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Multi-spectral imaging for the estimation of shooting distances

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ABSTRACT

Multispectral images of clothing targets shot at seven different distances (from 10 to 220 cm) were recorded at 18 specific wavelengths in the 400–1000 nm range to visualize the gunshot residue (GSR) pattern. Principal component analysis (PCA) showed that the use of violet-blue wavelengths (430, 450 and 470 nm) provided the largest contrast between the GSR particles and the white cotton fabric. Then, the correlation between the amount of GSR particles on clothing targets and the shooting distance was studied. By selecting the blue frame of multispectral images (i.e. the blue frame in the red-green-blue (RGB) system which falls at 470 nm), the amount of pixels containing GSR particles was accounted based on the intensity of pixels in that frame. Results demonstrated that the number of pixels containing GSR exponentially decreases with the shooting distance from 30 to 220 cm following a particular exponential equation. However, the targets shot at the shortest distance (10 cm) did not satisfy the above equation, probably due to the noticeable differences of the GSR-pattern of these targets (e.g. high presence of soot). Then, the equation was applied to validation samples to estimate the shooting distances, obtaining results with an error below 10%.

1. Introduction

Significant advances in the visible range of spectroscopy instrumentation such as multi-spectral and hyperspectral imaging systems, make the analysis of large surfaces considerably easy and fast, enabling the discrimination of pixels according to their different visible signatures [1–4]. Furthermore, some applications do not even require the complete visible range, but specific wavelengths that may be selected among the different wavelengths available in multispectral imaging systems. Multispectral imaging involves the collection of multi-frames (i.e. monocoloured images) of each sample, in which each frame is collected under a specific discrete detection wavelength. In this way, each frame of the image at each wavelength (bidimensional frame, 2D), can be examined separately, or, on the contrary, the whole image comprising all frames (tridimensional image, 3D) can be statistically analysed like hyperspectral images [5]. In fact, the information contained in one or few wavelengths is usually enough to overcome specific challenges in many different fields including food quality control [6–8], cultural heritage [9] or forensics [10–12]. These investigations support the use of multispectral imaging as a fast and relatively inexpensive technique for different forensic purposes. However, no attempts have been made to estimate the shooting distance (muzzle to target distance) by multispectral imaging.

Gunshot residues (GSR), which are produced when a gun is fired, are a complex mixture of burned and unburned particles coming from the propellant, primer components, and metals contained in the projectile (e.g., bullet, bullet jacket, cartridge case) [13–19]. Depending on the firing distance and other conditions (e.g. type of ammunition or firearm, firing angle, atmospheric conditions, etc.), the amount of particles that reach the target differs, creating different patterns [13–19]. The forensic analyst estimates the shooting distance through the visual examination of the characteristics of the GSR pattern and, if possible, its comparison to reference GSR patterns (produced under similar conditions) for more accurate results [15–17]. Colour tests based on chemical reactions have been the main method to assist the expert in the visualization of the GSR pattern for decades [14–17].

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However, some spectroscopic and imaging techniques have recently demonstrated their efficacy to reveal GSR patterns on clothing [20–23].

The main advantage of using imaging techniques involves the possibility to automatically examine the GSR pattern through quantitative approaches. Up to date, some interesting approaches for shooting distance estimation based on the image analysis of photographed targets through mathematical models have been explored. Most of these mathematical models are calculated taking into account either the amount, number, density, distribution or composition of GSR particles in the target [24–29]. The use of numerical data (besides the GSR pattern) enables to study the mathematical tendency for the variation of GSR pattern with the shooting distance, and the possibility to precisely determine the shooting distance within statistical deviation ranges. On the other hand, quantitative approaches for shooting distance estimation are specially affected by the possible loss of particles due to external factors (blood, water (e.g. rain or washing), first-aid procedures, recovering and handling victim's clothes, etc. [30–32]). Some interesting approaches based on image analysis and mathematical models are, for instance, the estimation of the firing distance performed with a riffle (0–45 cm distances) considering the GSR stained area [25], or the correlation of the density of IR-luminescent GSR particles with shooting distances from 20 to 300 cm performed with different pistols and revolvers [27]. Both studies seem to evidence an exponential decrease in the amount of GSR particles with the shooting distance.

In this respect, this study explores the potential of multispectral imaging as a forensic tool for the visualization of the GSR pattern and the subsequent mathematical estimation of the shooting distance in the 10–220 cm range through a specific exponential equation. To this aim, multispectral images of the clothing targets shot were recorded in the 400–1000 nm range to determine the wavelength that provided the largest contrast between the GSR particles and the white cotton fabric. Then, the correlation between the amount of pixels containing GSR particles and the shooting distance has been mathematically established. Finally, the equation obtained was applied to a set of validation samples.

2. Material and methods

2.1. Samples

28 square cardboard pieces of 10 × 10 cm covered with standard white cotton clothing were used as targets. White cotton clothing was used in order to enhance the contrast between GSR and background facilitating thereby the visualization of GSR particles. The targets were shot using a Glock G17 pistol and 9 × 19 mm semi-jacketed hollow point conventional ammunition manufactured by Sellier&Bellot (Czech Republic). Shots were executed at the shooting range of the Spanish National Scientific Police (Madrid, Spain). Targets were shot at seven different shooting distances, including 10, 30, 50, 70, 100, 150 and 220 cm. Four replicates per distance (28 samples) were prepared. Three replicates (21 samples) were used to create the mathematical model whereas a fourth replicate of each distance was used as validation set (7 samples) to test the model.

2.2. Multispectral imaging

A Videometer Lab 4 (Cambridge, UK) was used to collect a multispectral image of each sample at 18 different specific wavelengths from 400 to 1000 nm (430, 450, 470, 505, 565, 590, 630, 645, 660, 700, 850, 870, 890, 910, 920, 940, 950 and 970 nm). Images contained 960 × 1280 pixels, being the spatial resolution of each pixel 0.12 × 0.12 mm.

2.3. Image processing

Image processing was performed in MATLAB R2016b (Mathworks, USA). After comparing the 18 frames of each multispectral image separately, and all together, using principal component analysis (PCA), the frames at violet-blue wavelengths (430, 450 and 470 nm) were identified as the frames that provided the largest contrast between dark GSR and white cotton fabric. As an example, Fig. 1 displays the loading and scores plot for the first principal component of one of the targets shot at 30 cm. According to the loading values and keeping in mind the absolute value, the highest contribution was provided by wavelengths at 430, 450 and 470 nm with 0.50, 0.50 and 0.41, respectively. It should be noted that the contribution of the next wavelength (505 nm) decreases to 0.25 of absolute value. Those 3 violet-blue frames were studied by quantifying the pixels that fall below a specific value of intensity and similar results were obtained for the three frames. From those three, the frame at 470 nm was selected as the most relevant frame because, even though it provided the lowest contribution, it corresponds to the blue channel in commercial ordinary digital RGB cameras. In order to carry out the pixel quantification, different ranges of intensity were tested, selecting the range from 0 to 0.45 as the optimum range that gave the best correlation with the presence of GSR. It is important to highlight that MATLAB works, by default, with intensity values from 0 (black) to 1 (white) after converting an image into a numerical matrix. Therefore, the dark pixels within this frame were quantified. Afterwards, the image was binarized, i.e. converted only to black and white (only 0/1 values) for image purposes and these values were inverted for better visualization. Finally, the pixel quantification was plotted against the shooting distance (by calculating the average and standard deviation), and different fitting trendlines using the trendline options of Excel (Microsoft Office 2016) and Origin (OriginPro 9.0) were tested by evaluating their R^2 coefficient.

3. Results and discussion

First, it is important to highlight that the particles imaged in the white cotton targets exclusively came from the shots, since the shootings were performed under controlled conditions to remove any potential interferent. Also worth noting is the fact that, in this study, the term GSR pattern/GSR particles includes all the particles expelled by the firearm, i.e. particles from both primer and

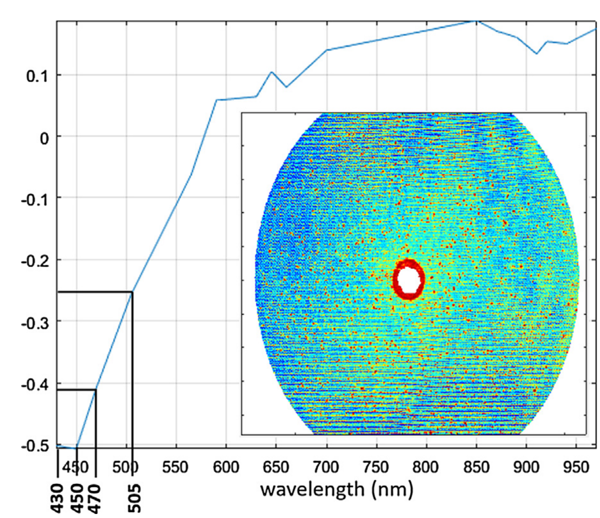

Fig. 1. Graphical loading plot for the first principal component of one of the targets at 30 cm. Principal component analysis using singular value decomposition (svd) algorithm. GSR particles are observed as red dark pixels in the scores image.