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Abstract

Ballistics firearm identification based on image processing is of paramount importance in criminal investigation. The efficiency of traditional ballistics imaging system is heavily dependent upon the expertise and experience of end-user. An intelligent ballistics imaging system is highly demanded to address this issues. The segmentation of cartridge case object from the original image is a key step to subsequent process. It is very difficult to segment cartridge case from the original image using traditional threshold based methods due to the shadows or unlimited environments to acquire image. In this paper, we proposed a novel approach based upon the colour invariant and geometrical shape of objects. The experimental results show the proposed method can precisely segment the objects in various images such as heavy shadow, low contrast, uneven illumination etc.

Keywords
Ballistics system, firearm identification, image processing

INTRODUCTION

The analysis of marks on the cartridge case and projectile of a fired bullet is very important to identify the firearm from which the bullet is discharged [1, 2]. When a firearm is loaded and fired, the characteristic marks are produced on the cartridge case and projectile. These marks are significant evidences for identifying the suspicious firearm. Over thirty different features within theses marks can be referred as a 'fingerprint' for ballistics recognition [3]. Since each firearm owns its unique toolmarks [4, 5], it is possible to identify both the type and model of a firearm and each individual weapon as effectively as human fingerprint identification.

For ballistics image processing segmentation is the first essential and important step of low level vision. In all these areas, the quality of the final output depends largely on the quality of the segmented output[6]. Conventional algorithms are mainly based upon one of two basic properties of reflective light intensity values, namely discontinuity and similarity[7]. Given that the objects in an image appear lighter (or darker) than the background, one may attempt to segment the image by means of global threshold or local thresholds. A drawback of these approaches is that the result of segmentation is strongly affected by luminance, shadow and noise. In this paper, we proposed a new segmentation algorithm, which based upon the colour invariants and geometrical shape of objects. The colour invariant functions are demonstrated to be invariant to a change in the imaging conditions, such as viewing direction, object's surface orientation and illumination conditions[8]. Therefore this method can overcome the impact of luminance and shadow which is often a difficult task in the traditional pre-treatment of images.

The satisfactory results are obtained using this method in segmentation of cartridge in ballistics images. These images are often acquired across a range of different conditions and usually include shadows. Most background will be removed by using colour invariant properties. But the resulting image still contain some points which belong to the original background which cannot be removed because the RGB values are unstable near the black vertex of the RGB space, where it is undefined[9], while hue is unstable near its singularities at the entire achromatic axis[10]. The remaining points will be removed based on the geometry of cartridge. After these two steps, the cartridge can then be precisely segmented from the image. The method of the algorithm is detailed as follows:

Step1: Image acquirement. In order to benefit segmentation of cartridge, a selection of background colour is done firstly. The colour invariant values of background have at least 0.2 differences from the invariant values of the objects which will be segment from the image. Then the original image can be acquired using selected background.
Step2: Remove the most background from the original image depend upon colour invariant properties
Step3: Remove the rest black shadows which cannot be removed using colour invariant properties because colour invariant properties are unstable near the black vertex of the RGB space.

Step4: Search for the range of objects by geometrical shape of objects using Hough transform, then segment the objects base upon the result of Hough transform.

This paper is organized as follows. In Section 2, describes the colour invariant properties, selection of background and image acquirement method, whilst the segmentation algorithm is described in Section 3. Experimental results are presented in Section 4, and in Section 5 conclusions are given.

IMAGE ACQUIREMENT

2.1 Color invariant properties

Firstly, we briefly describe the colour invariant properties employed in our approach. Photometric colour invariants are functions which describe the colour configuration of each image point discounting shadows, and highlights[11]. These features are demonstrated to be invariant to a change in the imaging conditions, such as viewing direction, object's surface orientation and illumination conditions[8]. Colour invariants features are acquired by RGB[3]. In particular, among the different photometric invariant colour features, as stated in[11], we adopted the $c_1c_2c_3$ model. The $c_1c_2c_3$ invariant colour features are defined as follows:

$$C1(x,y) = \arctan \frac{R(x,y)}{\max(G(x,y),B(x,y))}$$

$$C2(x,y) = \arctan \frac{G(x,y)}{\max(R(x,y),B(x,y))}$$

$$C3(x,y) = \arctan \frac{B(x,y)}{\max(R(x,y),G(x,y))}$$

The R(x,y),G(x,y),B(x,y) representing the red ,green and blue components of a pixel in a image.

Fig. 1 is an example of colour invariant features. There are same background in Point A and B. The difference is point A in light but point B in shadow. Table 1 shows the values of point A and B in two spaces. The invariant colour values have a small change caused by noise but RGB values have a large change.

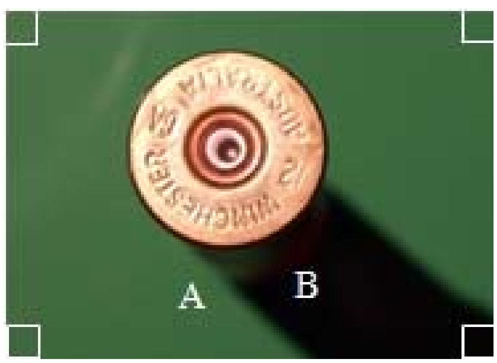


Fig. 1.Invariant colour features

Table 1 invariant colour and RGB value

point	Invariant color Values			RGB Values		
	C_1	C_2	C_3	R	G	B
A	0.55	1.00	0.54	65	106	62
B	0.54	1.03	0.38	3	5	2

2.2 Select color of background

It is not an easy problem to segment cartridges from image initially obtained due to the shadows of cartridges and unequal luminance. The Dong[12] used a ring lights to help to minimize these effects. Yet, such a system still has two major drawbacks. One is that the ring lights depress the contrast density which is very important information for recognition, the other is it has a limited range dependent upon the technician, the lighting as well as other environmental conditions. However, the segmentation process based on invariant properties can work well on the images acquired without any special conditions.

Fig2. 8 typical samples of cartridge

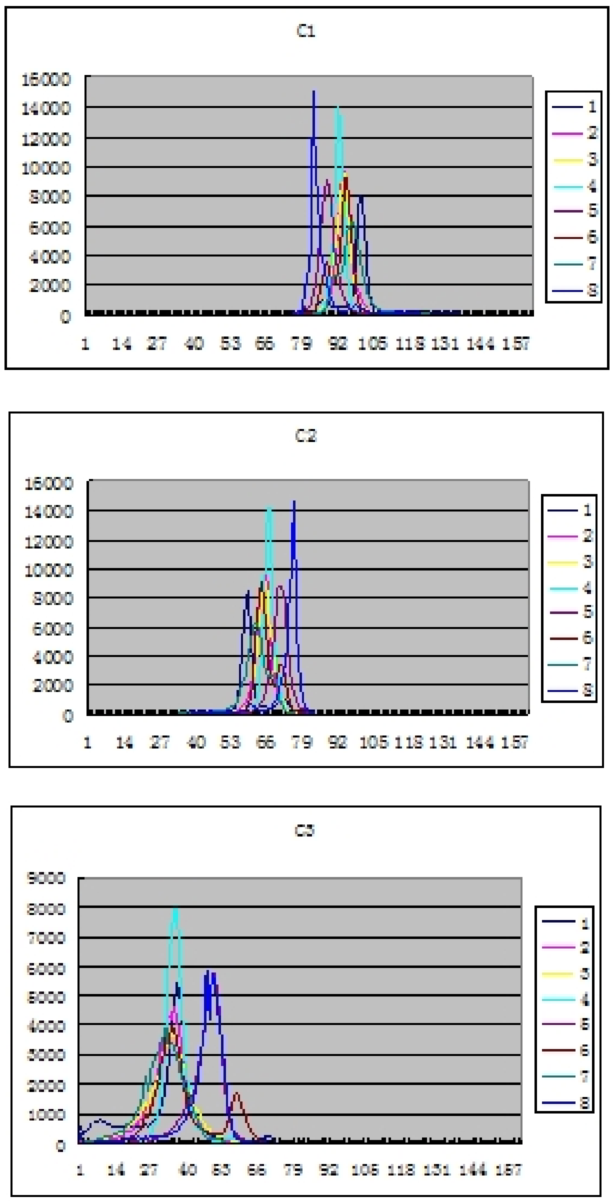


Fig. 3 Values of c1, c2 and c3

In order to use colour invariants, we must select a background and ensure that its colour invariant values do not overlap the cartridge's values. Firstly, we have measured eight familiar types of cartridge. We know that $\arctan \in [-\pi/2, \pi/2]$. Moreover, RGB are positive, so $c_1c_2c_3 \in [0, \pi/2]$. In order to find the range of $c_1c_2c_3$ of cartridge, we select 8 typical images of cartridge [Fig. 2] to compute their values of $c_1c_2c_3$. The results show in Fig. 3, where, X-axis is the value of c_1, c_2 or $c_3\times100$, Y-axis is the number of pixels with the same invariant value, and the size of sample images is 300×300. The Fig. 3 shows the values of c_1, c_2 or c_3 are concentrated, and their values are respectively $C_1 \in [0.71,1.11], C_2 \in [0.4,0.80], C_3 \in [0,0.80]$. So it's easy to select a background which values of $c_1c_2c_3$ have enough distance with the values of cartridges. Therefore, we set the distance to 0.2, which means the values of $c_1c_2c_3$ in background colour are respectively $C_1 \in [0,0.5] or C_1 \in [1.3,1.57], C_2 \in [0,0.2] or C_2 \in [1.0,1.57], C_3 \in [1.0,1.57]$. According to the range of $c_1c_2c_3$ in background, we search the available background using RGB by computer and get the values are $R \in [0,106], G \in [0,24]], B \in [120,255]$. The RGB values produced by the same object may change because of differences in input devices, illumination etc. Therefore, we select the middle value of available RGB as the background, which is R=54, G=12, B=170, their corresponding values of colour invariant properties is c_1= 0.31, c_2=0.07, c_3=1.26. The colour with R=54, G=12, B=170 is near to purple, so we select a purple as a background. And it is proved that the purple is a good background to segment cartridge by extensive experiments.

2.3 Image acquirement

Image acquirement is a simple step and requires no other condition except using a background such as that described in section 2.2. Then the image can be acquired using a digital camera or a video camera.

IMAGE SEGMENTATION

A novel method to segment the cartridge based on the colour invariant features and geometry is employed. This method included three steps. 1)Removing background using colour invariant; 2)Removing black shadow; 3)search for the range of cartridge by geometry. A detailed description of the three steps is given in the following sections.

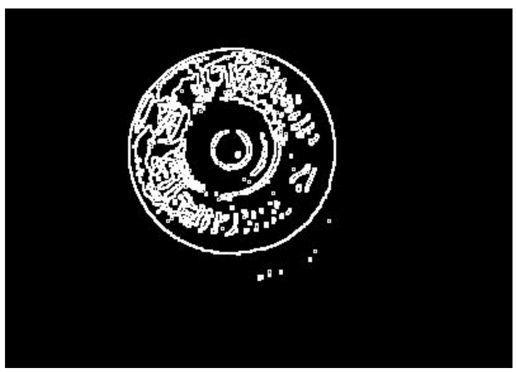
3.1 Removing background

In order to remove the background, we must know the values of $c_1c_2c_3$ in that background. The 4 corners in each image are the background due to the circular cartridge, so we get a small image with 10×10 in each corner of the image (shows in Fig. 1 with a white rectangle in each corner). Thus, we obtain 4 small images, and compute the average values of $c_1c_2c_3$ in all 4 small images, and save them in variables rc1, rc2 and rc3 as the reference values of background. Then all pixels in the image are scanned and set to white if the differences between the invariant value of pixel and the reference value are all more than 0.2. Benefiting from the special background colour, the differences between the invariant value of the cartridge and the reference value are generally more than 0.2. Thus the operation cannot modify the value of cartridge. Fig.4 (a) is a result after this operation from Fig. 1.

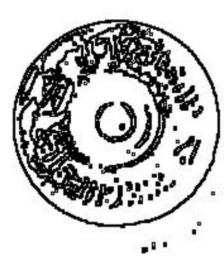
(a)

(b)

(c)



(d)



(e)

(f)

Fig. 4 (a) Remove background using colour invariant features
(b) Remove black point whose R+G+B value is below 30
(c) Binary image using threshold value 255
(d) Sobel filter of (c)
(e) Binary image of (d)
(f) Segmented cartridge using fitting circle

3.2 Removing black shadows

Comparing the Fig. 1 and Fig. 4(a), we find the most background colour has been removed. However, it still possesses some pixels which belong to the background which cannot be removed because the RGB values are unstable near the black vertex of the RGB space, where it is undefined[13]. Therefore, the pixels give rise to unstable invariant features values in presence of noise[10]. Otha [12] thinks that the colour invariant properties become unstable and meaningless when R+G+B value is less than 30. So we extracted those pixels whose R+G+B value is below 30 and which are also verified in a wide range of test images that these regions belong to shadows. Therefore we set those pixels to white. After this operation, we obtain the image Fig 4(b) where the black pixels have been removed.

3.3 Search for the range of cartridge by geometry

Now, good cartridge images are obtained, but they still have some background pixels, and the borders of cartridge are not smooth [Fig.4 (b)]. Moreover, some pixels of cartridge also are removed because its invariant values fall in removed window. In order to resolve this issue, we use the prior knowledge. It is well know the cartridge is a circle, so we segment the cartridge fitting it into a circle. The method is as follows:

1) Firstly we bifurcate the image [Fig.4 (b)] by setting the pixels to black if its RGB values less 255 whilst the remaining pixels are set to white. The aim of this operation is to change the cartridge into black and the background into the white. The best result of this operation is a solid black disc on a white background because such a solid black disc is very useful in detecting the circle of the cartridge. The Fig.4(c) shows the image after this operation.
   In Fig.4(c), we can see the black edge form a circle which is just the edge of cartridge. So if we can detect the circle, the cartridge will be segment precisely. It is well know Hough transform is a popular algorithm to detect circle. But the computational cost is very large if the Hough transform is directly undertaken using image [Fig.4 (c)], because the number interesting points, the black pixels, is also very large. So we perform the following two steps to reduce the computational cost of the Hough transform. Firstly, the Sobel filter is applied to produce image [Fig.4 (c)] and also obtain the edge image [Fig.4 (d)]. Then image is binarized [Fig.4 (d)] using Otsu algorithm[9] and the image [Fig.4 (e)] obtained. Now the number of interesting pixels is much less than before, so the amount computation required is also greatly reduced. It should be noted that if the image [Fig.4 (c)] is a solid disc, the image [Fig.4 (e)] will have the least black pixels resulting in the least computational cost of Hough transform.
2) Detect the circle in [Fig.4 (e)] using Hough transform. The equation of circle is $(x-a)^2+(y-b)^2=r^2$, This familiar equation can be changed into the form $b = y \pm \sqrt{r^2 - (x-a)^2}$. So the key to reduce the computational of detecting a circle is to reduce the range of parameters a, b, and r. The steps of setting their range are as following:
   Ⅰ) Making sure the rectangle contains the points where the circle exists. It is easy to make sure the up left coordinates (LeftX,LeftY) and the bottom right coordinates (BottomX,BottomY). The Fig. 5 shows the rectangle.

Ⅱ) Once the rectangle is confirmed, the parameter r can be confirmed in the following way: the maximum r maxR=min(BottomX-LeftX,BottomY-LeftY)/2 and the minimum r minR= min(BottomX-LeftX,BottomY-LeftY)/3. The minR is an heuristic value obtained by extensive experiments.

Ⅲ) Now we can discover the range of a and b easily. Minimum a minA=LeftX+minR and maximum a maxA=BottomX-minR. Correspondingly we can also discover the values of Minimum b minB=LeftY+minR and maximum b maxB=BottomY-minR

The three steps mentioned above greatly reduce the range of parameters a, b and r, and so the computation overhead of Hough transform is also greatly reduced.

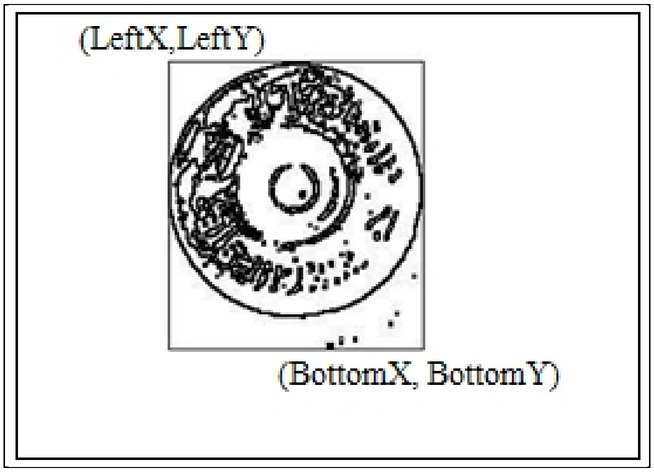


Fig. 5 The Hough Transformed Image

3) Set each cell in accumulator A(a,b,r) to 0. Then, for each black point (x,y) in Fig. 4(e), we let the r, a equal each of the allowed values, and compute the corresponding b value using the equation $b = y \pm \sqrt{r^2 - (x-a)^2}$. The b values are rounded off to the nearest integer. If $b \in$ (minB,maxB), then we let A(a,b,r)= A(a,b,r)+1. At the end of the procedure, a value of A(a,b,r) means that the number of black points lie on a circle $(x-a)^2+(y-b)^2=r^2$. We can see that the value of a,b,r in the cell with maximum value in accumulator A(a,b,r) is the value of the circle which is the edge between the cartridge and the background. (i.e. in [Fig. 4 (e)], a=178, b=113, r=81). Thus, we can extract the circular region of cartridge which coordinates of circle centre is (a,b) and radius is r from the original image [Fig. 1]. The image [Fig.4 (f)] is the result of segmentation.

EXPERIMENTAL RESULTS

1.1 Test set

In order to test the proposed algorithm, an experimental database was constructed. Which contained 35 cartridges, and each cartridge had 3 images acquired in different environments: outdoor, indoor, and using a single light source. The Fig. 6A shows images obtained respectively from these three different environments. The image size is given in pixels. Basically, the door image has no shadow, and indoor image has some light shadow, whilst the single light source image has heavy shadowing.

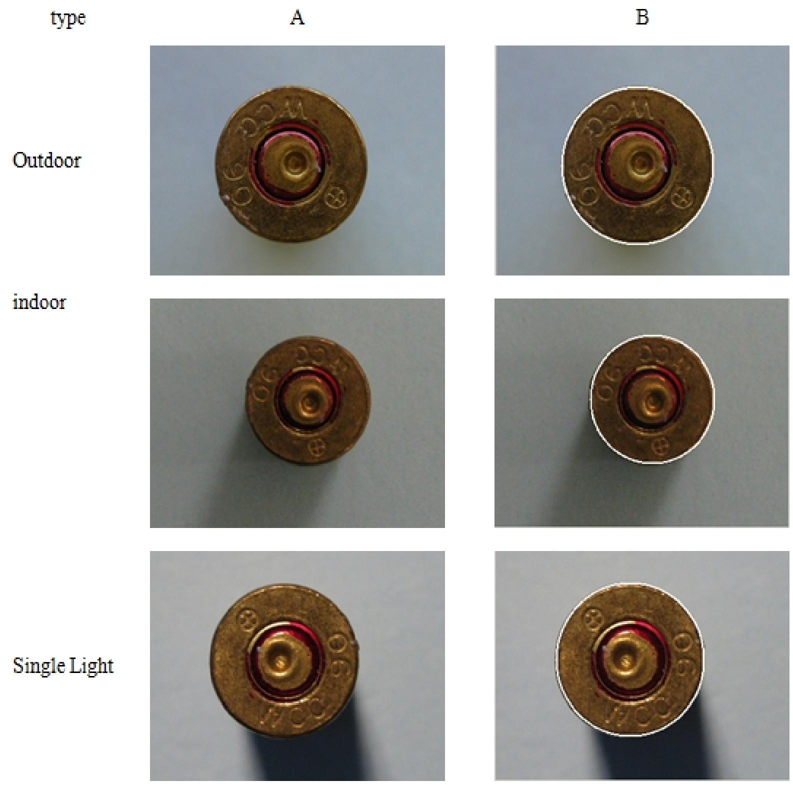


Fig 6 Cartridge segmentation results.
A: Original image
B: Detected cartridge (within white circle)

1.2 Cartridge segmentation results

The 105 640×480 images in our database were segmented. All cartridges could be segmented precisely. Figure 6 shows the results of the proposed algorithm for one cartridge in 3 environments. The original images (Fig. 6A) and the detected cartridges on the original image (Fig. 6B) are displayed. In order to display the detected precision, we do not segment the cartridge from the original image, but show the detected region by a white circle. From Fig.6B, we can see the cartridges are precisely detected by the proposed algorithm. It takes about 1.2s to segment object from the source image with 640*480 pixels on PC(CPU: Intel Pentium4 2GHz, RAM: 1GB).

CONCLUSION

In this paper, we described an efficient method for segmenting cartridge images. This proposed method is based on colour invariant properties as well as geometry. The proposed approach was demonstrated through its application to a number of test images obtained under three common different forms of illumination. This method has no special limitations in respect to the image input environment except that of a designated background. A method of reducing computational overhead was also presented.

Firearm identification aims to provide a link between the suspect firearm and the forensic ballistics specimens based on the depressions, scratches and markings on the specimens of cartridge cases and projectiles. These various marks are called 'toolmark' and it is thought that the toolmark is unique to itself. In this regard, it is possible to identify the suspect firearm by toolmark left on ballistics specimens with advanced image processing technologies.

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