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A STUDY ON LOW RESOLUTION ANDROGENIC HAIR PATTERNS FOR CRIMINAL AND VICTIM IDENTIFICATION

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Abstract— Identifying criminals and victims in images (e.g., child pornography and masked gunmen) can be a chal- lenging task, especially when neither their faces nor tattoos are observable. Skin mark patterns and blood vessel patterns are recently proposed to address this problem. However, they are invisible in low-resolution images and dense androgenic hair can cover them completely. Medical research results have implied that androgenic hair patterns are a stable biometric trait and have potential to overcome the weaknesses of skin mark patterns and blood vessel patterns. To the best of our knowledge, no one has studied androgenic hair patterns for criminal and victim identification before. This paper aims to study matching performance of androgenic hair patterns in low- resolution images. An algorithm designed for this paper uses Gabor filters to compute orientation fields of androgenic hair patterns, histograms on a dynamic grid system to describe their local orientation fields, and the block wise Chi-square distance to measure the dissimilarity between two patterns. The 4552 images from 233 different legs with resolutions of 25, 13.75,12.5, and 6.25 dpi were examined. The experimental results indicate that androgenic hair patterns even in low-resolution images are an effective biometric trait and the proposed Gabor orientation histograms are comparable with other well-known texture recognition methods, including local binary patterns, local Gabor binary patterns, and histograms of oriented gradients.

Index Terms— Hair pattern identification, criminal and victim identification, soft biometrics, skin marks.

I. INTRODUCTION

DENTIFYING criminals and victims is always an important task in police investigation and forensic evaluation. Finger marks, blood samples, DNA, dental records, tattoos, face images and face sketches are used regularly by law enforcement agents all around the world. However, they can- not handle the cases, where only images describing crime- scene specimens are available.

These cases include but not limited to child pornography, violent protests (e.g., the Rome and the London riots in 2011), masked gunmen and terrorist attacks, where criminals always cover or hide their faces and tattoos to avoid identification.2 Because of the recent advances in imaging technology and the popularity of digital cameras, images with criminals and victims have been increasing significantly. To show the seriousness of the problem, we list some statistics about child sexual offenses. The U.S. Customs Service estimated that around 100,000 websites involve with child pornography . From 2002 to 2003 in Canada alone, approximately 30,000 child pornography cases were reported . The U.S. Bureau of Justice Statistics concluded that the low prosecution rate of child sex exploitation offenders was

mainly due to inadmissible or weak evidence . Though the U.S. Bureau of Justice Statistics defined neither inadmissible evidence nor weak evidence clearly, our forensic partners in two countries showed many child pornographic images and videos, which have only non-facial body sites of pedophiles and victims to the last author. In addition to child sexual offenders, terrorists also make use of this identification difficulty. It is worth mentioning that tattoos are prohibited in extreme Islamic terrorist groups . Once they wear face masks, there is currently no way to identify them. Numerous masked terrorist images are available on the Internet [50]–[57], [64]. Some masked terrorists even accept interviews from media.

Though neither faces nor tattoos are observable in these images describing crime-scene specimen, other body sites are often apparent. In child pornography cases, we likely obtain close up images with backs, chests and thighs of criminals or victims and in masked gunmen, violent protest and terrorist attack cases, we likely obtain images with arms and legs of criminals since they often wear T-shirts, short sleeve shirts and shorts, in particular in summer and hot climate regions. Some of these images can be found in [40]–[57] and [64]. To address this challenging identification problem, blood vessel patterns and skin mark patterns are proposed recently , [13], [14]. Blood vessel patterns are universal and are considered stable over a long period of time. Traditionally, near infrared imaging systems are used to capture blood vessel patterns. Methods are

It was developed recently to visualize blood vessel patterns hidden in color images captured by consumer digital cameras , [14]. However, their visibility depends on image quality and physiological factors such as the thickness of the subcutaneous fat layer in the skin and its pigmentation level. Skin marks, occurring on the skin surface, are more easily observable than blood vessels. Skin mark patterns and blood vessel patterns both require high resolution images and dense androgenic hair can cover them completely. New biometric traits have thus to be developed.

Medical research results have indicated that androgenic hair patterns can be used as a biometric trait. There are no additional follicles naturally formed after birth in human beings . All androgenic hairs manifest a cycle. When one hair drops, another new hair grows at the same follicle . They are two different hair shafts, but appear at the same location. Androgenic hair cycle is long. A leg hair cycle can be up to one year . Within this long period of time, we can find the same hair shaft. There are seasonal changes in androgenic hair growth [62]. A study showed that thigh hair grows faster in summer than in winter [63]. However, hair follicles have their own rhythm and their cycles are asynchronous, except in groups of three follicles called Demeijère [10], [53]. This implies that human hair does not fall out at the same time and we can always find some corresponding androgenic hairs for matching. The vellus-to-terminal hair follicle switch is irreversible. Even if men are castrated, their beards would not return to prepubertal level [11], [12]. Only around 10% androgenic hair follicles exit permanently from cycling. Others cycle throughout the entire lifespan to produce hair . Fig. 1(a) and (b) show two skin images from the same leg collected in August 200 and October 2003 respectively. The color circles in Fig. 1(a) and (b) indicate the partial corresponding androgenic hair follicles. From this small area, we can find more than 40 corresponding androgenic hair follicles. The remaining images in Fig. 1 show four image pairs collected in different time periods. As with Fig. 1(a) and (b), a lot of corresponding androgenic hair follicles can be identified. However, androgenic hair follicles are only observable in high resolution images. This paper studies matching performance of androgenic hair patterns in low resolution images as an alternative biometric trait for criminal and victim identification. Fig. 2 shows four male legs with distinctive androgenic hair patterns. As with other biometric traits, including face and fingerprint, androgenic hair can be modified (e.g. laser hair removal). This paper does not consider modification of androgenic hair.

Forensic scientists have studied hairs for many years. There are two common approaches, microscopic examination and mitochondrial DNA (mtDNA) comparison to analyze hairs collected from crime scenes. The microscopic examination has been accepted as a standard technique for forensic hair comparisons for over 50 years. It has been widely accepted by courts around the world [24], [33], [3]. Forensic scientists use microscopes to observe the microscopic features of hairs, including but not limited to cortex cell pigment, cuticle, scale protrusion and medulla, to perform hair comparisons. They performed extensive comparisons on hairs. Wickenheiser et al. and Gaudette et al. performed respectively.

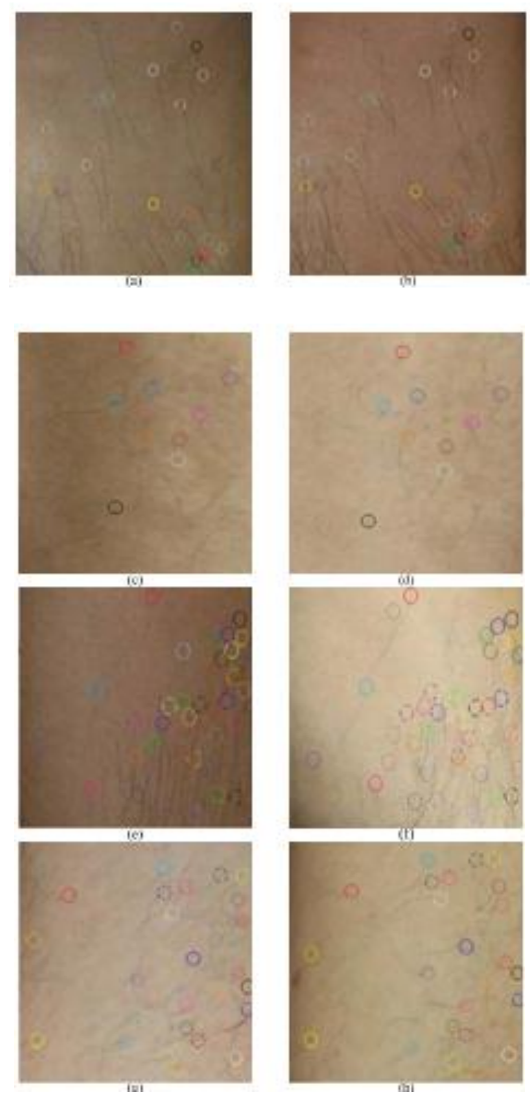

Fig. 1. Skin images from five legs. Each row shows images from the same leg collected at different time periods. The color circles indicate the partial corresponding androgenic hair follicles. (a) Collected in August 200; (b) collected in October 2003; (c) collected in February 2012; (d) collected in April 2012; (e) collected in October 2003; (f) collected in February 2012; (g) collected in May 2010; (h) collected in July 2013; (i) collected in August 200; and (j) collected in February 2012.

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366,630 and 431,35 scalp hair comparisons and found that only less than 10 pairs were indistinguishable [25], [26]. Forensic scientists studied not only scalp hairs but also pubic hairs [27]. mtDNA is an alternative, which is also accepted by courts [15], [16]. In addition to these two standard methods, a nondestructive neutron activation method that measures

Fig. 2. Four legs with different androgenic hair patterns.

seventeen chemical compounds, an image-based method that extracts statistical features from microscopic images and uses pattern recognition techniques to determine whether or not two hairs come from the same person and a macroscopic feature method that measures hair length, distance and area were also proposed [17]–[1]. However, they were examined on very small databases. The nondestructive neutron activation, image-based and macroscopic feature methods were respectively examined on hairs from 15, 20 and 3 subjects. These methods, including the microscopic examination and the mtDNA comparison, were developed for hairs collected from crime scenes. They require direct chemical tests and measurements on hairs. It should be emphasized that forensic scientists study hairs collected from crime scenes, while we study patterns formed by androgenic hairs in low resolution images. In addition to forensic analyses, front head hair images were proposed to enhance face recognition systems [20], [21] and scalp hair images captured by overhead cameras were proposed for surveillance [22]. Note that scalp hair is in fact not androgenic hair and they have different biological properties. Though the medical research results have implied that androgenic hair can be a reliable biometric trait, we have not found any scientific papers that study androgenic hair patterns in images for criminal and victim identification.

The rest of this paper is organized as follows. Section II presents our database. Section III provides the computational details of the proposed algorithm. Section IV reports the experimental results. Section V discusses the impacts of our findings and lists future research directions of using androgenic hair for criminal and victim identification.

III. THE PROPOSED ANDROGE NIC HAIR PATTERN IDENTIFICATION AL GORIT HM

The proposed androgenic hair pattern identification algorithm has three computational components, preprocessing, feature extraction and matching. The schematic diagram of the proposed algorithm is given in Fig. 3. The algorithm takes a color leg image as an input and compares it with templates in a given database. First, the input leg image is segmented and normalized. The segmentation process is to remove all irrelevant information e.g. background. The normalization process is to identify the common region and standardize the image size for matching. Real parts of Gabor filters with different scales and orientations are then applied to the preprocessed image to compute Gabor magnitudes [Fig. 3(c)]. These magnitudes are combined to extract local orientations and form an orientation field [Fig. 3(d)]. It is divided into small regions for computing local orientation histograms as features [Fig. 3(e)]. Each small region is composed of about 300 pixels. Finally, these histograms are matched with those in the database. Section III.A presents the preprocessing scheme and Section III.B presents the feature extraction and matching schemes.

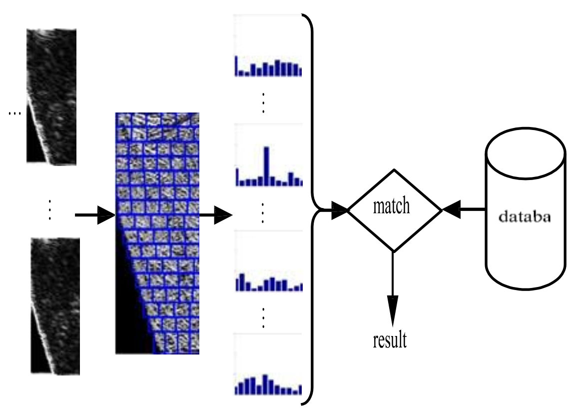

Fig. 3. The schematic diagram of the proposed algorithm. (a) Original image. (b) Normalized image. (c) Gabor magnitude. (d) Orientation field. (e) Histograms.

A. Preprocessing

In forensic analysis, images describing crime-scene speci- men are always captured in uncontrolled and non-cooperative environments. However, images in a given database can be captured in a controlled environment. These images can be captured from inmates in a prison under strict instructions from prison officers. Images describing crime-scene specimen and images in the database can differ in size, resolution and orientation. These differences should be minimized to increase matching performance. Fig. illustrates the pro- posed preprocessing scheme. First, input color leg images are segmented. Currently, a semi-automatic approach3 that is composed of an automatic segmentation scheme and a manual correction process is employed. The automatic scheme uses the skin color and leg boundaries to perform segmentation and is summarized below:

Step 1: An input color image is first converted to a grayscale image for extracting leg boundaries and then is smoothed by a two dimensional median fil- ter. Sobel edge detector is applied to the smoothed grayscale image to obtain an edge image denoted as J . The threshold used in this edge detection is automatically determined for every image.

Step 2: A predefined skin color range is used to detect skin pixels in the input color image. If a pixel color is within the color range, it is retained; otherwise, the pixel value is set to zero. More precisely, if the color difference between the red channel value and the green channel value of a pixel is less than 5 or greater than 30, this pixel is considered as a non-skin pixel. These parameters proposed algorithm. Fig. 20 shows that when the image sizes decrease, the accuracies also decrease. The images with resolutions of 25 and 13.75 dpi provide a similar perfor- mance. The performance drops relatively significant for the images with resolutions of 12.5 and 6.25 dpi. Their rank-one accuracies are still over 71% and 64%, respectively. These experimental results demonstrate that androgenic hair patterns even in low resolution images are an effective biometric trait. This experiment aimed to evaluate the proposed algorithm on androgenic hair patterns from the same race. 52.7%, 32.2% vand 7.4% of the subjects in our database are Chinese, Malays and Indians, respectively. Fig. 21 shows different androgenic hair patterns from the same race and Fig. 22 shows the identification results. More clearly, the gallery and probe sets were all from the same race and the resolution of the images was 25 dpi. These figures show that androgenic hair patterns from the same race are different enough for identification.

The last experiment aimed to evaluate androgenic hair patterns and the proposed algorithm for identification with a large gallery set. The number of images in the probe set was still 575 images from the 233 right legs, but the number of images in the gallery set was increased to 1,111 images from 553 legs of the 233 subjects. Since the left legs of eight subjects have tattoos, they were excluded from this experiment. The left leg images were flipped and therefore, they could be regarded as right legs. The resolution of the images was 25 dpi. To avoid genetic factors influencing the results, the images from the left and right legs of the same person were not allowed to match. Fig. 23 shows the CMCs. Even though the gallery set was increased to 1,111 images, the rank one identification accuracy is still over 72%. It shows the effectiveness of androgenic hair patterns for identification with a large gallery set.

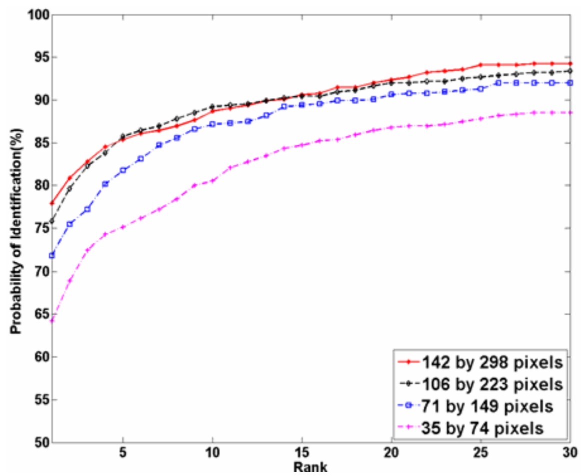

Fig. 20. Cumulative match curves from the proposed algorithm on low resolution images.

V. DISCUSSION AND FUT URE WORK

Identifying criminals and victims in images describing crime-scene specimen is a challenging task, especially when neither faces nor tattoos are observable. Though blood vessel patterns and skin mark patterns have been proposed to address this problem, they demand high resolution images to visualize hidden blood vessels and accurately detect skin marks. This paper first provides a list of medical studies and images to justify that androgenic hair patterns are a stable biometric trait. Though hairs collected in crime scenes are regularly used for forensic analysis, according to our best knowledge, androgenic hair patterns in images were never studied for criminal and victim identification. For matching androgenic hair patterns, we propose an algorithm based on a dynamic grid system and Gabor

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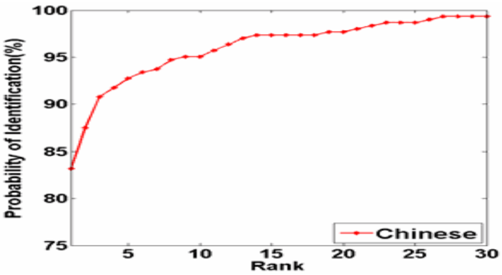
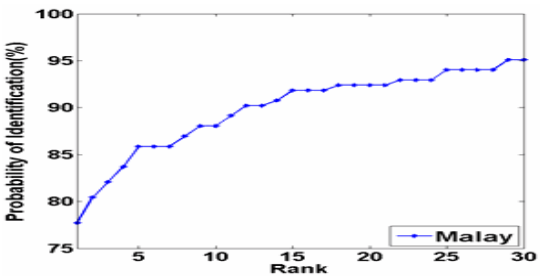
orientation histograms. The experimental results on a database containing 4,552 images from 233 different legs with resolutions of 25, 13.75, 12.5 and 6.25 dpi demonstrate two points: androgenic hair patterns in low resolution images are an effective biometric trait and the proposed Gabor orientation histograms are comparable with other well-known texture recognition methods, including local binary patterns, local Gabor binary patterns and histograms of oriented gradients. This paper exposes a new way to address the challenging criminal and victim identification problem.

In forensic identification, image quality is always a problem. Images of child pornography, masked gunmen and violent protestors are our targets. Child pornographic images often have good quality because pedophiles enjoy high quality images. For cases of masked gunmen and violent protectors, the original images can be taken by reporters, who always use professional DSLR cameras, e.g. Canon EOS 10DX. Sometimes good quality images are obtained. For web images describing crime-scene specimen, no matter what cameras are used to take the original images, one great challenge is low resolution, which is the focus of this paper. Although the resolution of surveillance videos is also very low, the challenges in surveillance images and web images are different. Surveillance cameras are always mounted in high positions. They likely capture head-print, instead of androgenic hair [22]. This paper demonstrates that androgenic hair patterns in low resolution images can be used as a biometric trait for criminal and victim identification. However, low resolution is only one of the problems. For robust identification, new algorithms should be developed for viewpoint and pose variations and occlusions. These algorithms can enhance the performance of the proposed algorithm, which uses the dynamic grid system and the features to absorb all variations and distortions. In addition, an automatic segmentation algorithm should be developed to reduce manpower, even though a semi-automatic approach is not uncommon in forensic analysis. Our database size is comparable with other biometric databases for scientific studies e.g. West Virginia University iris database, but it is small comparing with fingerprint databases in law enforcement agents. We will continue collecting more images for algorithm development and evaluation. Once law enforcement agents use androgenic hair patterns in real applications, numerous images can be collected from inmates and suspects for this research direction. Though low resolution images are the focus of this paper, androgenic hairs and their follicles in high resolution images should also be studied, because in child pornography cases, high resolution and close up images are commonly obtained. In addition to searching a suspect in a given database, how to assign evidential values in the form of a likelihood ratio to androgenic hair patterns is also equally important [61]. More detailed description of forensic biometric applications can be found in [65]. In this paper, a list of medical studies and images are given to justify that androgenic hair is a stable biometric trait. A large-scale study for determining the permanence of androgenic hair is still demanded. Since each hair has its own rhythm and hair shafts fall out at different time, how these issues impact matching accuracy should also be further studied.

Fig. 21. Different androgenic hair patterns from the same race. The first, second and third rows are androgenic hair patterns from Chinese, Malays and Indians, respectively.

In addition to androgenic hair, our research group is studying blood vessel patterns hidden in color images and Relatively Permanent Pigmented or Vascular Skin Marks (RPPVSM) for criminal and victim identification [13], [14], [61]. These features and androgenic hair should be used simultaneously when they are available. We aim finally to develop a powerful system to identify criminals and victims and link different cases based on non-facial skin in images describing crime- scene specimens.





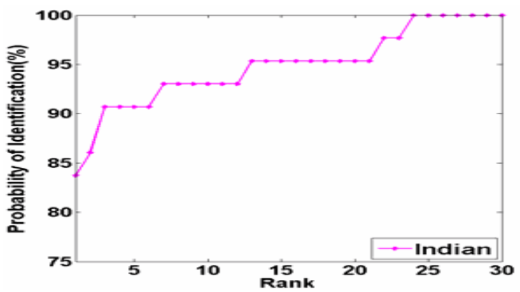


Fig. 22. Cumulative match curves from the same race. (a) Chinese, (b) Malays and (c) Indians.

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