Image processing for the positive identification of forensic ballistics specimens

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Abstract - *The need for firearm identification systems by police services continues to increase with greater accessibility to weapons in the national and international contexts. The difficulties associated with traditional imaging of ballistics specimens are numerous, and include the smallness of the samples, the nature of the surfaces and shapes for the cartridge cases and projectiles.*
The "mechanical fingerprint" on fired bullets and cartridge cases can be used to identify the firearm that they passed through. A PC based firearm identification system, Fireball, has been developed at Edith Cowan University and used by police ballistics sections in Australia. This paper will give a brief description of this system and details of the image processing such as segmentation, feature extraction and image processing before saving images to the image database. Examples will be given to demonstrate the methodology.

Keywords: Firearm identification, Image segmentation, edge detection, feature extraction.

1. Introduction

Firearm identification is an intensive and time-consuming process that requires physical interpretation of forensic ballistics evidence. Especially as the level of violent crime involving firearms escalates, the number of firearms to be identified accumulates dramatically. The demand for an automatic firearm identification system arises.

The forensic identification of ballistics specimens relies on the detection, recognition and ultimate matching of markings on the surfaces of cartridges and projectiles made by the firearms [1]. Traditional methods for the comparison of these marks are based on incident light microscopy. The image formed from the oblique illumination of the mark gives a representation of the surface of the specimen in the region of the mark [2]. This representation is critically dependent on the material of the surface, on which the marks have been made, and the geometry and intensity of the illumination system. The assessment by the ballistician of the similarity between comparable marks on respective ballistics specimens from crime scenes and test firings will be based on the expertise and experience of the technologist. Thus the traditional method of matching markings has inherent difficulties, while maintaining an element of subjectivity [3].

The identification of the ballistics specimen from the crime scene with the test specimen is traditionally conducted by mapping the marks by visual images from a low-powered optical microscope. The selection of features within the identifying mark is chosen for their apparent uniqueness in an attempt to match both crime scene and test specimens. A decision is made whether the same firearm was responsible for making the marks under examination on the crime scene and test ballistics specimens. The selection of the mark or set of marks for examination and comparison is a critical step in the identification process, and has the capacity to influence subsequent stages in the comparison process [4].

The difficulties associated with traditional imaging of forensic ballistics specimens are numerous, and include the smallness of the samples, the nature of the surfaces for the cartridge cases (brass) and projectiles (lead) where features have low contrast, the cylindrical shape of the cartridge cases, and the distorted shapes of the projectiles (after striking objects). Traditional ballistics identification using conventional low powered comparator microscopy examinations of forensic ballistics specimens is a labour intensive activity with several weeks of time being devoted to a single analysis and comparison. Digital image processing systems have the potential to reduce this period for identification to several hours. A well established imaging system will both quickly pay for its research and development costs, and also provides rapid response by police at a crime scene incidence.

A few systems for firearm identification have been developed around world. These includes DRUGFIRE [5], developed by Federal Bureau of Investigation, USA, IBIS[6], developed by Forensic Technology, a division of the Walsh Group, and The *Fireball Firearm Identification System* developed after the initial research conducted by Smith and Cross [7] and Smith (1997) [8], and later by an ECU software team [9].

These systems integrate digital imaging, database and networking technologies to enhance the capabilities of the forensic firearm examiner.

When a firearm is loaded and fired, the mechanisms and parts of the firearm that come into contact with the cartridge case or projectile cause striations and impressions that are considered as a ballistics signature. Study has shown that no two firearms, even those of the same make and model, will produce the same unique signatures on fired bullets and cartridge cases [8]. The measurement of these features allows precise ballistics metrics to be obtained for the identification of the make and model of the firearm.

The characteristic markings on the cartridge and projectile of a bullet fired from a gun can be recognised as a *fingerprint* for identification of the firearm [10]. Over thirty different features within these markings can be distinguished, as shown in Figure 1, which in combination produce a "fingerprint" for identification of a firearm. The analyses of marks on cartridge cases and projectiles, such as calibre, firing pin location and shape, numbers and widths of land marks and groove marks, and the direction and angle of twist of the marks, provide a precise tool for identifying the class of firearm from which a bullet was discharged.

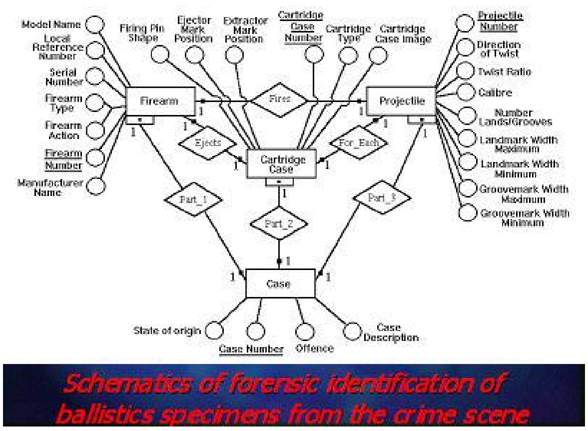

Figure 1

Forensic ballistics imaging has the capacity to produce high-resolution digital images of cartridge cases and projectiles for matching to a library of ballistics images [8]. However, the reliance upon imaging technologies makes identification of ballistics specimens both a demanding and exacting task, where the control of the error of measurement in the imaging technique must not allow compromise of integrity of the identification process.

The FIREBALL firearm identification system is developed as recognising the need for a low-cost alternative to other established systems. Furthermore, the system is tailored to Australian conditions.

The initial FIREBALL system acquires the firearm images by manually adjusting the sample position and illumination, and focusing. The acquired images show inconsistency in orientation, position and brightness. It is necessary to pre-process the acquired images, such as identify the firearm image area, centre the firearm, rotate the image to a proper orientation and adjust the brightness, before storing them to the final database system for future comparison. This is also the fundamental of a proposed automatic image acquisition system in which the position, orientation of the cartridge case, image size and focusing will be tuned automatically according to the acquired image. The following sections will describe these processes.

2. Image acquisition system

The positive identification of persons [7][11] and ballistics specimens [12][4] from imaging systems is an important application of technology in criminal investigation. While the image capture methodology for persons and specimens is similar, the process of identification for each is dependent upon the level of certainty required for the identification.

The image acquisition system, shown in Figure 2, consists of a CCD camera, microscope and ring light source that provides the conditions for image formation. Illumination is always a crucial aspect regarding image quality of image acquisition. This ring light illumination guaranties high quality image acquisition. Figure 3 shows the cartridge case image captured by this system.

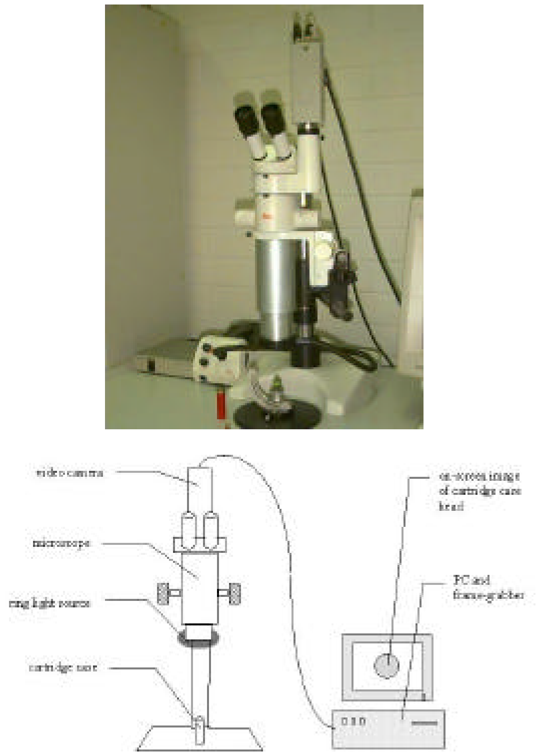

Figure 2. Image acquisition system

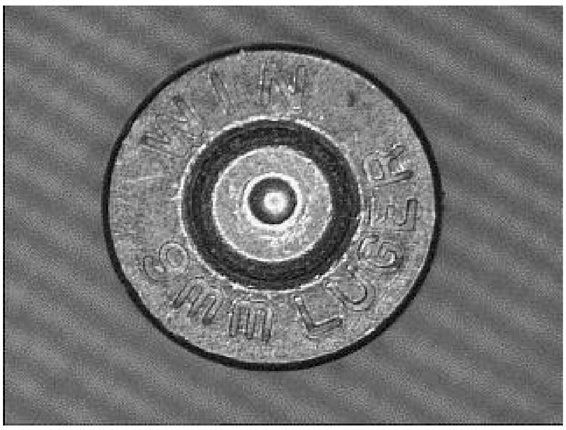

Figure 3, a sample cartridge case image

3. Image pre-processing

As shown in Figure 3, the acquired image shows randomises in orientation, position and noise in the background. It is necessary to reduce the background noise and normalise the orientation, position and size of the image before storing the image to the database.

3.1 Edge detection

The first step of the image pre-processing is to find the cartridge case area in the image. Because of the good illumination and focusing, the acquired image has higher brightness in the cartridge case area than that in the rest. There is a clear edge around the cartridge case area. The edge detection should be an efficient way to detect cartridge case.

The proposed method employs Canny edge detection [13] for detecting edges. The Canny method finds edges by looking for local maxima of the gradient of intensity. The image is first smoothed by a Gaussian filter with some fixed width σ. After computed the local gradient G, The second directional derivative D is computed in the direction of local gradient. Then, the zero crossings of D are identified that define closed contours of D=0. To accept or reject resulting edges based on signal-to-noise selection technique. The method uses two thresholds, to detect strong and weak edges, and includes the weak edges in the output only if they are connected to strong edges. This method is therefore less likely than the others to be "fooled" by noise, and more likely to detect true weak edges.

Figure 4 shows the edges detected using Canny edge detection with low threshold of 0.2, high threshold of 0.6 and Sigma of 1.6. Strong edges are obvious. The outside circular edge defines the cartridge case. The second most inside circle edge is that of the firing pin mark.

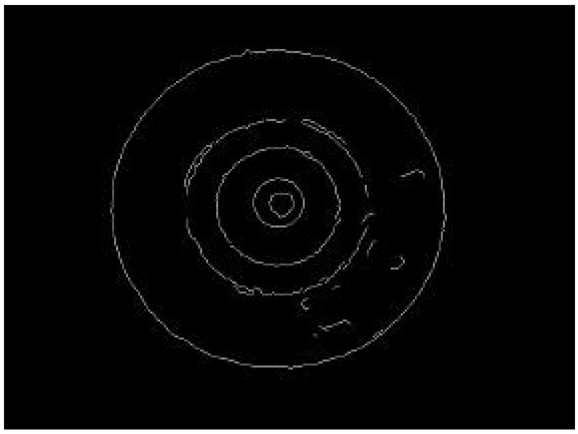

Figure 4, edges detected for figure 2 using Canny edge detection.

3.2 Feature extraction and image pre-processing

The feature extraction is performed based upon the result of the edge detection. The outside circular edge defines the boundary of the cartridge case. The background outside boundary will be removed. The result image is shown in Figure 5.

Since the bottom of the cartridge case appears as a large circle and the firing pin mark is close to a small circle inside. After edge detection we use "direct least squares fitting of ellipses" [14] to fit the cartridge case edge data set and the firing pin mark's edge data set to obtain centres and radius of the cartridge case and firing pin mark.

This fitting algorithm provides an efficient method for fitting ellipses to scattered data. It solves the problem naturally by a generalized eigensystem and is extremely robust and computationally efficient. It should be possible to use the same algorithm for the active control in our proposed automatic image acquisition system. The fitting results are drawn in Figure 6.

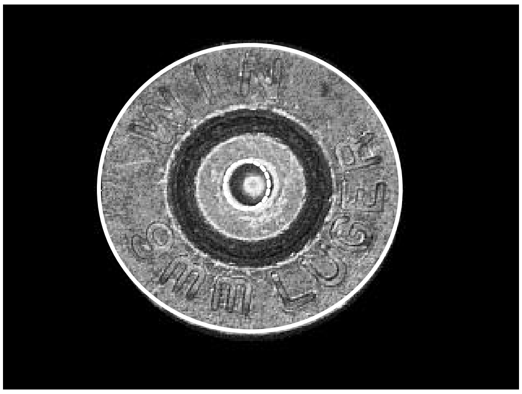

Figure 5 the image with defined boundary and dark background

When we take the image we do not take care of the orientation of the acquired image. It is necessary to find a reference and normalize all images to this reference for future comparison. We proposed to use the vector pointing from the centre of the cartridge case to the centre of the firing pin mark as a reference and rotate the image to make the vector sit on the positive X axis.

Suppose the centre and radius of the cartridge case and firing pin mark are (X_c, Y_c, R_c) and (X_f, Y_f, R_f), respectively. In general case, these two circles are not concentric. The angle of the vector (X_c, Y_c,) $\rightarrow$ (X_f, Y_f) is

$$q = \arctan\left(\frac{Y_c - Y_f}{X_c - X_f}\right) \qquad (1)$$

We then use spatial transformation to rotate the cartridge case for -*q* around the centre (X_c, Y_c) as

$$\begin{cases} x' = X_c + (x - X_c)\cos q - (y - Y_c)\sin q \\ y' = Y_c + (x - X_c)\sin q + (y - Y_c)\cos q \end{cases} \qquad (2)$$

Where (x,y) and (x',y') are the coordinate of before and after the transformation. After the transformation, the vector (X_c, Y_c,) $\rightarrow$ (X_f, Y_f) should be on the positive X-axis.

The acquired image size may show inconsistency, because of manual focusing. This can be compensated by scaling the image according to the radius of cartridge case area we have obtained above.

If we define a normalised cartridge case radius as R_0 and obtained radius in the image is R_f. We will scale the image by R_f/R_0.

Another randomises of acquired images is that the cartridge case area is not in the centre of the image. The spatial transformation will fix it. First, we calculate the centre of the image (X_i, Y_i), then do the transformation by

$$\begin{cases} x' = x + X_i - X_c \\ y' = y + Y_i - Y_c \end{cases} \qquad (3)$$

The image after pre-processing is shown in Figure 6. It sits in the centre of the image in the normalised orientation.

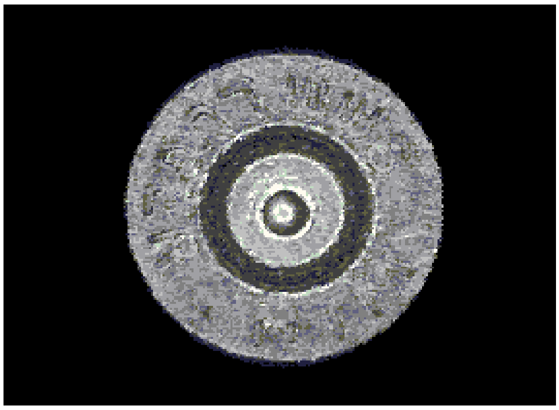

Figure 6 the image after pre-processing.

4 Conclusion

The proposed image pre-processing for the firearm identification system that based on Canny edge detection is working fine for the cartridge case image. The pre-processing mostly concerned the normalisation of the acquired image so that there is consistency in comparison. It is also critical for extracting characteristic features of the firearms automatically in the future.

We are in the design stage of an automatic firearm image acquisition system. In this system, the computer that acquires the image will actively control the sample stage and the illumination according to the position, orientation and focusing of the acquired image.

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