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A Geometric-Based Tattoo Retrieval System

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***Abstract*—Various soft biometric traits have been used as hints in forensic investigation. Tattoo, as one of those soft biometric traits, has been used extensively because it is easy to be remembered and described by witnesses and appears very often among criminals and victims. Most of the tattoo retrieval systems currently used in police departments are still text-based systems. They depend on labels tagged on the tattoo images in databases. This manual labelling process is very time consuming and subject to loss of some detailed information, such as the accurate location and the shape of tattoos. These problems can make tattoo retrieval inefficiently and misleading. To address them, a geometric based tattoo retrieval system is developed. It allows witnesses to draw the boundary of a query tattoo and retrieve all the tattoos with similar shape around the particular location. The system comprises a tattoo detection algorithm, which detects tattoos from full body images, a full body coordinate algorithm, which defines locations of input tattoo boundaries and locations of tattoos in databases and a tattoo shape matching algorithm, which measures similarity between input boundaries and boundaries of tattoos in databases. The experimental results on 2188 images show the effectiveness of the proposed system.**

Keywords—tattoo; sketch; matching; forensics

I. INTRODUCTION

Crime is happening every day and everywhere. Taking Canada as an example, in 2013, there were 48,862 assaults, 23,213 robberies, 3,239 kidnapping and 26,597 sexual violence cases reported [1]. Many countries and international organizations, such as Interpol, have put great effort to fight against crime. Currently, law enforcement agencies in many countries record faces, fingerprints and tattoos of their prisoners to establish suspect databases. These databases are important for forensic investigation because ex-prisoners have higher chance to commit another offense in the first few years of their release [2]. During investigation, police gathers evidences left in crime scenes or from witnesses for identifying and searching criminals or victims. The biometric traits collected from crime scenes or witnesses, such as fingerprints and faces, are matched with the records in the databases to narrow down the suspect list.

Fingerprints have been widely used by law enforcement agencies because of their uniqueness and the development of highly accurate matching methods. In addition to fingerprints, faces are another important biometric trait because they are always captured by CCTV cameras and seen by witnesses. However, using face recognition in forensic environments is not straight forward because of low resolution CCTV cameras, low light environments, viewpoint differences, similarity between different faces and inaccurate descriptions from witnesses. To address these problems, numerous face recognition research has been performed. Some algorithms are designed to match low resolution face images, enhance their resolution, match face sketches with face images and assist witnesses to describe face more precisely. Besides faces and fingerprints, soft biometric traits such as height, body size, age, race, skin color, eye color, hair color, language and tattoo are also used regularly by law enforcement agencies [3]. Occasionally, voice [4] and gait [5] are applied. Among the soft biometric traits, tattoo is more informative and very distinctive in many cases, although it is not unique. It carries rich personal information, e.g., gangster groups and appears on different body sites with different sizes. Fig. 1 shows tattoos with different meanings. They are usually not too small and often have describable contents such as words, symbols, some meaningful patterns with particular shape and objects. Some examples are given in Fig. 2. Therefore, they can be easily observed, remembered and described by witnesses. Because of these characteristics, tattoos have been widely used by law enforcement agencies all around the world.

(a) (b)

Fig. 1 Tattoos with different meanings. (a). symbol of the Latin Kings gang. (b) five dots represents time done in prison, the four dots on the outside represent four walls, with the fifth on the inside representing the prisoner.

(a) (b) (c)

Fig. 2. Tattoo examples with describable contents (a) cross, (b) face of Jesus and (c) sun

Currently, most of the tattoo retrieval systems used in police departments are text based retrieval systems. They rely on labels tagged on tattoo images. These images are generally collected from ex-prisoners or previous suspects. The annotation process is performed manually. This data collection process and annotation process are very time consuming and error-prone. To increase annotation consistence, the U.S. National Institute of

Standard and Technology (NIST) established a standard [6]. In this standard, tattoos are divided into 8 classes and 70 sub-classes and human body is divided into 31 body sites, such as back and chest. Fig. 3 shows tattoos with NIST labels given by NIST [12]. Note that not all police force employs this standard. Some police forces do not use any standard in the annotation. This annotation process has a number of weaknesses because the labels do not describe shapes, locations and size information accurately. Fig. 4 shows tattoos with the same label and color, but different sizes, shapes and locations. Shape, location and size of tattoos can be easily remembered and described by witnesses. Though this information is not distinctive enough for uniquely identifying criminals and victims, it can significantly narrow down suspect lists. To make use of this information, in this paper, a geometric tattoo retrieval system is proposed.

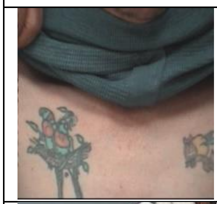
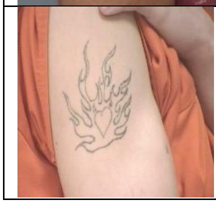
Image	NIST Label (ansi_nist_class|description|color|body_location|rect_coordinates(x,y,width,height)|orientation)
	ANIMAL/BIRD|two parrots|MULTI|TAT CHEST| 5,213,283,279|0 Remarks: MULTI means multiple color
	OTHER/WORDING;HUMAN/FFACE|female face and text with a heart in it||TAT UR ARM| 83,139,350,427|0 Remarks: UR ARM means upper right arm
	OBJECT/FIRE; SYMBOL/MSYMBOLS|Flames; Heart|BLACK|TAT R ARM|92,41,369,384|0

Fig. 3. Tattoo samples with NIST labels. The samples are given by NIST. [12] The NIST style in the labels, including uppercase and lowercase, are retained in this figure.

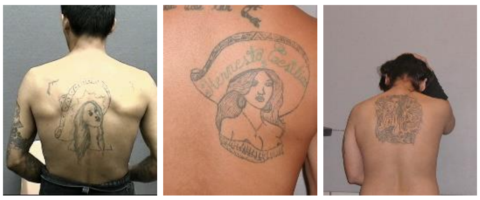


Fig. 4. Tattoos with the same HUMAN/FFACE labels, color and location description, back, but in different locations of the back with different shape and size.

Researchers have proposed several image based tattoo retrieval systems to make use of tattoo images more effectively. Jain et al. [7] proposed a content-based image retrieval (CBIR) system called Tattoo-ID to perform image-to-image tattoo matching. Lee et al. [8] improved the performance of the Tattoo-ID system by using a more robust similarity measure. Manger et al. [9] also proposed a large-scale tattoo retrieval system that can retrieve corresponding images within a matter of seconds searching in a corpus containing more than 300,000 tattoo images. The image based tattoo retrieval systems assume that the query tattoo image is available for matching. However, in many cases, the query tattoo image is not available. To search a tattoo from a database without the query tattoo image, Han and Jain [10] proposed a method to match tattoo sketches and tattoo images. Their method requires witnesses to draw a tattoo sketch on paper as an input. The sketch is scanned and SIFT operator is applied to both the scanned sketch and tattoo images in databases. Their difference is measured based on the SIFT descriptors. However, their method may not be always applicable because it requires witnesses to draw a tattoo with great details. Tattoos can be very complex and witnesses may not remember the details. In addition, it highly depends on their drawing skill. Their method does not consider accurate location and actual size of tattoos during matching. To address these problems, a geometric-based tattoo retrieval system is proposed 1) to provide a simpler matching process relying on limited information from witnesses and 2) to establish tattoo databases with accurate shape and location information for effective retrieval. The proposed system comprises three components, a tattoo detection algorithm, a full body coordinate system algorithm and a tattoo shape matching algorithm. The tattoo detection algorithm detects tattoos in images collected from prisoners or suspects. The full body coordinate system algorithm defines locations of input tattoo boundaries and locations of tattoo boundaries in databases. The tattoo shape matching algorithm measures similarity between input boundaries and tattoo boundaries in databases.

The rest of the paper is organized as follows. Section II presents the system design and the modules. Section III describes the algorithms employed by the system. Section IV reports the experimental results. Finally, Section V concludes the paper and discusses the future work.

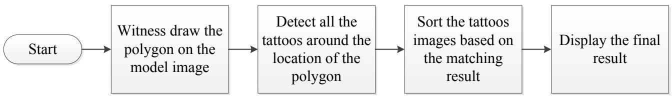


Fig. 5. A schematic diagram of the proposed system.

II. System Design

The geometric-based tattoo retrieval system includes three modules, an input interface, tattoo extraction module and tattoo matching module. It is designed to search tattoos with similar locations, shapes and sizes given by witnesses. Fig. 5 shows a schematic diagram of the proposed system. The system provides an interface to a witness to draw the shape of a tattoo on a human model. The human model is one of the six standard poses that we designed for a full-body imaging system for collecting biometric traits from prisoners [11]. The system detects all the tattoos in a given database near the location provided by the witness. The retrieved tattoo images are sorted based on the shape matching scores from the tattoo boundaries and the boundary drawn by the witness.

The input module manages input from witnesses. It first displays one binary human model to witnesses, which can be selected from six models with six different poses, i.e., front pose, back pose and four side poses [11]. Fig. 6 shows the front pose model and the input interface. Witnesses are required to draw the tattoo shape on the model so that shape, location and size information can be collected. This information can be easily remembered by witnesses and the drawing task is simple without requiring high level drawing skill. Once the witnesses finish the input, the polygon given by witnesses will be used as a query to search tattoos in a given database with similar shape and size and on similar location.

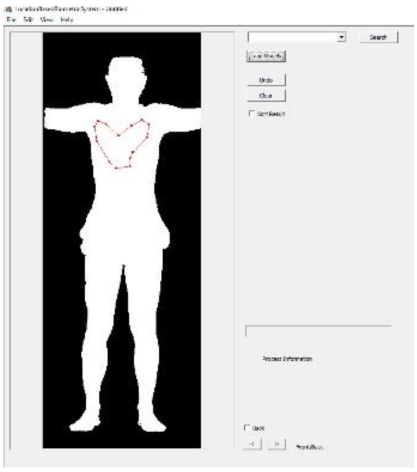


Fig. 6. The interface for the witness to draw the query tattoo boundary.

To use the query tattoo boundaries from witnesses, the system has to detect tattoos in images collected from ex-prisoners or suspects, extract their boundaries and define their locations. In the tattoo extraction module, the images are processed through a tattoo detection procedure that was introduced for the full-body imaging system [11]. Note that it is not necessary to use the full-body imaging system because high resolution cameras are commercially available and their resolution is enough for full body tattoo imaging. During this procedure, the system records boundary and location of each tattoo using the full body coordinate system. If a detected tattoo and a query boundary intersect, the detected tattoo is considered as a potential match. The full body coordinate system is based on the joint point of the human body to define tattoo locations. For each full body image, the system first detects all the joints and three closest joint points to the tattoo are used as reference points. Then the location of the tattoo can be defined through the reference points. More details will be introduced in section III.

After retrieving tattoos around the location given by witnesses, all the tattoos are sorted according to matching scores, which measure the differences between the shape of the tattoo and the shape of the query tattoo boundary. The shape of the tattoo is acquired by a snake algorithm [13]. The coherent point drift (CPD) algorithm [14] is employed to match two shapes and calculate the matching score. The system will return the retrieval result based on the scores.

III. Algorithms Used in the System

This section presents the algorithms used in the proposed system, which include the tattoo detection algorithm, the coordinate system algorithm and the shape matching algorithm.

A. Tattoo Detection

The images employed by this geometric-based tattoo retrieval system are full body color images, which can be collected by the full body imaging system [11] or high resolution cameras. The tattoo detection algorithm reported in [11] is used to detect the tattoos in the images. For the sake of completeness, it is briefly reviewed. For each full-body image, the skin is segmented using a color model. The red channel is extracted from the skin image and processed by the median filter. Then an edge density map is obtained by using a local adaptive threshold operation. The skin area that contains strong edge response is considered as a tattoo candidate area. The tattoo candidates can be real tattoos or the body sites with strong edges, e.g., androgenic hair or nipples. The tattoo candidates are divided into blocks and each block is classified as tattoo and non-tattoo blocks using a decision tree. The decision tree is trained by 20,000 image blocks with size of 50x50 pixels extracted from the training images. The classified tattoo blocks describe the rough shape and location of the tattoos.

B. Coordinate System

One of the key features of the proposed system is to retrieve tattoos around the location indicated by witnesses. To represent the location of the tattoo and the area that witnesses draw on the model, a coordinate system is needed. Though the image coordinates can be used, the retrieved area is not accurate because the position and pose of the subject in each image are different. In order to describe the tattoo location and boundary accurately, a full body coordinate system based on the joint points is proposed. Fig. 7 illustrates the difference between two coordinates systems. Obviously, the area calculated by the full body coordinate system is more accurate compared with the area based on the image coordinates.

(a) (b) (c) (d) (e)

Fig. 7. (a) is an input shape on the model. (b) and (d) show the areas calculated by the image coordinates. (c) and (e) show the areas calculated by the full body coordinate system.

The algorithm determining the full body coordinate system is given below. Let S represent the joint points of the human model, which can be pre-computed by the joint point detection algorithm [11] and B represent the boundary of the area that is drawn by a witness. The distances between each joint point in S and the boundary B are calculated and the three closest joint points are selected. Let C represent the three selected joint points. Mathematically, they are determined by

$$C = argmin_E \sum_{p \in E} \min_{q \in B} \|p - q\| \quad (1)$$

where E is a set with three non-duplicated joint points from S.

For a full-body image from a given database, an adaptive threshold method is first used to generate a binary image. Then the joint detection algorithm is applied to detect all the joint points from the binarized full-body image. Let S' be the joint points of the full body image. Using the locations of C, the corresponding joint points in S' can be determined. Let these joint points in S' be C'.

Two matrixes M_1 and M_2 representing respectively C and C' are constructed and given below.

$$M_1 = \begin{bmatrix} C_x^1 & C_y^1 \\ C_x^2 & C_y^2 \\ C_x^3 & C_y^3 \end{bmatrix}, M_2 = \begin{bmatrix} C_x^{1\prime} & C_y^{1\prime} \\ C_x^{2\prime} & C_y^{2\prime} \\ C_x^{3\prime} & C_y^{3\prime} \end{bmatrix} \quad (2)$$

where (C_x^i, C_y^i) and $(C_x^{i\prime}, C_y^{i\prime})$ are respectively points in C and C' and $i \in \{1,2,3\}$. Using M_1 and M_2, a transform matrix T between C and C' can be calculated as

$$M_1 T = M_2 \quad (3)$$

$$T = (M_1^T M_1)^{-1} M_1^T M_2 \quad (4)$$

Using the matrix T, the boundary B can be mapped to B' in the body image space. More clearly, B' is the corresponding boundary of the query tattoo boundary in the full body image. Let B_M and $B_M{}'$ be two 2 by n matrixes storing the boundary points of B and B', respectively, where n is the number points in B. The mapping is described by the equation,

$$B_M{}' = B_M T \quad (5)$$

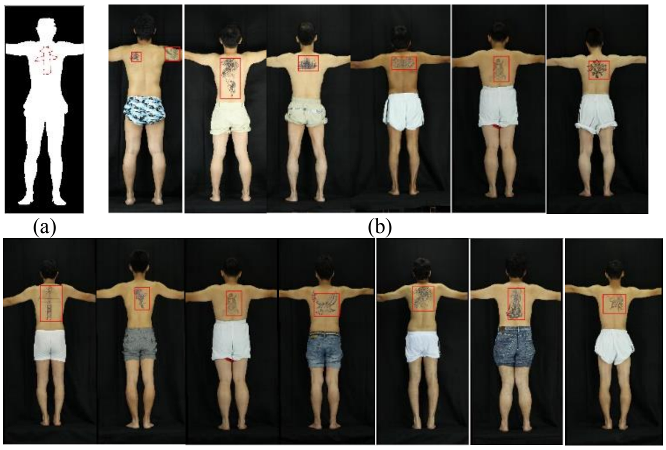
In the proposed system, the joint points are preprocessed and saved in files. During the matching procedure, the system loads the joint points file to reduce processing time.

C. Shape Matching

With the help of the full body coordinate system, the query tattoo boundary drawn by the witness can be mapped to the full body image. This mapped region is compared with tattoo regions denoted by the tattoo detection algorithm. If the two areas have intersection, the tattoo is considered as a potential match. By doing that, it ensures that the tattoos retrieved by the system are around the location given by the witness. Then the system compares shapes of the tattoo candidates with the shape of the query tattoo boundary.

To perform this comparison, the detected tattoo in a full body image is first converted to a binary image using the adaptive threshold method in order to remove the skin from the tattoo. Then, a snake algorithm is applied on the binarized image to find the boundary of the detected tattoo. Let B_t be the boundary extracted by the snake algorithm. Fig. 8 shows some sample images with the boundaries extracted by the snake method. If the area enclosed by one of the boundaries is 4 times larger than another one, the candidate tattoo is considered as an incorrect match. In addition, the aspect ratios of the two boundaries are also calculated. If the difference between the aspect ratios is larger than 0.5, the candidate tattoo is also considered as an incorrect match. After applying these two selection criteria, the rest of the tattoo boundaries are down-ampled and form point sets. Let P_m and P_t be respectively the point sets of the input boundary and tattoo candidate boundary. The coherent point drift algorithm (CPD) [14] is applied to find the rigid transform T_r between P_m and P_t for mapping P_t to P_t'. The Euclidean distance between the corresponding points in P_m and P_t' is calculated and used as the matching score. All the tattoo images detected by the system are sorted in the ascent order based on the matching scores. Fig. 9 shows the retrieved tattoo images without sorting and with sorting.

Fig. 8. Some samples tattoo image with boundaries (red line) extracted by the snake method.



(a) (b) (c)

Fig. 9. (a) the query tattoo boundary. (b) the retrieved tattoos without sorting and (c) the retrieved tattoos after sorting. The images in (b) and (c) are the rank 1-7, from left to right.

IV. Experimental Result

The dataset used to evaluate the system contains 2,188 full body images with tattoos on different parts of the human body. 547 images in the dataset are original full body images and the other 1641 images were generated from the original full body images by flipping and stretching. Some of these images are given in Fig. 9. The images will be shared to other researchers [15]. Note that the dataset has images from six poses [11], including front, back and four side poses. The 547 images in the dataset were considered as the query images and the1641 images were regarded as the suspect images in a given database. Each image in the query set has three corresponding images from the same person. To evaluate the performance of the proposed system, a volunteer was asked to draw 182 tattoo boundaries. In each test, one image was randomly picked from the query image set and shown to the volunteer for 10-20 seconds. Before the volunteer drew the shape of the tattoo on the interface, there was one minute break. The system used the boundary and location information to search the corresponding images. Fig. 6 illustrates the query tattoo boundary inputted by the volunteer. The system searched full body images in the gallery set and recorded the rank of the corresponding image of the query image in the retrieval results. The CMC curve is plotted to report the matching accuracy. The proposed method is compared with Han's method [10], which relies on the textural details on a tattoo sketch. However, in this study, it is assumed that witnesses cannot provide these details, except for location and shape of the tattoos. In this comparison, the query tattoo boundary was used to generate a binary image, which indicates skin and tattoo regions as an input of Han's method. The same approach was applied to gallery images for Han's method. Fig. 10 shows the CMC curves. The proposed method achieves accuracy of 45.24% at the rank 30 and 52.38% at the rank 50, while Han's method achieves accuracy of 21.67% at the rank 30 and 39.44% at the rank 50.

The proposed method outperforms Han's method because: (1) The proposed method uses the location and the shape of the query tattoo boundary to narrow down the searching range. (2) The proposed method matches the boundary of the sketch with the boundary of the tattoos using CPD, while Han's method depends on textural details in the sketch so that SIFT descriptors can be used for matching. Once witnesses cannot provide the textural details, Han's method cannot perform well.

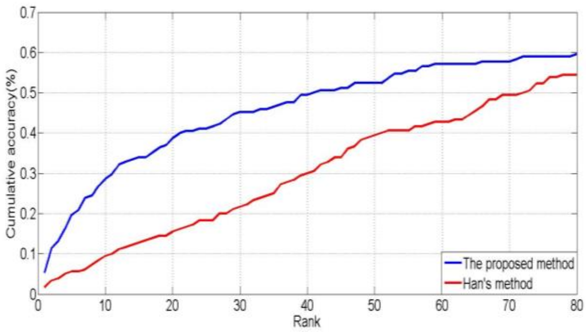


Fig. 10. Matching performance of the proposed method comparing to Han's method.

During the experiment, it was found that the quality of the sketch affects the performance of the matching. To evaluate how the sketch quality influences the matching performance, another experiment was conducted. In this experiment, the volunteer drew the sketch when the tattoo images are displayed. Thus, he does not need to remember them. The matching was performed on the new boundaries, which are denoted as high quality input sketches in Fig. 11. The sketches from the previous experiment are denoted as low quality input sketches in Fig. 11. Fig. 11 shows that the quality of the sketches is critical for the matching performance.

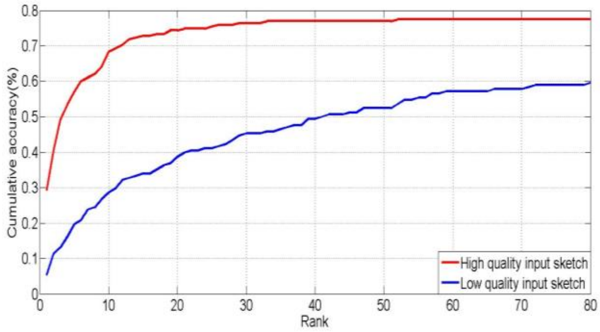


Fig. 11. Comparison of the matching performance of the proposed method with guide image and without guide image

This result proves that the performance of the matching depends on the quality of the witness's sketch. This means if the witness can sketch as closely as the boundary of the query tattoo, the system has higher chance to retrieve the correct suspect image. However, as we mentioned in the introduction section, it is quite challenging for the witness to provide such an accurate description of the tattoo image on the suspect body. In most cases, the witness can only provide a rough boundary and the location of the tattoo. Our proposed system is proved to be able to achieve a promising matching rate in such situation.

V. Conclusion

To collect tattoo shape and location information automatically and accurately as well as to increase overall retrieval accuracy, a geometric based tattoo retrieval system is developed. A full body coordinate system is proposed to calculate the location of the tattoo area and a tattoo shape matching algorithm is proposed to sort the retrieval results. The system does not require witnesses to sketch the tattoo details. It only uses shape and location information. Combining with our previous full body imaging system or using a high resolution camera to take full body images, the system can automatically collect and locate tattoos and also record their shapes. It can significantly reduce workload of law enforcement officers, who perform these tasks manually. In addition to saving manpower, the proposed system collects more accurate location and shape information of tattoos. This information is not accurately described by the NIST labels. In real operations, the manual labels and the proposed system should be used together because they collect different information from witnesses.

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