Research on Detection of Gunshot Residues on Textile by Infrared Spectroscopic Imaging

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Abstract. The different chemical components of gunshot residues and the corresponding carrier medium give rise to different spectroscopic features. By utilising this property, infrared spectroscopic imaging is employed to detect the gunshot residues on the surfaces of different textiles. Compared to traditional imaging methods, this technique produces higher-contrast images. Factors such as the composition of gunpowder, material burned, surface property of the carrier medium, range of excitation light, and starting and ending wavelengths are analysed. This research offers a novel idea for the detection of gunshot residues.

1. Introduction
It is well-established that non-destructive imaging is the most effective technique for the inspection of various forms of physical evidences [1]. Infrared non-destructive testing is a technique that has been newly developed. It is a non-contact testing method, which is able to inspect a large area quickly; moreover, real-time testing is also possible with this technique [2]. Gunshot residue detection is a research topic that has just emerged in the field of infrared spectroscopic imaging. In this paper, experiments are carried out to explore this technique. As demonstrated in the results, infrared spectroscopic imaging has potential to be defined as a novel method for detecting gunshot residues on textiles.

2. Experimental principle
When an object is irradiated by an infrared wave with continuously varying frequency, its molecules absorb radiation of certain frequencies. Certain vibrational and rotational modes are triggered, causing changes in the dipole moment of the molecule. Molecular vibrational or rotational energy level transits from the ground state to the excited state. As a result of these transitions, less light is transmitted at the wavelengths of molecular absorption [3-5]. An infrared spectrum can be obtained by plotting the percentage transmission of infrared wave against wavenumber or wavelength. Distinct infrared spectra are obtained from different materials, which makes it possible to use infrared spectroscopic imaging for the qualitative analysis of materials.

The absorption capacity of gunshot residues in visible light area is on par with that of textiles but differs greatly in the infrared range. This difference forms the basis of infrared spectroscopic imaging.
3. Experimental conditions

3.1. Experimental equipment
The equipment and specifications used in the experiment were: (1) Nuance multispectral imaging system (CRI, USA); (2) Varispec400 Liquid crystal infrared filter; (3) Samsung notebook, processing software for Nuance developed by CRI, and the processing software by Xingbo; (4) mini400 multi-band light source; (5) iodine tungsten lamp; and, (6) Jingguang Type-I multi-functional light source.

3.2. Modification of the infrared spectroscopic imaging system
To use the spectroscopic imaging system, the liquid crystal infrared filter was placed in front of the objective lens, and the channel was set to “white”. The spectral readings changed subsequently to 00-680 nm, 450-700 nm, 500-750 nm, 550-800 nm, 600-850 nm, 650-900 nm, and 700-950 nm, as shown in Figure 1.

![Figure 1. Spectral distribution of the imaging system in white channel](image)

3.3. Test sample

3.3.1. Experimental materials. Six types of textiles (polyester, pure cotton, wool, etc.) with different textures and patterns were used as the carrier media of gunshot residues. For each type of textile, 4 pieces of 20 cm×15 cm fabric were used.

3.3.2. Test sample preparation. The following set of equipment was used in the experiment: Type 64 7.62 mm pistol, conventional digital measuring tape, target plate, earmuffs, goggles, etc. For each group of tests, gunshot residues were produced with the Type 64 pistol on four pieces of the same fabric, at a distance of 5 cm, 30 cm, 60 cm and 150 cm respectively. The obtained four samples were considered as one group. This step was repeated for different textiles to prepare a total of 6 groups, namely 24 samples. Details of the sample preparation procedure can be found in Table 1.

| Sample number | Sample texture                        | Number of samples at each shooting distance | Subtotal |
|---------------|---------------------------------------|-------------------------------------------|----------|
| 1             | Pure cotton (red and black checks)     | 1                                         | 4        |
| 2             | Satin (ivory)                          | 1                                         | 4        |
| 3             | Polyester (pale green with woven pattern) | 1                                         | 4        |
| 4             | Nylon (coffee with woven pattern)      | 1                                         | 4        |
3.4. Experimental procedure

3.4.1. Image acquisition. Image acquisition was carried out at room temperature. The prepared sample was placed on copy stand. A suitable light source was chosen for optimal lighting (white light from a 200 W iodine tungsten lamp was used in this experiment, at an angle of incidence of approximately 45 degrees). The objective was directed at the region of interest on the sample. The sample position, magnification and focus of the lens were adjusted until a clear image of the area to be inspected was formed on the computer screen.

3.4.2 Image scans. Parameter values such as the scan range and the resolution were entered into the image scanning interface of the CRI software. The Vs Software was launched, and the corresponding parameters such as the scan range and scan time, were specified. The scan range of the Vs processing software was set at 650 nm-1100 nm, and the scan interval was 20 nm. Each scan cycle was 5000 ms. Scan range of the CRI processing software was set to 420-720 nm. Synchronization between the two programs was enforced. On the image scanning interface, IR scans were performed at both wavelength ranges on the area to be inspected. The exposure time was determined by the image recording software of the imaging system.

3.4.3 Image analysis. The software developed by Cambridge Research & Instrumentation, Inc. (CRI) that comes with the imaging system was used to perform de-mixing and adjustment on the information contained in the input image. The sample was scanned by IR radiation to generate spectroscopic image. This image was a pseudo-color image automatically formed by the spectrometer. Wavelength ranges can be selected to produce multiple combinations of the three primary colors, and multiple pseudo-color images, which can be displayed on the screen for analysis.

4. Results

4.1. Detection rate of gunshot residues
Images of textiles with gunshot residues produced at different shooting distances are collected and imported into the data library of the software. These images are then transformed into their pseudo-color counterparts and analyzed for gunshot residue detection. The detection results are shown in Table 2 and are compared with the observations made with stereomicroscope.

| Sample number | 1 | 2 | 3 | 4 | 5 | 6 |
|---------------|---|---|---|---|---|---|
| Sample texture and original color | Pure cotton (red and black checks) | Satin (ivory) | Polyester (pale green, shadow pattern) | Nylon (coffee, shadow pattern) | Synthetic knits (black) | Woolen knits (dark red) |
| 5cm Stereomicroscope | √ | | √ | - | - | - |
| Spectroscopic imaging | √ | | √ | √ | √ | √ |
| 30cm Stereomicroscope | - | - | - | -- | -- | -- |
| Spectroscopic imaging | √ | | √ | √ | √ | √ |
As shown in the experimental results of the above table, gunshot residue detection by both stereomicroscope and spectroscopic imaging is influenced by shooting distance. However, as noticed in the observation of textiles with different color and texture under stereomicroscope, textile color interferes to a considerable extent with the detection of gunshot residues. On some dark-colored textiles, it is difficult to discern gunshot residues produced even at a shooting distance of 5 cm. This, however, is not a problem with the pseudo-color images formed by infrared spectroscopic imaging, as unambiguous detection is always possible. Representative images are shown below for comparison.

4.2. Gunshot residue detection on different carrier media

Figure 2. Gunshot residues left on printed pure cotton fabric from 30 cm away, as seen under natural light.

Figure 3. Gunshot residues left on printed pure cotton fabric from 30 cm away, as seen on the image formed by scanning the sample at 575 nm wavelength.

Figure 4. An analysis of the spectroscopic image in Figure 3 (dark speckles around the bullet hole are the gunshot residues).
4.2.1. Comparison of gunshot residue detection on colored pure cotton fabric with prints.
Owing to the long shooting distance and interference from printed pattern, gunshot residues left on pure cotton fabric from 30 cm away are no longer observable by naked eye and stereomicroscope under ambient lighting (Figure 2). With infrared imaging, the residues are clearly viewable after the sample is scanned at 575 nm wavelength and the image is processed. Even the unburned gunpowder particles can be seen (Figure 3). An analysis of the spectroscopic image is shown in Figure 4.

4.2.2. Comparison of gunshot residue detection on pale green polyester fabric.
Owing to the interference of fabric color and rubbing of the fabric, gunshot residues left on polyester fabric from 30 cm away are barely observable by naked eye and stereomicroscope (Figure 5). With infrared imaging, diffused dark masses of the residues are clearly viewable after the sample is scanned at 575 nm wavelength and the image is processed. Even the unburned gunpowder particles can be seen (Figure 6). An analysis of the spectroscopic image is shown in Figure 7.

4.2.3. Precautions of the experiment.
- The test samples collected should be kept in separate bags to avoid contamination;
- During the operation of CRI and Vs software, the scan range and scan time should be set such that the two programs run in a synchronized manner;
- For de-mixing of the input image using the software developed by CRI, several reference points should be selected among the gunshot residue pixels of the pseudo-color image and one in the background.
5. Conclusions

- Reports on the use of spectroscopic imaging function of infrared spectroscopy for the inspection of physical evidence are rarely seen in literature. The adoption of infrared spectroscopic imaging in forensic science, such as the detection of trace physical evidence including gunshot residues, has yet to be realized. This study is the first case in China that used infrared spectroscopic imaging for the detection of gunshot residues on textiles. Moreover, a special liquid crystal tunable wavelength filter covering the entire infrared region is also used. This study is expected to open up new directions for the research of both gunshot residue detection and infrared spectroscopic imaging.

- The proposed gunshot residue detection by infrared spectroscopic imaging is a novel method for the fast detection of gunshot residues. The NIR image generated also gives the identity and distribution of the chemical compounds found in the residues. The qualitative analysis of specific target components could also be realized through statistical analysis, enabling the qualitative analysis of gunshot residues by infrared spectroscopic imaging.

- Gunshot residues are almost always found on the scene when shooting takes place within a certain distance. However, little gunshot residue could be extracted due to shooting distances, extraction methods, and other factors. Direct observation of the residues is also difficult. Infrared spectroscopic imaging is a quick and intuitive method that allows for the easy and accurate detection of shooting, and the inspection of the state of gunshot residues. It provides a basis for analyzing the shooting distance, gun type, gun power, and muzzle devices.

- Common gunshot residue detection methods used at present include the paraffin method, neutron activation analysis, atomic absorption, and scanning electron microscopy/Energy-dispersive X-ray spectroscopy (SEM-EDX) [6]. These techniques all have their strengths but are also difficult to implement. Infrared spectroscopic imaging does not place high requirements on samples, and sample collection could be performed in a variety of ways. The detection is also simple and fast. Compared with other methods, it offers more comprehensive information, and can be used in the cross-verification with traditional methods, giving it unique advantages.

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