

Enhanced Tattoo Image Quality Assessment Through Multispectral Sensing

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Abstract—The impact of using tattoo images in biometrics and forensics-related applications for human identification or in the case of ruling out suspects, has been significantly increased in recent years. The NIST Tatt-C and Tatt-E biometric tattoo challenges have focused on pushing forward tattoo related research in terms of human identification, detection, localization, and sketch-matching. However, current tattoo research has been limited to the use of the visible wavelengths (380-750nm) when imaging tattoo skin regions. Variations in skin pigments, ink colors, and ink types make the imaging of tattoos inherently challenging when operating in a conventional band only. For example, enhanced imaging techniques are needed to improve the contrast between skin and tattoo regions in individuals with darker skin pigment, or in instances where the ink color is close to the skin pigment. In this work, we propose the use of various wavelengths within the short-wave infrared (SWIR) spectrum that provide enhanced tattoo imaging and as a result, an enhanced human identification capability. First, we performed a data collection process that resulted in the generation of a large scale database of visible and SWIR tattoo images for 133 subjects (Session 1) with 80 subjects coming back for a second round of data collection (Session 2). Furthermore, we conducted an empirical study using various skin pigments (determined via known ethnic group meta data) and when image quality varies within and across different SWIR wavelengths. Experimental results indicate that specific SWIR wavelengths, namely the range between of 1100nm to 1300nm, show superior tattoo image quality in the majority of the ethnic groups studied, except one (i.e. Asian group). To the best of our knowledge, this study is the first attempt to bring forward the benefits of tattoo imaging outside the visible band for the purpose of human identification.

Index Terms—Short-wave Infrared, tattoo imaging, biometrics, image quality, law enforcement.

I. INTRODUCTION

THE potential benefit of tattoo based biometric systems to law enforcement and homeland security applications has led to an increased interest in the development of advanced tattoo based human identification technologies [1]. The recent NIST Tatt-E [2] and Tatt-C [3] challenges focused on the development of more efficient algorithms for the purposes of tattoo-based human recognition (including matching tattoo to tattoo or matching of tattoo images to sketches generated by an forensics expert [4]), detection or localization, and grouping of similar tattoo types based on content. One of the main outcomes of the studies conducted in Tatt-C list the largest recommendation for future work as to improve tattoo image

capturing techniques, including better sensing capabilities [3]. Other outcomes of the studies discuss that the following factors, including variability in image angle, orientation, size of tattoo relative to the image, low illumination, low contrast, and background interference as major contributors to failures in tattoo detection and matching algorithms. In this work, we discuss mitigation strategies to improve the aforementioned issues that degrade the quality of tattoo image sensing and, as a result, tattoo based recognition performance by exploiting multispectral sensing capabilities that go outside the visible band.

Despite their added benefits, the dynamic nature of tattoos make them exceptionally hard to image properly with consistent quality that is acceptable for further processing, including tattoo-based matching [5]. Since tattoos are not a naturally occurring biometric trait, often added for aesthetic, or other personal reasons, they can be found on nearly any area on the human skin and vary significantly in terms of size, pose, and complexity (ranging from a single flower to nearly whole body tattoo with various objects overlapping). This presents a particular challenge in performing basic operations, such as segmentation or registration [6], where no common reference points can be found for alignment. This is often further complicated by the numerous ink types and pigments used when combined with variations in human skin pigments of different ethnic groups, and changes in imaging sensors or lighting conditions. Thus, a novel way of imaging and processing tattoo images would benefit the academic as well as the law enforcement community. In this paper, we proposed the usage of various wavelengths of the short wave infrared band, known to offer unique properties when imaging skin for medical applications [7]. We demonstrate that multi-wavelength SWIR imaging captures good quality tattoo images that can be used, more efficiently, in forensic or biometric based applications.

The use of different infrared (Short-wave, Middle-wave, and Long-wave) bands in surveillance and biometric technologies has shown to be very beneficial in past research. Imaging in these wavelengths is often able to create enhanced and diverse image representations of various biometric traits that was simply not possible when only operating in the visible band. In this work, we explore the added benefits of tattoo imaging when operating in a set of SWIR wavelengths ranging from 1100-1500nm, and verify our hypothesis via a set of image quality (IQ) based evaluation algorithms. Our contributions to this work are as follow:

- 1) The collection of a multispectral tattoo dataset (MTB) containing images collected in the visible band, and SWIR wavelengths of 1100nm, 1200nm, 1300nm,

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1400nm, and 1500nm for 133 subjects with 81 subjects repeating for a second session. The MTB is private but can be available upon request.

- 2) Determined the effect of SWIR, wavelength-specific imaging, on tattoo image quality, before after our MTB was grouped in terms of skin pigmentation (via ethnic group metadata).
- 3) Studied the effect of wavelength-specific tattoo imaging on tattoo recognition performance and determined, by a set of same spectral tattoo matching experiments, which wavelength results in the highest rank-1 identification rate.

A. Literature Review

Many algorithms have been proposed for tattoo identification, detection, and registration in the visible band. The most recent tattoo identification efforts involve the use of deep learning proposed in Tatt-C [8]. In that work, Di et al. proposed the use of the AlexNet and a custom architecture to extract deep features from tattoo images. The deep features are then used in conjunction with a SVM classifier to perform tattoo detection, while another architecture is used to extract deep features that can be used for matching by using the Euclidean distance between feature vectors. In one of their recent works, Hrka et al. [9] use deep learning for the purpose of tattoo detection and localization in a sliding window approach using convolutional neural networks (CNNs).

A recent work by Xu et al. [6] the authors used tattoo registration to improve image quality and the ability to better compare two tattoo images. This method used the Universal Image Quality Index (UIQI) to compare the image quality between a query and a reference tattoo image. In the cases where tattoo registration failed, the system uses a color channel enhancement algorithm to further improve registration before matching using tattoo images is then more efficiently performed.

In the open literature we see only visible band tattoo image related algorithms. However, the use of various wavelengths including the ultraviolet band (10-400nm), visible band (400-700nm), near infrared band (750-1100nm), short-wave infrared band (900-1900nm), middle-wave infrared band (5-8 μ m) and long-wave infrared (8-14 μ m) have been used across many biometric applications and traits. Operating in various wavelengths have often shown to provide complementary or finer details for many biometric modalities, including face and iris. Furthermore, various wavelengths near the SWIR wavelengths have shown to be particularly advantageous for its properties in surveillance for law enforcement and skin imaging for biomedical applications. While these techniques have not been studied before in the use of skin, or markings on the skin (i.e. scars, marks, and tattoos [10]) in biometric applications, they have shown promise in the detection of finer features in medical applications [11] and need further investigation.

II. METHODOLOGY AND RESULTS

Following the description of our contributions above, we will discuss the tattoo database collection process, and the

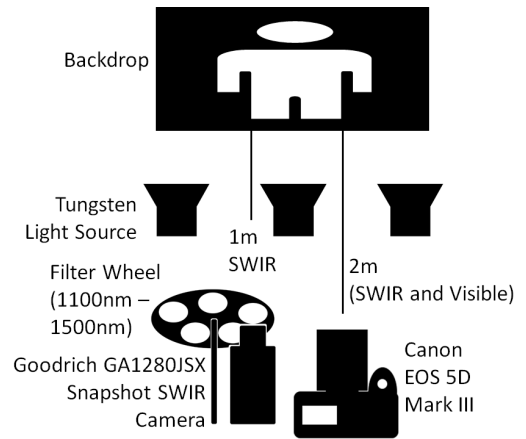


Figure 1. **Multi-Spectral Tattoo Collection Setup** - The collection setup used SWIR tattoo images, collected at 1m and 2m distance with filters ranging from 1100nm-1500nm and visible tattoo images collected at 2m distance.

algorithms developed and tested to assess tattoo image quality and determine the most advantageous wavelength, which results in the highest rank-1 identification rate.

A. Multispectral Tattoo Image Data Collection

The goal of the collection process performed was to gain a better understanding of the tattoo image sensing and quality in varying wavelengths. It was observed through a pilot study that when tattoos are created through different processes (i.e. varying ink types, professional vs. amateur, color vs. black and white, etc.), they often appear visually different at specific wavelengths to their visible counterparts, and should be examined for suitability in inter-spectral biometric studies.

In this work, a data collection study was conducted by the WVU Multispectral Imagery Laboratory for the creation of a multispectral tattoo dataset that can be used for the development and testing of enhanced tattoo related imaging technologies. The collection consists of a set of visible and SWIR tattoo images (collected at specific wavelengths focused at 1100nm, 1200nm, 1300nm, 1400nm, and 1500nm). The collection spans across two sessions that are at least one month apart. We collected data for a total of 133 subjects for the first session with 81 subjects of returning for a second session. Of these 81 subjects, one subject mistakenly had separate tattoos collected for each session and, therefore, could not be used for any multisession experiments.

A detailed description of the lighting and camera setup is shown in Figure 1. The visible tattoo images were collected at a standoff distance of 2m (from the camera to the subject's tattoo). A Canon 5D Mark III camera was used to capture visible band images and equipped with Canon EF 70-200mm f/2.8L IS II USM lens. The lens was manually zoomed and focused to fit the tattoo and a set of 10 images were captured per session. The SWIR images were captured at a distance of 1m and 2m (due to the different lens capability of the IR imaging sensor) using the Goodrich 1280JSX (formerly the 640KTSX) equipped with the String Optics Fuchsia SR1499-

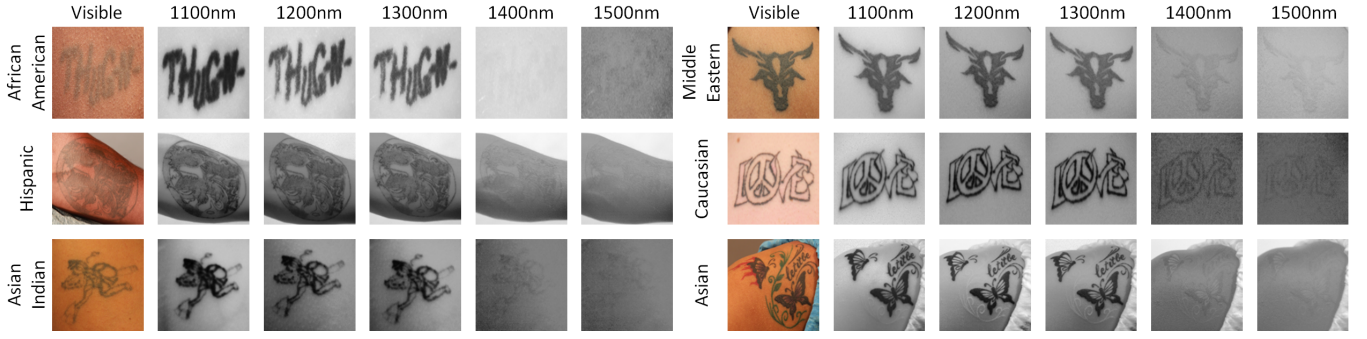


Figure 2. **Tattoo Images of Various Ethnic Groups** - The large range of skin pigments of various ethnic groups can reduce contrast between skin and tattoo regions in the visible band. However, the SWIR band shows invariance to these contrast changes caused by various skin pigments of many ethnic groups. This is most evident in the darker skin pigments of the African American, Hispanic, and Asian Indian ethnic groups studied.

Table I
WAVELENGTH IMAGE QUALITY FACTOR ASSESSMENT

Quality Factors	Wavelength					
	Visible	1100nm	1200nm	1300nm	1400nm	1500nm
C_{RMS}	10.2590	10.9716	10.3024	10.3640	8.6494	8.5468
C_{Mic}	0.9549	0.9850	0.9895	0.9759	0.7128	0.6632
C_{Global}	4.5683	6.2026	5.5246	5.3848	3.4227	3.1882

A01. A filter system was also used for this study, similar to the one used in previous SWIR face verification and identification studies [12]. A set of five band pass filters were used, centered at the wavelengths of 1100nm, 1200nm, 1300nm, 1400nm, and 1500nm with a band pass of 50nm. Each SWIR image was captured by rotating the filter wheel to a specific wavelength and capturing a new image. This process was repeated for all SWIR wavelengths. To form the SWIR-based wavelength specific tattoo image sets used for analysis, the 1m SWIR tattoo image and the zoomed-to-fit visible tattoo images were selected. In the instances where the 1m field of view in the SWIR tattoo image was not large enough to capture the entire tattoo, the image collected at the 2m distance was used instead. The images were then manually cropped to fit the tattoo and remove background information.

B. Image Quality Assessment Empirical Studies

To assess how the contrast between the skin and tattoo regions, we have considered three non-referenced based IQ assessment methods. Although more advanced referenced based techniques may provide better detail on image quality, they are biased from the reference image and, thus, cannot provide a fair comparison. Firstly, the Root Mean Square (RMS) contrast is defined as:

$$C_{RMS} = \sqrt{\frac{\sum_{m=1}^M \sum_{n=1}^N [I(m,n) - \mu]^2}{MN}} \quad (1)$$

where M is the height of the image, N is the width of the image, $I(m,n)$ is the image intensity at position m and n , and μ is the mean intensity of the image. Secondly, the Michelson contrast, proposed in [13], was used and is defined as:

$$C_{Mic} = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \quad (2)$$

Table II
ETHNIC GROUP IMAGE QUALITY ASSESSMENT

Wavelength	Ethnic Group					
	Hispanic	African American	Middle Eastern	Asian Indian	Asian	Caucasian
Visible	9.4066	8.9797	10.5851	8.5705	10.8416	10.2638
1100 nm	10.7599	11.2552	12.1387	10.4578	10.7673	10.9715
1200 nm	10.2642	10.9306	11.6047	10.2580	10.045	10.301
1300 nm	10.1640	10.9292	11.3810	10.5322	9.9811	10.3629
1400 nm	9.5965	9.0303	5.5126	9.4971	8.3908	8.6478
1500 nm	9.4541	9.2375	4.823	9.1555	7.9378	8.5453

where I_{max} and I_{min} are then max and min intensities of a image I . Lastly, A newer technique of computing image contrast was proposed in [14] that uses a weighted average over various image resolutions to produce a global contrast factors (in this work we define this factor as C_{Global}).

We have conducted an empirical study by applying these IQ assessment methods to all of the first session images collected from the 133 test subjects in order to compare the tattoo image quality of the various wavelengths collected. These results are shown in Table I, where the SWIR wavelengths of 1100nm and 1200nm show significant improvement over the visible band for all IQ assessment methods.

A second empirical study was conducted by dividing the data by ethnic groups present from the 133 subjects collected in the first session. Using additional ethnic metrics collected from the test subjects, we found that the ethnic groups in our dataset consisted of 8 Hispanic, 11 African American, 2 Middle eastern, 4 Asian Indian, 4 Asian, and 104 Caucasians. Sample images from each ethnic group are shown in Figure 2. As the assessment methods of contrast are highly correlated, for this study, we have only considered the C_{RMS} IQ assessment method. In Table II we can see that 1100nm, 1200nm, and 1300nm achieve a higher indication of contrast for all of the ethnic groups except Asian. These results largely indicate that tattoo images collected in the SWIR wavelengths of 1100nm, 1200nm, and 1300nm are able to achieve higher tattoo to skin contrast, especially in the ethnic groups with darker skin pigments. We can see that contrast measures between the SWIR and visible bands are much closer in ethnic groups with lighter skin pigment, such as Caucasian and Asian. This can be largely explained due to already present contrast between lighter skin pigment and dark tattoo ink. Visually,

Table III
SAME SPECTRUM RECOGNITION EXPERIMENTS

Wavelength	Rank 1 Score
Visible	95%
1100 nm	91.25%
1200 nm	96.25%
1300 nm	93.75%
1400 nm	66.25%
1500 nm	47.50%

these results can be observed in Figure 2 where the image contrast of the SWIR wavelengths of 1100-1300nm in the ethnic groups with darker skin pigments is much higher.

C. Further Studies on Biometric Recognition

To further illustrate the improved image quality, a series of same spectrum tattoo recognition experiments were performed at each wavelength. Although, advanced matching techniques using deep learning have recently been proposed for use with tattoo images in the visible band [8], the adaptation of these techniques to multiple bands would require more data and resources than we were able to collect for this study and is currently outside of the scope of this work, but may be explored in future work. As such, we used a fusion technique of several traditional approaches for tattoo matching, including the use of the SIFT algorithm [4], and the rotation invariant uniform patterns extension of LBP [6]. The scores from these algorithms were fused together using Tanh score fusion [15] to form a single distance metric that can be used for tattoo recognition. We then performed recognition experiments using data collected between two session (at least one month apart) for 80 subjects. The results of these experiments are shown in Table III, where 1200nm achieved the highest Rank-1 score of 96.25%.

III. CONCLUSION

In this work we have conducted a multispectral tattoo data collection and demonstrated the potential benefits of conducting tattoo related vision research outside of the visible band. Our results indicate that imaging in the 1100-1300nm range can, on average, result in a 13.8% increase in image quality contrast (from Table II between visible and 1100nm) between skin and tattoo regions, and an even higher increase in ethnic groups with darker skin pigments (i.e. in 1100nm a 25.3% increase in IQ contrast was observed for the African American ethnic group and a 22.0% increase for the Asian Indian group). Furthermore, we conducted same-spectrum experiments in tattoo recognition to illustrate the potential benefit of SWIR tattoo imaging to the biometric community, e.g. when operating at 1200nm, tattoo-based identification results are better than any other SWIR band including the visible. This is important for future data collections and studies, for both the academic and law enforcement community. This work could also help alleviate the challenges and inconsistencies associated with tattoo imaging listed by NIST as “Recommendations for Future Work” in the recent Tatt-C challenge results [3].

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