 and 20 years highlighted that compared to hand and foot dimensions, foot and hand index values recorded a higher accuracy level in sex prediction [8]. Krishan et al. in a study that primarily dealt with footprint of North Indian population (18–25 years) revealed that the mean footprint ridge density across four areas of the print was higher in females as compared to males [9]. However, most of these works deal with complete footprints consciously taken from the footprint owners. This work is aimed at understanding bloodstained patent footprints at a crime scene and how such broken prints in coherence with other circumstantial evidence could be effectively used for predicting the sex of the print owner.

A complete patent bloody foot impression is only formed when the concerned individual has stepped on a pool of blood spread along the length and breadth of the lower surface of his/her foot. Again, study of bloody footprint/shoeprint becomes difficult when the surface on which the person has stepped with bloody foot/shoe is absorbent, porous and has dark coloration. Not only does the surface area exposed to blood pool but also the quantity of blood that adhered to the lower surface of the foot play an important role in the formation of a bloody footprint. Such prints are fragile and often stand distorted owing to walking pattern of an individual or subsequent activity at the crime scene.

The basic idea in this work was to develop a computer based system that could effectively predict the sex of an individual from the morphological features of the bloody broken footprint left by an individual while walking with bloody feet.

2. Literature review

In times of mass disaster such as aircraft crashes, explosion and warfare, mutilated body parts and extremities are the only remains that can be recovered from the scene [10,11]. A considerable amount of work has been done towards prediction of height or stature of an individual from measurements conducted on the footprint of the individual. Oberoi et al. worked on the estimation of height and sex of an individual from footprint length [12]. A complete ink footprint database was created by the authors by taking foot impressions from 200 subjects (100 male and 100 female) [12]. The analysis indicated a strong positive

statistically significant relation between the height and footprint length of both male and female subjects [12]. The linear regression model developed successfully predicted the sex of the print owner in 80% cases [12]. Rutishauser [13], Saxena [14], Giles & Vallandigham [15], Krishan & Sharma [16], Krishan [17], Atamturk & Duyar [18] made significant contribution towards estimation of the height/stature and weight of an individual from his/her footprint morphology. Moorthy et al. [19] in his work reconfirmed the strong correlation between the stature and foot length of an individual.

Abdel Moneim et al. worked on the anteroposterior radiographs of the right foot and the knee of 80 males and 80 females of Egyptian origin to estimate the possibility of sex determination from radiographic measurements [20]. The multivariate model developed on radiographic measurements yielded a classification accuracy of 87.5% [20]. On similar lines, Riepert worked on the estimation of sex of an individual from the radiographs of the calcaneus [21]. Medical literature indicates that 93.15% correct sex classifications were made when samples of humerus bone [22] were used. The use of radius length [22], ulna [22] and femur [23,24] for sex classification yielded a classification accuracy of 89.13%, 90.58%, 92.5–95.5%. Pelvis [25], vertebrae [26], acetabulum [27], sternal ribs [28], clavicle and scapula [29], metacarpals [30] have all been used for sex determination.

Compared to bone morphology, the success of sex classification based on footprint or foot impression is still limited. Footprint based multivariate sex classification systems are particularly modeled on foot morphology parameters (such as length, breadth etc.) and the calcaneus or heel structure. Riepert et al. [21], Murphy [31], Bidmos & Asala [32], Smith [33] and Abdel Moneim et al. [34] have used calcaneus as a basic factor for sex determination and achieved a success rate of 70–93.5%.

Work by Atamturk deals with sex estimation using features of footprint, foot and shoe size for an individual [35]. The accuracy rate (84.6%) of sex determination by Atamturk's model [35] closely resembles the sex determination accuracy rate (85%) achieved by Wunderlich and Cavanagh [36]. Wunderlich and Cavanagh identified foot length as a prime determinant for sex determination [36].

This work is particularly unique in the sense that it uses broken footprints formed by movement action of individuals.

3. Methodology

The method used for the study can be subdivided into the following heads—dataset development, image preprocessing, image registration, feature selection/extraction and classification. Fig. 1 represents a schematic diagram of the methodology that has been used for the study.

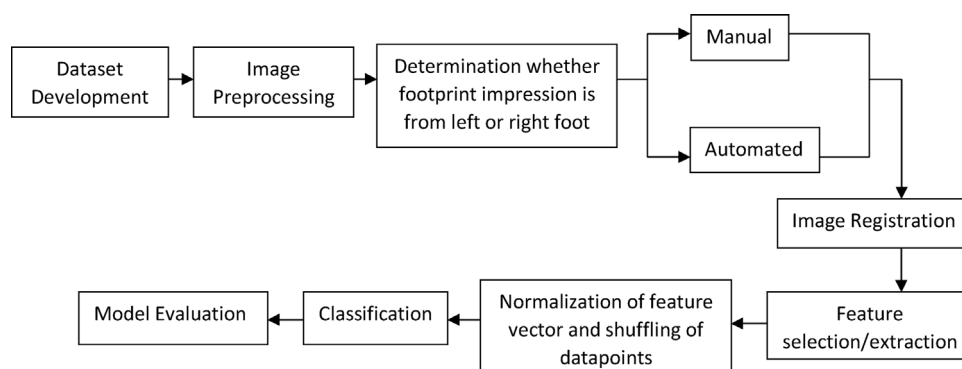


Fig. 1. Data model developed for sex estimation from bloody broken crime scene footprint images.

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