Model-Based Segmentation of Impression Marks

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ABSTRACT

Impression marks are commonly found at crime sites. These forensic marks are compared to archived marks to find connections to other crimes or to suspects. Up to now, this processing is done mainly manually and can be accelerated by using automated comparison techniques. The illumination conditions in the marks are often difficult to handle. To optimize the lighting automatically, it is necessary to identify the marks in images taken from the specimen or its casting.

Finding the marks in the image of the specimen or its cast is also the first step of an automated comparison. In many cases this segmentation can be automated with a model-based approach. For example, gripper marks and faked serial numbers on engine blocks or on electronic devices are often situated on approximately plane surfaces. Therefore, the segmentation task can be defined as detecting indentations in plane objects.

In this paper the depth-from-focus method is applied to obtain $2\frac{1}{2}$D-data from the object. A robust plane estimation method finds the flat parts of the surface. The estimated plane is used as local threshold and leads to a binary segmentation image. The results is improved by removing small regions that do not belong to the impression mark. The introduced segmentation is exemplarily performed on a serial number in aluminium sheet.

With the introduced method, it is possible to optimize the illumination in order to achieve a higher contrast of surface details. The improved image quality helps the examiner in identifying correlated specimens and will help to improve automated comparison strategies for impression marks.

Keywords: forensic science, impression mark, segmentation, illumination series, focus series

1. INTRODUCTION

Many forensic marks can be found on crime sites. These marks or their castings are compared with archives of marks to find connections to other crimes. If suspect tools are found, comparison marks are produced and compared to the archive or the specimen of a specific crime. Up to now, this comparison process is done by forensic experts mainly manually and can be accelerated by the use of automated comparison techniques. In this paper, impression marks are investigated like serial numbers, gripper marks and the marks on cartridge cases. Photos of some impression marks are given in Figs. 2 and 9(a).

There are several steps for an automated comparison, see the flow chart in Fig. 1. First, the marks have to be found in images of the specimen by an automated segmentation. With the knowledge of this segmentation step it is possible to improve the image quality by optimizing the illumination in the indentations. The improved image quality helps the examiner in comparing the specimen manually and is prerequisite for a successful automated comparison.

In this article an approach to the segmentation task is presented. In many cases the segmentation can be automated by a model-based approach. For example faked serial numbers on engine blocks or on electronic devices are often situated on approximately plane surfaces. Other examples are gripper marks or the firing pin mark in the plane primer of a cartridge case. Therefore, the segmentation task can be defined as detecting indentations in plane objects.

The depth-from-focus method is applied to obtain $2\frac{1}{2}$D-data. The segmentation starts with the preselection of data points followed by a plane estimation that leads to the feature extraction.

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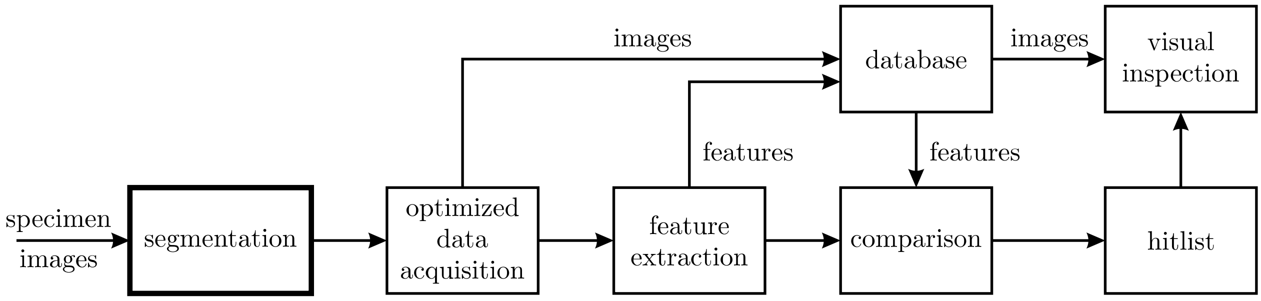

Figure 1. Flow chart: automated comparison.

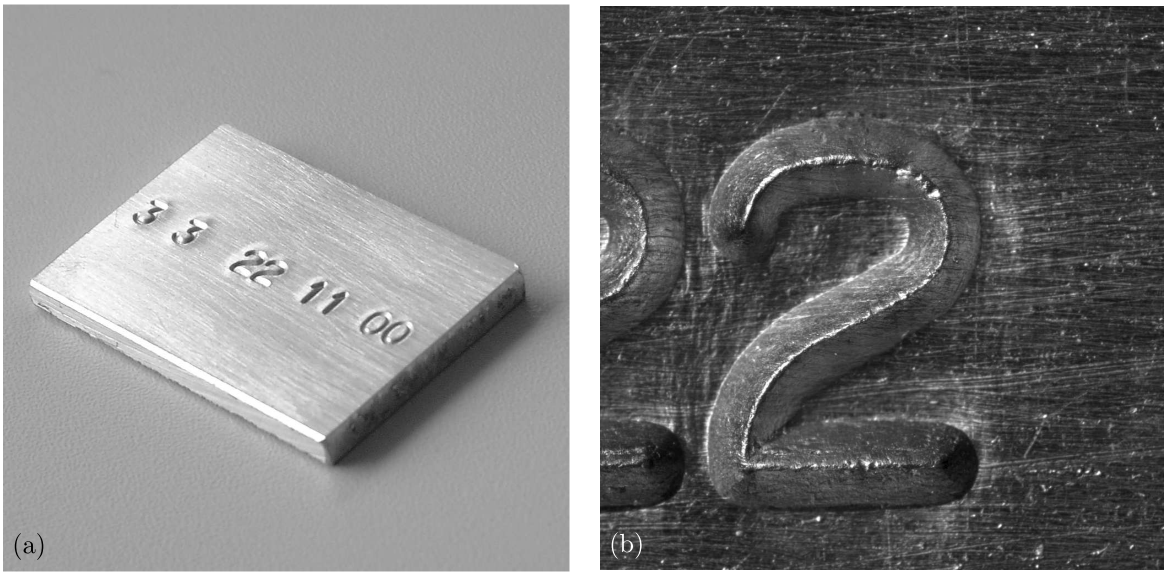

Figure 2. (a) Photo of a serial number in an aluminium sheet; (b) detail.

2. DATA ACQUISITION

2.1. Image Acquisition Setup

The specimen of interest are modeled as a plane surface containing several indentations. Due to their creation process the interesting marks occur in the regions deeper as the considered plane only.

The shape information can only be used if three dimensional data of the object is available. Therefore, this approach requires at least $2\frac{1}{2}$D-data, which can be obtained by one of the numerous standard methods, e. g. interferometry, active triangulation[1] or the depth-from-focus[2] method. The image acquisition system of GE/2, see Fig. 3, used for the measurements shown in this paper is able to record various illumination as well as focus series automatically.[3] See Fig. 4 for some of the possible illumination configurations. Thus, the system is able to deliver the data that is necessary for the depth-from-focus method. The advantage of the depth-from-focus method compared to interferometry and active triangulation is, that the images for the depth reconstruction and for the subsequent 2D comparison can be acquired using the same setup with reproducible position and orientation of the specimen.

The illumination conditions for the segmentation task are optimized for the image processing but not for the visual comparison. The goal is to choose a lighting of the scene that generates as much contrast as possible. Therefore, directional light from a spotlight illumination is used to achieve a high contrast in the image.

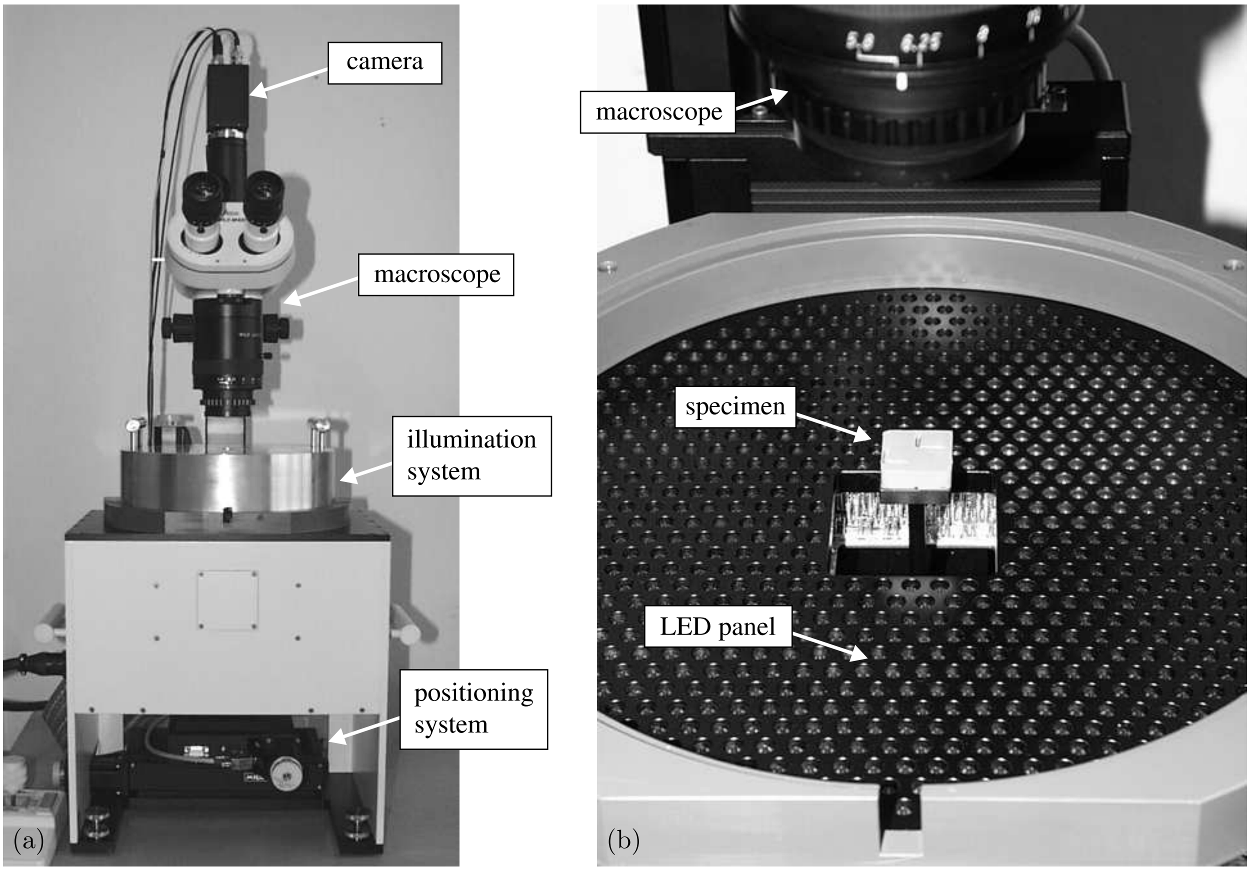

Figure 3. Image Acquisition Station (IAS) of GE/2: (a) general view; (b) illumination system (parabolic reflector removed).

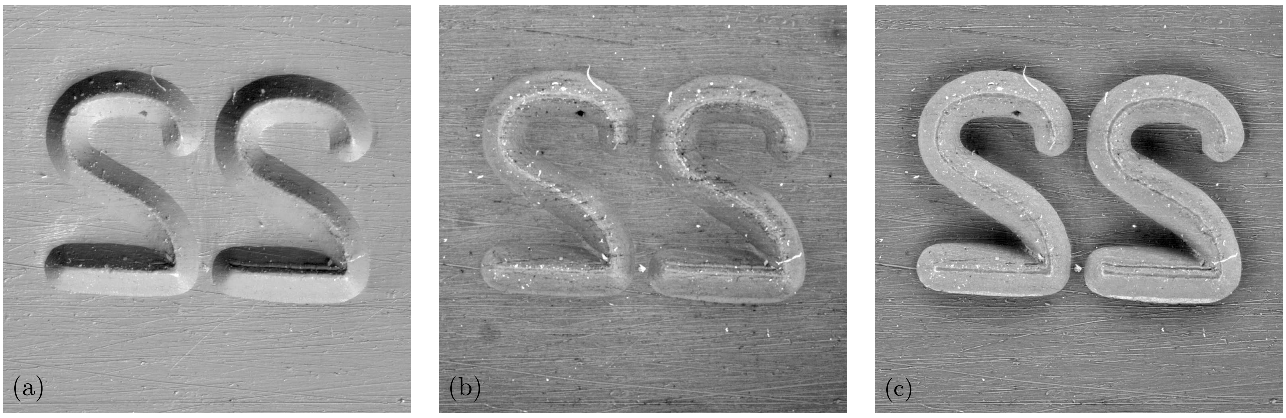

Figure 4. Part of a serial number casting illuminated with: (a) spot, (b) diffuse and (c) ring light.

2.2. Depth-From-Focus

The well known depth-from-focus method is applied to obtain $2\frac{1}{2}$D-data of the impression mark. Therefore, a focus series of the mark is acquired, see Fig. 5 for an example.

The local blur can be estimated by measuring the local variance,[4] in this case the standardized local variance:

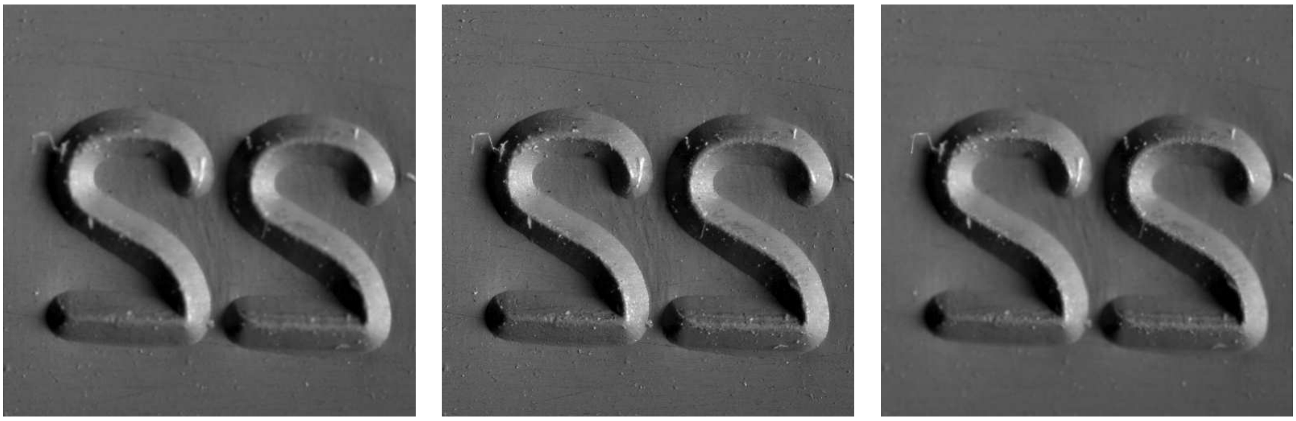

Figure 5. Focus series of a serial number casting.

$$\sigma_{\mathrm{s}}(\mathbf{x}) = \frac{\sum\limits_{\mathbf{a}\in\mathcal{U}} \left(g_z(\mathbf{x}+\mathbf{a}) - \overline{g}_z(\mathbf{x})^2\right)}{\overline{g}_z(\mathbf{x})} \quad ; \quad \overline{g}_z(\mathbf{x}) = \frac{1}{|\mathcal{U}|}\sum_{\mathbf{a}\in\mathcal{U}} g_z(\mathbf{x}+\mathbf{a}) \tag{1}$$

This calculation results in a contrast curve over the distance to the focal plane for each pixel. The position of the curve maximum is used as depth position.

2.3. Fusion of depth maps

The specimen usually have a surface with high depth range. Therefore, cast shadows occur often in the images, causing areas with very little contrast. Highlights on edges create a similar effect.

Thus, the depth reconstruction with several focus series captured under different illumination conditions is advantageous. The exemplarily presented series are acquired with both, spot light azimuth and focus position variation. First, the depth maps of the different illuminated focus series are computed. Then a quality factor for each pixel is calculated from the difference of maximum and minimum of the contrast curve:

$$q(\mathbf{x}) = \max\{\sigma_{\mathrm{s}}(\mathbf{x})\} - \min\{\sigma_{\mathrm{s}}(\mathbf{x})\} \quad . \tag{2}$$

Then, the depth maps of different illuminations are merged using the depth information with the highest quality for each resulting pixel. See Fig. 6 for an example.

3. SEGMENTATION

3.1. Preprocessing

In the obtained $2\frac{1}{2}$D-data many gross errors are found. Therefore, a preselection of data points is accomplished in two steps. The first useful information arises from the geometry of the acquisition setup. The object holder is nearly perpendicular to the optical axis of the microscope. Therefore, the plane to be estimated is approximately horizontal. Hence, there is a peak in the depth histogram of the $2\frac{1}{2}$D-data. The data points are restricted in the subsequent way:

$$z_{\max} - f_1 < z_i < z_{\max} + f_1 \quad , \tag{3}$$

where $z_{\max}$ the position of the maximum of the depth histogram and f_1 a positive tolerance factor. In the next step the data points are restricted a second time:

$$\mu - \sigma_2 \cdot f_2 < z_i < \mu + \sigma_2 \cdot f_2 \quad , \tag{4}$$

where μ is the average and f_2 a positive tolerance factor.

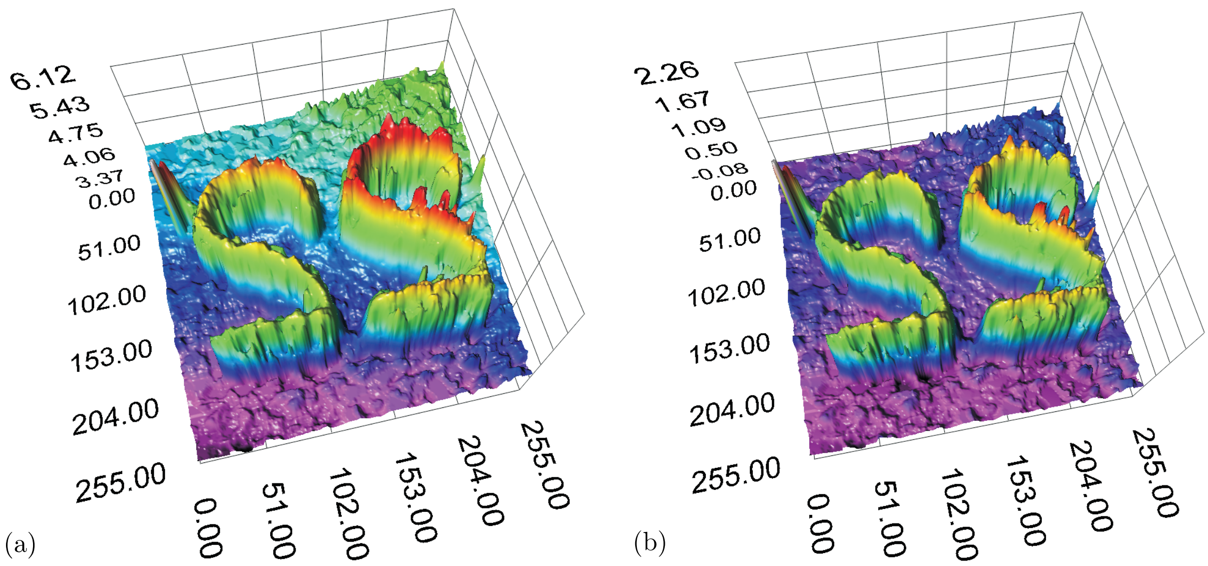

Figure 6. 3D plot: (a) median filtered image; (b) distance image.

3.2. Parameter estimation of surface planes

After the data selection step the position and orientation of the plane part of the surface is estimated robustly. The parameters of the wanted plane are calculated using a Total-Least-Square (TLS) fit.[5] The plane is given by $\mathbf{n}\mathbf{x} - d = 0$, where the vector $\mathbf{n}$ has the length of one. $M_0 = (x_0, y_0, z_0)^{\mathrm{T}}$ is a point in the plane. The distance d_i of any point $M_i = (x_i, y_i, z_i)^{\mathrm{T}}$ to the plane is:

$$d_i = a \cdot (x_i - x_0) + b \cdot (y_i - y_0) + c \cdot (z_i - z_o) \quad . \tag{5}$$

The aim is the minimization of the distance

$$\sum_{i=1}^{n} d_i^2 \rightarrow \min \quad , \tag{6}$$

where n is the number of points in the data set. Solving this problem leads to the plane with the least square error.

3.3. Feature extraction

After estimating the parameters of the surface plane, the extraction of features can be accomplished. The $2\frac{1}{2}$D-data is filtered with a median filter to remove gross errors as depicted in Figs. 6(a) and 7(b). The distance to the plane is calculated for each data point, see Figs. 6(b) and 7(c). Then, a threshold is applied to this distance image.

The result is depicted in Fig. 8. The letters of the serial number were found. But there are still small areas not belonging to the impression mark.

3.4. Postprocessing

The threshold result suffers from errors that lead to small black or white regions in the image. The data can be improved by the use of morphological operators. The size of all regions in the image is calculated. Regions smaller than a threshold are removed. See Fig. 8 for an example.

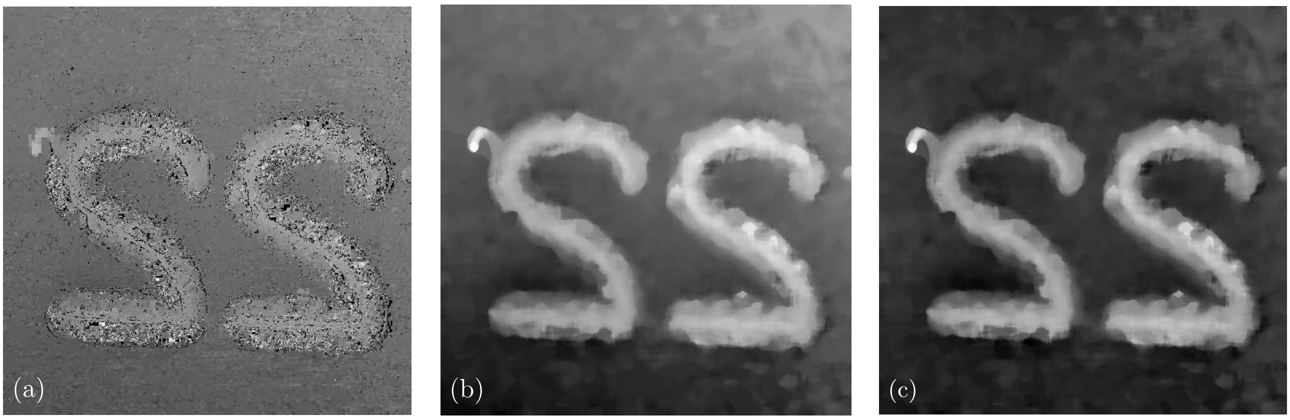

Figure 7. Segmentation based on $2\frac{1}{2}$D-data: (a) $2\frac{1}{2}$D-data, depth coded as gray value; (b) median filtered data; (c) distance image.

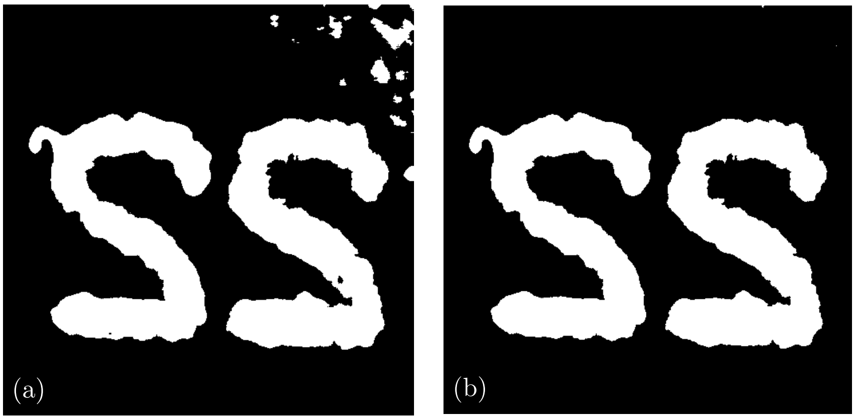

Figure 8. Data improvement: (a) threshold result; (b) small regions removed.

3.5. Other examples

The described approach is also very useful for other forensic specimen like cartridge cases as depicted in Fig. 9.[6] In this case the manufacturing of the cartridge case is responsible for the plane shape of its bottom. In Fig. 9(b) the $2\frac{1}{2}$D-data of a cartridge case is shown. The threshold results in an image where the letters in the cartridge case as well as the cartridge case border, the primer and the firing pin are clearly visible, see Fig 9(c). Thus the marks of the firing pin and the breech face can be separated automatically for the comparison.

4. CONCLUSIONS

A segmentation of impression marks is required for an automated comparison of specimen found at crime sites.

A model-based segmentation approach based on $2\frac{1}{2}$D-data obtained from a depth-from-focus method was introduced in this paper. The data is segmented by fitting a plane to the flat parts of the specimen surface. This divides the impression mark from the surrounding manufacturing marks.

The approach delivers promising results for many tasks. The method can be applied to arbitrary but accurate $2\frac{1}{2}$D-data. Thus, it is independent from the data source.

Altogether, it was shown that the presented approach is useful to realize an automated segmentation of serial numbers as well as cartridge cases. The illumination conditions in the area of the impression marks can be optimized to achieve an appropriate image quality for the visual inspection and to accomplish an adequate feature extraction for an automated comparison.

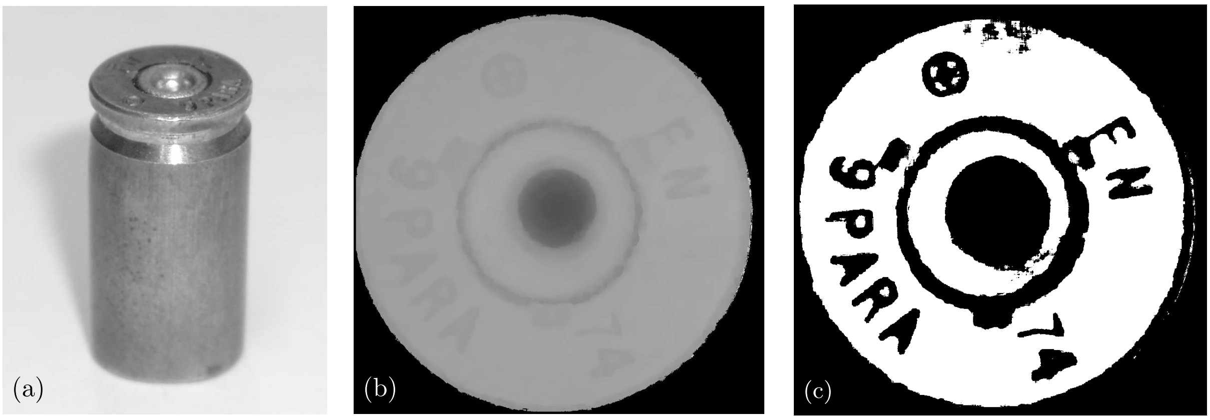

Figure 9. Segmentation of a cartridge case based on $2\frac{1}{2}$D-data: (a) cartridge case photo; (b) $2\frac{1}{2}$D-data; (c) threshold result.

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