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Short Communications

Ridge patterns of blood-transferred simulated fingerprints observed on fabrics via steam thermography

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ABSTRACT

Steam thermography is used to image ridge patterns of blood-transferred artificial fingerprints on acrylic, polyester and cotton fabrics. Microscale thermal imaging confirms that the ridge patter transfer occurs on the tops of the most prominent threads in weave. Prints are readily imaged on the more hydrophobic fabrics in both heat-up and cool-down phases of vapor exposure. On the more hydrophilic cotton fabric, ridge detail is obscured by the strong background response of the fabric to moisture. Microscale thermography reveals that loose cotton strands with transferred blood may respond differentially to moisture relative to uncoated strands.

1. Introduction

Several reports in the literature describe efforts to detect fingerprints and bloodstains on various surfaces via visible light fluorescence or infrared reflectance [1–6]. This laboratory recently demonstrated a new method for thermographic imaging of dried bloodstains on hydrophobic synthetic fabrics exposed to steam or water vapor [7]. The thermal contrast observed is derived mostly from differential adsorption of water with its associated enthalpy of adsorption, but there are numerous unknowns about the method. Questions arising from Ref. [7] that remain unanswered include whether fine detail could be preserved despite wicking of the stain into the fabric, whether the necessary adsorption of water would obscure any fine detail that might be preserved, and whether the method could be extended to hydrophilic fabrics such as cotton.

To address these questions, we utilized a new infrared camera with higher spatial and temporal resolution than the camera used in Ref. [7], and simulated fingerprints with ridge patterns transferred in rat blood. The present report describes these experiments and provides definite answers to the first two of these questions, and insight into the third. Even in conditions where the fingerprints wick into a synthetic fabric, the ridge patterns remain visible in both the initial exposure to steam and repeated exposures, in the heat-up and in the cool-down phases of the experiment. Further, it appears that high-speed micro-imaging may offer a method for suppressing the strong background fabric response observed in cotton by visualizing individual cotton fibers at the surface where ridge patterns may be preserved.

2. Materials and methods

2.1. Simulated fingerprint stamp

A custom rubber stamp (Smith Rubber Stamps & Seals, Columbia, SC) was made with which to transfer simulated ridge patterns to any surface of our choice, using any transfer medium compatible with the stamp materials. The stamp was designed by adapting artificial fingerprint artwork (Fig. 1) that was purchased from shutterstock.com (Image ID: 180872426). The final stamp is 51 × 33 mm in size, which is approximately 50% larger than a natural fingerprint; the size was chosen as the minimum that allowed the rubber stamp to be commercially fabricated with preserved ridge detail. To form the transfer prints on fabrics, a layer of rat blood thinner than the depth of the stamp ridges was formed on a glass dish. The stamp was then wetted with the rat blood, and pressed once onto the surface of three different fabrics, re-wetting between applications. Two transfer prints were placed on the surface of each fabric, one made with undiluted rat blood, and the other made with rat blood diluted 1:10 with water (Fig. 2). At the time of these experiments the prints had dried and aged in air for approximately eight months.

The visible light images of the transfer prints (Fig. 2) show that on the right edge of each transfer print, the blood did not maintain the ridge structure after it was stamped. The fused ridges were produced while transferring the blood to the fabric using the stamp, and are not a defect of the stamp itself, nor an artifact of steam thermography.

2.2. Fabrics

The acrylic used was a commercially obtained undyed directional plain weave fabric. It was triple-dyed to a purple color at North Carolina State University (NCSU, Raleigh NC) with Astrazon Golden Yellow GL-E, Astrazon Red Violet 3RN, and Astrazon Blue FBL, in 2004. Data for this same fabric type was reported in Refs. [7–14]. The areal density of this fabric has been reported as 0.0296 g/cm^2, with a specific

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Fig. 1. Left: Artificial fingerprint artwork. This pattern was used to create a rubber stamp as described as in the text. Right: The custom rubber stamp used to create the transfer prints.

surface area of 0.272 ± 0.007 m^2/g (see Supplemental Information for Ref. [11]). This fabric is warp-faced, meaning that it is the warp threads that form the most prominent features on the face of the fabric.

The polyester used was a commercially obtained undyed uniform plain weave fabric, triple-dyed to a brown color at NCSU with Dianix Red E-FB, Dianix Violet S-4R, and Dianix Yellow S-6G, in 2004. Data for this same fabric type was reported in Refs. [10–14]. The areal density of this fabric has been reported as 0.0121 g/cm^2, with a specific surface area of 0.057 ± 0.014 m^2/g (see Supplemental Information for Ref. [11]). Because this fabric is a uniform plain weave, the face of the fabric is composed equal of both the warp and the weft threads.

The cotton fabric used was a commercially obtained undyed 2/1 twill weave fabric, triple-dyed to a red color at NCSU with Remazol Orange 3G-A, Remazol BR Red 3BS, and Remazol Brilliant Violet 5R, in 2004. Data for this same fabric type was reported in Refs. [11–15]. The areal density of this fabric has been reported as 0.0257 g/cm^2, with a specific surface area of 0.940 ± 0.002 m^2/g (see Supplemental Information for Ref. [11]). Because this fabric is a twill, it has two distinct faces. One of the faces has warp threads that are the most prominent, while the other is dominated by weft threads. In both cases, however, the two types of threads contribute to the exposed surface. The transfer print was placed onto the warp-dominant side of the fabric.

2.3. Imaging

The samples were thermographically imaged in two ways: imaging an entire print at once using a 50 mm lens, and imaging a single ridge magnified by a 13 mm lens placed backwards from the standard configuration to act as an extreme macro-type lens for microscopic imaging. Both data sets were acquired using a FLIR Systems A6751sc SLS thermal imaging camera, using the settings in Table S1. The camera was operated using FLIR Systems ResearchIR software.

Steam was generated as described previously using a hand-held garment steamer [7]. Recordings began prior to the exposure of a fabric to moisture. Steam was directed toward the fabric from a distance of about 1 foot for approximately 3 s, and then the source was removed to allow the adsorbed moisture to evaporate back to near equilibrium. This process was repeated until the end of each recording. Each recording thus begins with the fabric at equilibrium followed by moderately rapid cycles (periods in the range of ~10 s) of adsorption and desorption.

3. Results and discussion

Steam thermography images of the undiluted ridge patterns on acrylic, polyester, and cotton are shown in Fig. 3A–F. The images in the figure are extracted from individual frames taken from 30 s recordings at 30 frames per second. Fig. 3A–C were recorded during a 3 s exposure to water vapor, while frames 3D–3F were recorded approximately 2 s after the end of the water vapor exposure during the evaporative cool-down cycle. The whole blood patterns on acrylic and polyester "leap out" for the observer immediately on exposure to steam with enough contrast to easily distinguish individual ridges in the transfer print on both fabrics. Prints on cotton however, are not readily observable. Patterns made with blood diluted ten-fold with water (see Supplemental Information) were also easily visualized on acrylic and polyester, but not on cotton, with the caveat that on polyester these lower-concentration prints showed a "halo" similar to that reported previously [7]. Despite this effect, the ridge pattern remains clear on two of the three fabrics. We attribute the halo effect observed on polyester to separation of components of the blood when the diluted solution wicks into the fabric. If this is the correct interpretation, at least some blood components that are important to steam thermography observation must remain at the site of initial deposition and resist transport.

A novel observation with the new thermal imaging camera used for this study was made possible by micro-thermographic imaging. The images of Fig. 3 are suitable to show that any preserved ridge-level detail on a fabric is retained in steam thermography. However, the microstructure of the ridge patterns on fabrics is not readily observable in Fig. 3 for any of the fabrics. By reversing a lens and using the camera in a close-up mode, we were able to produce images showing an area on the fabric that is approximately 3 mm across with enough spatial resolution to easily observe fibers and features smaller than 200 μm in diameter. Fig. 4 shows these magnified images aligned to match the orientation of the same regions in Figs. 2 and 3. Small boxes drawn in Figs. 2 and 3 for reference show where the magnified images in Fig. 4 were acquired. A higher frame rate of 120 frames per second enabled improved temporal resolution at the same time.

Fig. 4 shows detail of print ridges on acrylic, polyester and cotton. One problem that is observed in steam thermography is the difficulty of producing an even exposure to moisture. Micro-scale steam thermography, as shown in Fig. 4, effectively eliminates this problem because the spatial distribution of steam/vapor is uniform on a very small spatial scale.

On acrylic, the print ridge is readily observable on exposure to steam. Literature studies of transfer prints show that the transfer

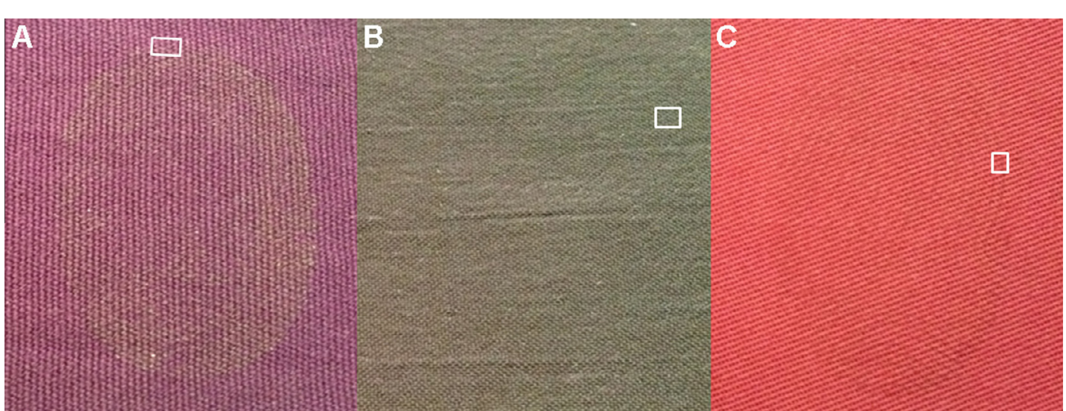

Fig. 2. Visible light images of the whole blood transfer prints on three fabrics. (A) Acrylic. (B) Polyester. (C) Cotton. Each fabric has two transfer prints, one in whole blood, and the other in ten-fold diluted blood (not shown) as described in the text. White boxes indicate the location of each fabric imaged by microthermography, as shown in Fig. 4.