Forensic Science International 245 (2014) 162–170

Contents lists available at ScienceDirect

Forensic Science International

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

A novel approach for latent print identification using accurate overlays to prioritize reference prints

Daniel T. Gantz [a], Donald T. Gantz [b], Mark A. Walch [a], Maria Antonia Roberts [c], JoAnn Buscaglia [d,*]

[a] The Gannon Technologies Group, 2303 Dulles Station Blvd., Suite 105, Herndon, VA, USA
[b] Department of Applied Information Technology, Volgenau School of Engineering, George Mason University, 4400 University Drive, Fairfax, VA 22030, USA
[c] Latent Print Support Unit, Federal Bureau of Investigation Laboratory Division, 2501 Investigation Parkway, Quantico, VA 22135, USA
[d] Counterterrorism and Forensic Science Research Unit, Federal Bureau of Investigation Laboratory Division, 2501 Investigation Parkway, Quantico, VA 22135, USA

ARTICLE INFO

Article history:
Received 11 July 2014
Received in revised form 14 October 2014
Accepted 15 October 2014
Available online 24 October 2014

Keywords:
Fingerprint
Latent print
Mark
Ridge flow

ABSTRACT

A novel approach to automated fingerprint matching and scoring that produces accurate locally and nonlinearly adjusted overlays of a latent print onto each reference print in a corpus is described. The technology, which addresses challenges inherent to latent prints, provides the latent print examiner with a prioritized ranking of candidate reference prints based on the overlays of the latent onto each candidate print. In addition to supporting current latent print comparison practices, this approach can make it possible to return a greater number of AFIS candidate prints because the ranked overlays provide a substantial starting point for latent-to-reference print comparison.

To provide the image information required to create an accurate overlay of a latent print onto a reference print, "Ridge-Specific Markers" (RSMs), which correspond to short continuous segments of a ridge or furrow, are introduced. RSMs are reliably associated with any specific local section of a ridge or a furrow using the geometric information available from the image. Latent prints are commonly fragmentary, with reduced clarity and limited minutiae (i.e., ridge endings and bifurcations). Even in the absence of traditional minutiae, latent prints contain very important information in their ridges that permit automated matching using RSMs. No print orientation or information beyond the RSMs is required to generate the overlays.

This automated process is applied to the 88 good quality latent prints in the NIST Special Database (SD) 27. Nonlinear overlays of each latent were produced onto all of the 88 reference prints in the NIST SD27. With fully automated processing, the true mate reference prints were ranked in the first candidate position for 80.7% of the latents tested, and 89.8% of the true mate reference prints ranked in the top ten positions. After manual post-processing of those latents for which the true mate reference print was not ranked first, these frequencies increased to 90.9% (1st rank) and 96.6% (top ten), respectively. Because the computational process is highly parallelizable, it is feasible for this method to work with a reference corpus of several thousand prints.

Published by Elsevier Ireland Ltd.

1. Introduction

Latent prints[1] are impressions made by friction ridges found on hands and feet, typically from an unknown source. Although latent prints can be visible to the unaided eye, they are usually made visible by the use of alternate light sources, chemicals, or powders. Detected latent prints are not always considered to be of value for identification purposes when analyzed by a latent print examiner, and can be so small that the proper orientation cannot be easily determined. Due to their fragmentary nature, latent prints often lack a core (center of pattern) or traditional minutiae such as ending ridges, bifurcations, and dots, which are used for automated and manual searching purposes. Latent prints containing a field of ridges without minutiae have been reported to be difficult to characterize and identify [1]. However, even in the absence of traditional minutiae, latent prints contain very important information in their ridges that permit the automated matching [2].

* Corresponding author. Tel.: +1 703 632 4553; fax: +1 703 632 7801.
E-mail addresses: dgantz@gannontech.com (D.T. Gantz), dgantz@gmu.edu (D.T. Gantz), mwalch@gannontech.com (M.A. Walch), maria.roberts@ic.fbi.gov (M.A. Roberts), joann.buscaglia@ic.fbi.gov (J. Buscaglia).

[1] The term "latent print" is the preferred term in North America for a friction ridge impression from an unknown source, and "print" is used generically for known or unknown impressions. We are using the North American terminology to maintain consistency with past and future papers by the authors, rather than the international preferred terminology of "mark" or "trace" for unknown impressions and "print" for known impressions.

http://dx.doi.org/10.1016/j.forsciint.2014.10.026
0379-0738/Published by Elsevier Ireland Ltd.

If it is determined that the latent print and the reference print are "mated" (i.e., impressions from the same finger) and a match is determined, then in some sense the latent image can be overlaid onto the reference image. Even when the prints are mated, a rigid placement of the latent onto the reference image will exhibit some distortion between the two images due to the physical circumstances of the creation of each impression. Every impression will be distorted somewhat due to several factors (e.g., skin elasticity, substrate and pressure). The automated technology developed in this research adjusts for the distortion between the latent print and reference print impressions, providing a very accurate overlay of the print images. Specifically, the latent image is locally adjusted so that the overlay of the adjusted image to the reference image is a good fit. This fully automated technology reliably finds an optimal distortion adjusted overlay of the latent image onto any matching or nonmatching reference image. This automated technology, which has been incorporated into a latent print examiner workstation, will improve the efficiency of the latent print comparison workflow process by providing the examiner with an accurate overlay of the latent print to each reference print, thereby reducing the number of comparisons performed by the examiners. Further, a computational algorithm exploits the overlay technology to quantify similarity between the latent and reference images, and is used to rank the reference images according to their similarity to the latent.

2. Method development

The methods described in this section are novel approaches developed in this research. In order to demonstrate their feasibility, we have tested the developed methods using images taken from the NIST Special Database 27 [3]; details of the feasibility testing are presented in Section 3.

There are four parts to executing these novel technological and computational methods. The first part is the automated processing of the latent image and the reference images to determine the regions of the images with clearly defined ridge flow. The second part is the automated creation of an accurate warp of a latent image to either the mated or a nonmated reference image. The third part is the quantification of the accuracy of a warp and the selection of the overlay (i.e., "best" warp) between the latent print image and each reference image. The fourth part is the prioritization of the reference images according to the latent image overlays.

2.1. Automated processing of the latent image and the reference images

All print images are subjected to a sequence of automated processing steps. Processing steps include the binarization and skeletonization of the images, and the marking of quality regions in the images. Quality regions of a print are defined and high-contrast print images are created. First, the print image is rendered as a high-contrast image that captures ridge flow (with black ridges and white furrows) and masks out areas where reliable quality ridge flow is not present. This initial rendering process is common among many fingerprint matching technologies and a number of rendering utilities are available to perform this task [4]. In this paper, a proprietary algorithm that enhances the contrast of ridge flow based on phase measurements of bands of light and dark patterns while masking out areas lacking any dominant ridge flow is used.

Fig. 2 shows the automated progression from a sample reference image (a1) to a high-contrast representation of the image (a2) and to a "quality mask" (a3) that selects the regions with reliable quality ridge flow. The same fully automated process is performed for the latent as shown in Fig. 2 b1–b3.

Latent prints pose a variety of clarity issues, differing significantly from that of reference prints. Therefore, the quality results of automated processing will vary depending on the attributes of the latent, including complex backgrounds, overlapping prints, image clarity and other artifacts. Fig. 2 shows the automated processing of a latent from the image (c1) to the high-contrast image with the quality mask (c2) and a manual refinement (i.e., ridge tracing) (c3) of the original image (c1). An examiner can manually refine the clarity of the high-contrast image portion of the automated process when the result of that process is not adequate [5].

2.2. Automated creation of an accurate warp of a latent image to any reference image

Creating an overlay requires adjusting the continuum of ridges and furrows of the latent image to accurately fit the ridges and furrows within a region of the reference image. The latent image and each of the reference images are further processed: first, using the high-contrast images created previously, all ridges and furrows within the latent and the reference images are thinned to one-pixel wide skeletons based on center lines (Fig. 3). In this paper, a skeleton refers to the totality of the ridges and furrows. Next, continuous marking of the ridges and furrows is accomplished by covering all ridge and furrow skeletons with small curve segments. A short polynomial curve segment will accurately provide an approximate cover to a local small segment of a ridge or furrow skeleton. Computer graphics frequently makes use of Bezier curves for such local approximation, and we have selected cubic and higher order Bezier curves to approximate small segments of ridge and furrow skeletons. A cubic Bezier curve is defined by two end points and two interior control points; the curve can be altered by manipulating these four control points (Fig. 1). Higher order Bezier curves, which have more control points, are used as required to fit more complex curvature on the skeleton.

Bezier curves offer a way of describing ridges that is both compact and accurate. The four Bezier control points concisely represent the entire set of Cartesian plot points that would otherwise be explicitly necessary for curve representation. In this paper, a new Bezier curve segment of 70 pixels in length is started every 22 pixels along a skeleton for a latent image and every 3 pixels along a skeleton for a reference image (note that the difference in lengths is to provide finer coverage in the reference collection). The selection of curve segment length and location is based on all images being scaled to 500 pixels per inch (ppi); these parameters are configurable. This process provides a set of short Bezier curves that redundantly approximate ridge and furrow skeletons. Collectively, the short Bezier curves form a basis for tracking the continuum of the ridge and furrow skeletons; each Bezier curve marks a short continuous segment of a ridge or furrow and serves as a "Ridge-Specific Marker" (RSM). RSMs are reliably associated with any specific local section of a ridge or a furrow using the geometric information available from the image, making an RSM a new feature in the image [6,7]. Bezier curves are produced "through" skeleton intersections as well, such that all possible Bezier curves of the given length and step increment

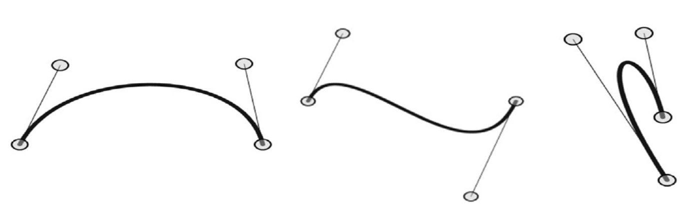

Fig. 1. Examples of cubic Bezier curves with two end and two interior control points. The curve can be altered by manipulating these four control points.