2007

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Li, G. (2007). Australian firearm identification system based on the ballistics images of projectile specimens. In Li, D. (Ed.). *Proceedings of the Sixth International Workshop for Applied PKC (IWAP2007), Mt. Lawley Campus, Edith Cowan University, 3rd-4th December, 2007. Western Australia: Edith Cowan University*. pp. 59-69.

Australian firearm identification system based on the ballistics images of projectile specimens

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Abstract. Charactetistic markings on the cartridge case and projectile of a fired bullet are created when it is fired. Over thirty different features within these marks can be distinguished, which in combination produce a "fingerprint" for a firearm. By analyzing features within such a set of fireann :fingerprints, it will be possible to identify not only the type and model of a fireann, but *also* each every individual weapon as effectively as human :fingerprint identification. A new analytic system based on fast Fourier transform (FFT) for identifying the projectile specimens by the line-scan imaging technique is proposed in this paper. Experimental results show that the proposed system can be used for firearm identification efficiently and precisely through digitizing and analyzing the fired projectiles specimens.

1 Introduction

The analysis of marks on bullet casings and projectiles provides a precise tool for identifying the firearm from which a bullet is discharged [1] [2]. Characteristic markings on the cartridge case and projectile of a bullet are produced when a gun is fired. Over thirty different features within these marks can be distinguished, which in combination produce a "fingerprint" for identification of a firearm [3]. This forensic technique is the vital element for legal evidence, in cases where the use of firearms is involve.

Projectile bullets fired through the barrel of a gun will exhibit extremely fine striation markings, some of which are derived from minute irregularities in barrel produced during the manufacturing process. The examination of these striations on land marks and groove marks of the projectile is difficult using conventional optical microscopy. However, digital imaging techniques have the potential to detect the presence of striations on ballistics specimens for identification.

Given a means of automatically analyzing features within such a firearm "fingerprint", identifying not only the type and model of a firearm, but also each individual weapon as effectively as human fingerprint identification can be achieved. Due to the skill required and intensive nature of ballistics identification, law enforcement agencies around the word have expressed considerable interest in the application of ballistics imaging identification systems to both greatly reduce the time for identification and to introduce reliability (or repeatability) to theprocess.

Several ballistics identification systems are available either in a commercial form or in a beta-test state. A Canadian company, Walsh Automation, has developed a commercial system called "Bulletproof', which can acquire and store images of projectiles and cattridge cases, and automatically search the image database for patticular striations on projectiles. However the impressed markings or striations on projectiles must be matched by user. This inherent limitation of the system with respect to projectiles has prohibited its use. The Edith Cowan University of Australia, in conjunction with the Australia Police, has developed a prototype database called FIREBALL [4]. It has the capability of storing and retrieving ilnages of cartridge cases heads, and of interactively obtaining position metrics for the firing-pin impression, ejector mark, and extractor mark. The limitation of the system is that the position and shape of the impression images must be h·aced manually by users. For the time being, we still have unsolved problems on projectiles imaging, storing and analyzing although the system has been put in use for 4 years. The efficiency and accuracy ofFireBall system must be improved and increased.

The research papers on the automatic identification of cartridge cases and projectiles are hardly to be found. L. P. Xin [5] proposed a cartridge cases based identification system for firearm authentication. His work was focused on the cartridge cases of center-firing mechanism. And he also provided a decision strategy by which the high recognition rate would be achieved interactively. C. Kou et al. [6] described a neural network based model for the identification of the chambering marks on cartridge cases. But no experimental results were given in their paper.

In this paper, a new analytic system based on fast Fourier transform (FFT) for identifying the projectile specimens captured by the line-scan imaging technique is proposed. The system gives an approach for projectiles capturing, storing and analyzing automatically and makes a significant contribution towards the efficient and precise identification of projectiles. Firstly, in Section 2, the line-scan imaging technique for projectiles capturing is described. Secondly, the analytic approach based on FFT for identifying the projectile characteristics and the experimental results are presented in Section 3. Finally, Section 4 gives a short conclusion.

2 Line-scan Imaging Technique for Projectile Capturing

2.1 Line-scan Imaging

The traditional optical microscopy for imaging the cylindrical shapes of ballistics specimen is inherently unsuitable for the expected high contrast imaging. It is difficult to maintain image quality using oblique lighting on a cylindrical surface, from low magni.fication microscopy, as the specimen is translated and rotated [7].

However, we can obtain the surface information from a cylindrical shaped surface using a line-scan imaging technique by scanning consecutive columns of picture information and storing the data in a frame buffer to produce a 2D image of the surface of the cylindrical specimen.

The periphery camera was the precursor imaging device to the line-scan camera, which consists of a slit camera with moving film in order to 'unwrap' cylindrical objects by rotating them on a turntable [8]. Relative motion between the line array of sensors in the line-scan camera and the surface being inspected is the feature of the line-scan technique. This relative motion is achieved by rotating the cylindrical ballistics specimen relative to the stationary line array sensor [7].

With the line-scan technique, because the cylindrical ballistics specimen is rotated about an axis of rotation relative to a stationary line array of sensor, all points on the imaging line of the sample are in focus. Hence, all points on the rotating surface will be captured on the collated image during one full rotation of the cylindrical ballistics specimen [7].

The line-scan imaging analysis system for projectiles in our study is shown in Fig. I. The stepper motor rotates with 2400 steps/360 degrees, namely 0.15 degree each step. We use CCD camera instead of the traditional camera used in [7] [8]. The graphic capturing card installed in PC has a resolution of240x 320 pixels/inch. A ring light source is adopted, which can provide uniform lighting conditions [9].

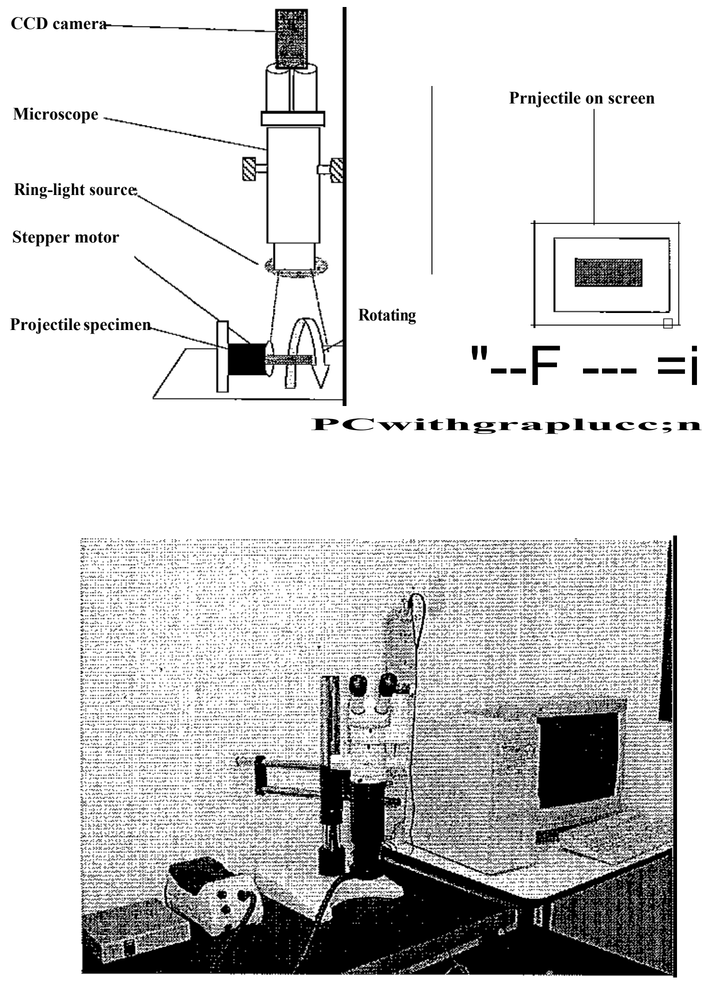


Fig. 1. The line-scan imaging and analyzing system

Being quite different from the method used io [7] [8], the procedure in our line-scan imaging approach is as follows:

1) With the stepper motor's every step
2) CCD camera captures the current image of projectile specimen and
3) Sends the image lei Graphic card in PC;
4) The middle column of pixels in this image is extracted and saved consecutively in an array io the buffer on PC, and
5) stepl) and 2) are repeated until the whole surface of the projectile specimen is scanned;
6) The array in the buffer is used to produce a 2-D line-scanned image for the whole surface of the projectile.

The resolution of the line-scan image is dependent on the rotational degree per step of the stepper motor, the resolution of CCD camera, the resolution of graphic capturing card, and the columns captured at each step in step 3). Therefore, the resolution of the line-scanned image of projectile specimen could be manipulated by adjusting the length of each step of the stepper motor and the number of columns captured in each step to meet forensic investigation requirements.

2.2 Projectile specimens and their line-scanned images

The projectile specimens in our study, provided by Western Australia Police Depatiment, are in four classes and belong to four different guns. They are:
1) Browning, semiautomatic pistol, caliber 9mm.
2) Norinco, semiautomatic pistol, caliber 9mm.
3) and 4) Long Rifle, semiautomatic pistol, caliber 22.

All the projectile specimens in our study are recorded using the line-scan imaging technique discussed in Section 2.1 under the same conditions (such as the light conditions, the stepping angle of stepper motor, etc.). The stepping angle of the stepper motor is adjusted to produce a image by just one full rotation (360 degrees), so that all the land marks and groove marks of projectile specimen are captured and displayed in the line-scanned image. Line-scanned images of four classes of projectile specimens in our study are shown Fig. 2.

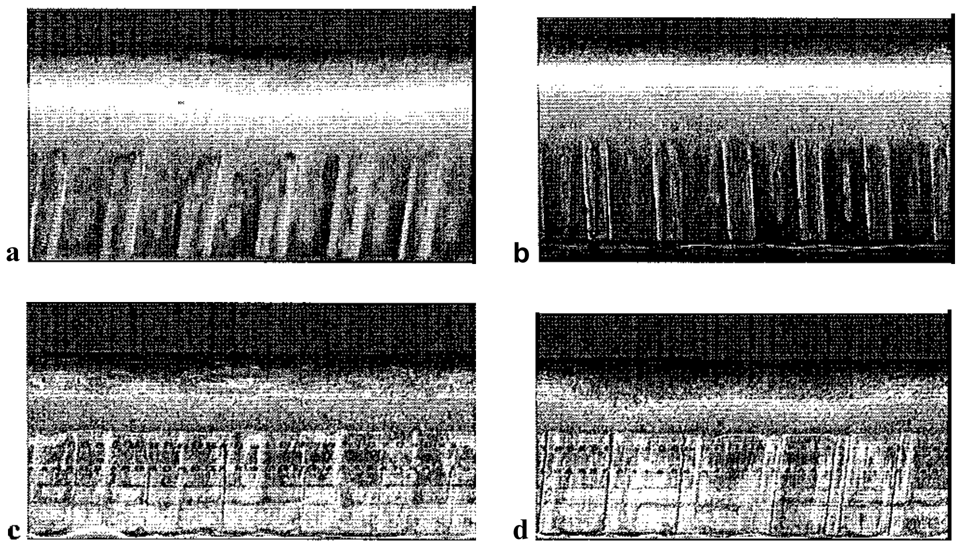


Fig. 2. Four classes of line-scanned images of projectiles in our study (with code: a, 101; b, 201; c, 301; d, 401)

2.3 Image Pre-processing for FFT analysis

In a practical application, the quality of the line-scanned image of a projectile specimen can be affected and noised by many factors such as the lighting conditions, the materials of the specimen, the original texture on the surface of specimen, and the deformed shapes. All these can bring strong noise into the line-scanned image or damage the shape of the line-scanned image, and would result in many difficulties to extract and to verify the important features used for identifying the individual specimen, such as the contours, edges, the directions and the width (or distance) ofland marks and groove marks. In order to remove or decrease the affection mentioned above, the following image pre-processing operations are applied to the line-scanned images obtained in Section 2.2.

2.3.1 Contrast Enhancement:

One of the general functions in image preprocessing is the contrast enhancement transformation [I OJ. Low-contrast images can result from poor lighting condition, lack of dynamic range of the imaging sensor, and a wrong setting of a lens aperture during image acquisition. The idea behind contrast enhancement is to increase the dynamic range of the gray levels in the image being processed. In our study, for the reason of the strong reflection from the metal surface, the images obtained are often blurred in a certain extent. The land marks or groove marks may be hidden within. Therefore, the contrast enhancement transformation is used upon the images obtained in Section 2.2. For the line-scanned images, only the regions that include the land marks and groove marks are useful for analyzing and identifying the characteristics of the projectile specimens. Hence, we only select the regions in images that are necessary and useful to our study. The images (the effective regions in original images) shown in Fig. 3 are transformed versions corresponding to the images in Fig. 2 by the region selecting and the contrast enhancement transformation.

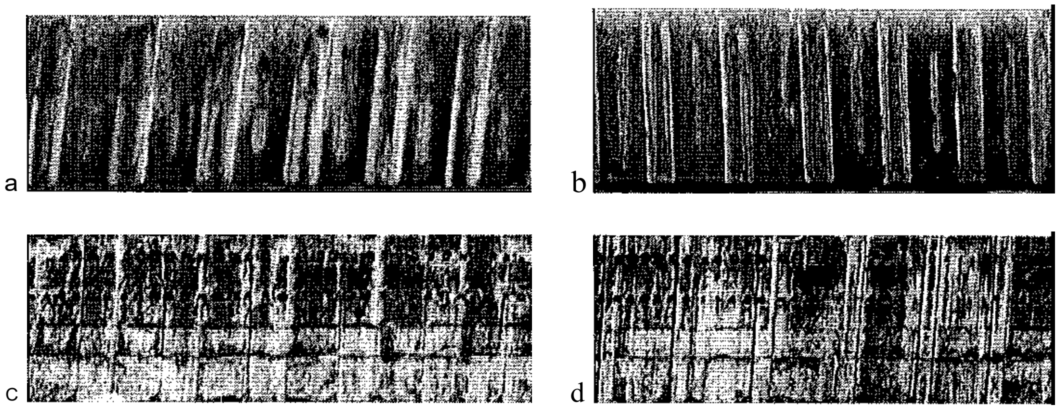


Fig. 3. Contrast enhancement results (a, b with size 400 x 110, and c, d with size 400 x 100)

2.3.2 Feature Extraction:

Feature extracting plays an important role in identification system. We pick up the first derivatives [I OJ as the images features. For a digital image, the most popular powerful masks used to approximate the gradient of J at coordinate(i,j) are *Sobel* operators in vertical and horizontal directions (shown in Fig. 4 with 3 x 3 window). In our study, we adopt the *Sobel* operators to extract the contours and edges of the land and groove marks on line-scarmed images of projectile specimens. For the reason that the directions of the land and the groove marks of the projectile specimens are all or almost along 90 degree in the line-scanned images, we only adopt the ve1tical direction mask (Fig. 4) for extracting the features of the line-scanned images. By observing the Fig. 5 in which there are lots of noises and disconnection on the land and groove marks, the conventional spatial techniques are not suitable for the nature oflocally. Hence, a FFT-based analysis for projectiles is introduced in.

-	-	-
0	0	0
-	-	-

-	0	-
-	0	-
-	0	-

Fig. 4. ***Sobel*** **masks in ve1iical and horizontal directions**

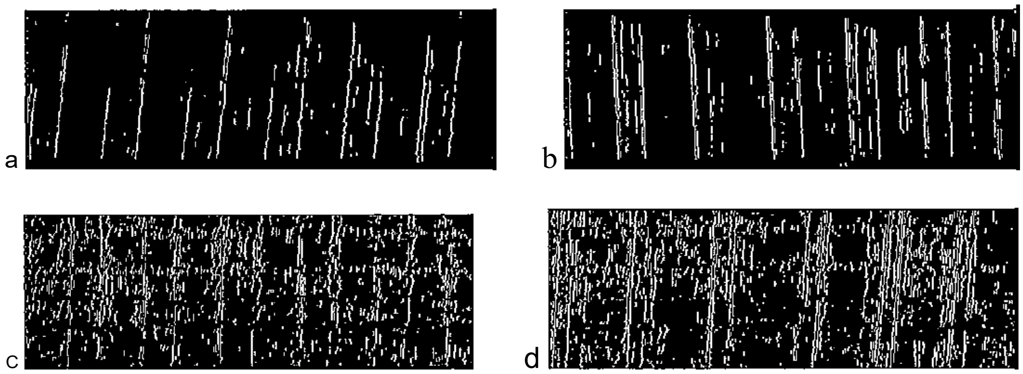


Fig. 5. The contours and edges extracting using *Sobel* operator in vertical direction

3 FFT-based Analysis

3.1 FFT and Spectrum Analysis

The Fourier transform of a two variables> continuous function, $f(x, y)$, is defined by the equation [10]

$$F(u,v)=\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)e^{-j2\pi(ux+vy)}dxdy \quad (1)$$

where j = -

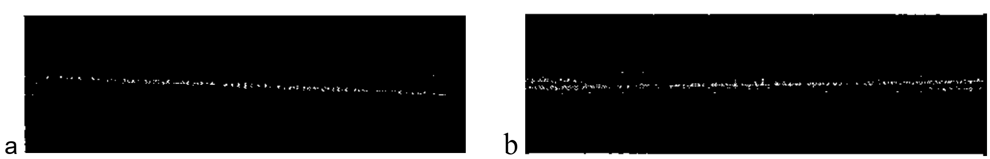
The Fourier transform of a two variables, discrete function (image), $f(x,y)$, of size $M \times N$, is given by the equation

$$F(u,v)=\frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)e^{-j2\pi(ux/M+vy/N)} \quad (2)$$

where j = , for all $u = 0,1,2,\cdots,M-1$, $v = 0,1,2,\cdots,N-1$. We define the Fourier spectrnm by the equation

$$|F(u,v)|=[R^2(x,y)+I^2(x,y)]^{1/2} \quad (3)$$

where $R(x,y)$ and $I(x,y)$ are the real and imaginary parts of $F(u,v)$, respectively.



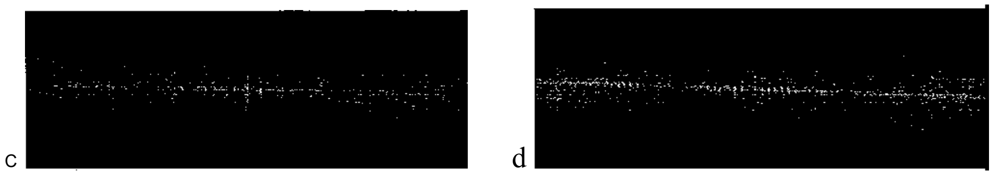


Fig. 6. Fourier transformation results of the images in Fig. 5

The Fourier spectrum is ideally suited for describing the directionality of periodic or almost periodic 2-D patterns in an image. These global texture patterns, although easily distinguishable as concentrations of high-energy burst in the spectrum, generally are quite difficult to detect with spatial methods because of the local nature of these techniques.

Here, we consider a set of features of the Fourier spectrum that are used for analyzing and description the line-scanned images of projectiles:

(1) Prominent peaks in the spectrum give the principal direction of the texture patterns.

(2) The location of the peaks in the frequency plane gives the fundamental spatial period of the patterns.

(3) Some statistical features of the spectrum.

Detection and interpretation of the spectrum features just mentioned often are simplified by expressing the spectrum in polar coordinates to yield a function *S(r,0),* where Sis the spectrum function, andr and *0* are the variables in this coordinate system. For each direction *0, S(r,0)*is a 1-D function $S_0(r)$. Similarly, for each frequencyr, *s,.(0)* is a 1-D function. Analyzing $S_0(r)$ for a fixed value of 0yields the behavior of the spectrum (such as the presence of peaks) along a radial direction from the origin, whereas analyzing S,.*(0)* for a fixed value of *r* yields the behavior along a circle centered on the origin. A more global description is obtained by integrating (summing for discrete variables) these functions [10]:

$$S(r) = \sum_{\theta=0} S_\theta(r) \quad (4)$$

and

$$S(\theta) = \sum_{r=1}^{R_0} S_r(\theta) \quad (5)$$

where R_0 is the radius of a circle centered at origin.

The results of Equations (4) and (5) constitute a pair of values [S(r),S(0)]for each pair of coordinates(r,0). By varying these coordinates, we can generate two 1-D functions, *S(r)* and *S(0),* that constitute a spectral-energy description of texture for an entire image or region under consideration. Futthermore, descriptors of these functions themselves can be computed in order to characterize their behavior quantitatively.

3.2 FFT based Analysis, Identification and Experimental Results

Some characteristics and descriptors of the line-scanned images for identification of projectiles using the radius spectrum and angular spectrum are discussed in details in this section.

We know that the slowest varying frequency component ($u = v = 0$) corresponds to the average gray level of an image. As we move away from the origin of the transform, the low frequencies correspond to the slowly varying components of an image. In a line-scanned image of projectile specimen, for example, these might correspond to the land and groove marks which are large in scale and regular in shape. As we move further away from the origin, the higher frequencies begin to correspond to faster and faster gray level changes in the image. These are the small or irregular marks and other components of an image characterized by abrupt changes in gray level, such as noises. So we focused our attention on the analysis oflow frequencies in the radius and angle spectrum of line-scanned images.

The plots of radius and angle spectrum corresponding to images in Fig. 6 a, b are shown in Fig. 7 a, b, c and d, respectively. The results ofFFT clear exhibit directional 'energy' distributions of the surface texture between class one and two. Comparing Fig. 7 a to b, the plots of radius spectrum, the former contains six clear peaks in the range of low frequencies (r <20), the later has only three peaks in the same range and is smooth in shape, this indicates that 'energy' of the class one specimen is distributed in several permanent positions, and also reveals that the class one specimens has a coarse surface texture and the wide land and groove marks, while the surface texture of class two is fine and the wide of land and groove marks is thin.

The angular spectrums (Fig. 7 c and d) display a great distinctness in position of prominent peaks between class one and two. Further study reveals that the angular spectrum can clearly indicate the angular position of periodic grooves or scratches on the surface with respect to the measurement coordinate. It can be seen from the angular spectrum there is a maximum peak at about 81 degree in Fig. 7 c. This is indicative of scratches (the land or groove marks) oriented in the direction 81 degree on the surface of projectiles, while the maximum peak in Fig. 7 d at about 95 degree. In addition, the former plot has a second prominent peak (corresponding to small or shallow marks on the projectile's surface) at about 100 degree. However, it is noted that the second peak of Fig. 7 dis at about 85 degree.

The characteristics of projectile specimen surface textures can also be revealed by examining quantitative differences ofspectrums using a set of features. To compare and analyze the spectrums differences between the class one and two easily, a set of features is used, and the quantitative results are shown in Table 1 (where, r_1 and a_2, Max; r_2 and a_3, Mean; r_3 and a_4, Std; r_4 and a_5, Max: Median; and a'' Position of maximum peak).

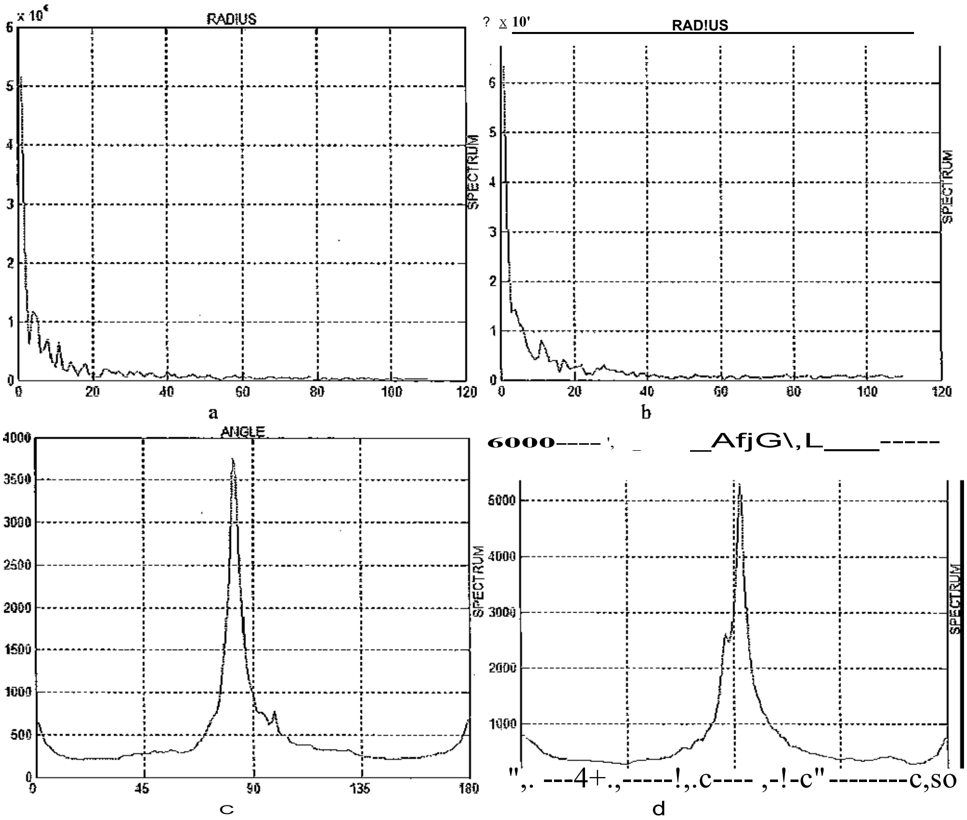


Fig. 7. Radial spectrum (a, b) and Angular spectmm (c, d) of the images (a, b) in Fig. 6

It can be observed from Table 1 that the Max, Mean, and Std of the class one are relatively smaller than the class two, while the relative variation for radio between Max and Mean is greater. And the difference between proininent peaks (corresponding to the orientations of land and groove marks) of class one and two is 14 degrees. This provides evidence that FFT spectrum analysis, in the form of quantification, can reveal characteristic and directional surface textures of projectile specimen.

Table 1. Radial spectrum and angular spectrum statistics results of Fig. 6 a and b

Class	Code	Radialspectrnm				Angular spectmm				
		$Y1$	r2	$r3$	$r4$	a_1	a_2	a_3	a_4	as
I	IOI	51517	1728	5372	29.81	81	3753	475.2	546.2	7.898
2	201	63646	2538	6809	25.07	95	5308	697.9	794.7	7.600

All experimental results based on the projectiles in our study are listed in Table 2.

Table 2. Radial spectrum and angular spectrnm statistics results based on the specimens in our study

Class	Code	Radialspectrum				Angularspectrnm				
		$r1$	r2	$r3$	$r4$	a_1	a_2	a_3	a_4	as
	IOI	51517	1728	5372	29.81	**81**	3753	475.2	546.2	7.898
	102	51162	1591	5187	32.16	**81**	3709	437.6	545.6	8,487
	103	51200	1520	5087	33.68	81	3583	418.2	509.8	8.571
	104	515561699		5348	30.34	81	3589	467.3	514.1	7,685
	105	62715	1962	6299	31.96	81	4219	539.5	617.8	7.827

	201	63646	2538	6809	25,07	95	5308	697.9	794.7	7.600
2	202	64381	2738	7038	23.51	95	5257	752.9	777.7	6.990
	203	64059	2545	6707	25.16	95	5193	700.0	794.0	7.419
	301	63959	2899	6942	22.06	86	2514	724.7	451.9	3.469
3	302	64448	2478	6889	26.01	86	2714	719.4	445.5	3.774
	303	64288	2743	7090	23.43	86	2517	685.8	439.9	3.669
	304	63694	3011	6999	21.23	86	2750	752.7	512.8	3.657
	401	76059	4040	8554	18.27	79	4965	1010	787.8	4.916
4	402	76406	5026	8982	15.20	79	4972	1256	835.6	3.959
	403	75607	3735	8035	20.23	79	4897	933.9	753.3	5.249
	404	76796	3786	8498	20.28	79	4135	946.3	738.6	4.371

By observing Table 2 and recalling that the calibers of type one and two are same, and so are the type three and four, we can easily identify the projectiles using any one of features listed in Table 2. For example, all the values of „$_4$ for type one are greater than 28.0, while for type two, no one is greater than 26.0. Same result can be obtained using other features in Table 2. The characteristics we used in spectrnm analysis can be formed as a set of features vectors for building an artificial intelligent (AI) system for the automatic firearm identification based on the spent projectiles.

4 Conclusion

In this paper, a new analytic system for firearm identification based on the projectile specimens automatically is proposed. We not only present an approach for capturing and storing the surface image of the spent projectiles at high resolution using line-scan inlaging technique for the projectiles database, but also presented a novel and effective FFT-based analysis technique for analyzing and identifying the projectiles. This system can make a significant contribution towards the efficient and precise analysis of firearm identification based on ballistics projectiles. The study demonstrates that different types of land and groove marks generated by different guns have distinctive surface textures, and these textures can be measured and identified effectively by spectral analysis. It is clear that spectral analysis is an effective method to study line-scanned images of projectile specinlen. The method can surmount difficulties with descriptions in the normal spatial domain in identifying texture featnres formed by land and groove marks on the surface of projectiles.

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