Topography measurements for correlations of standard cartridge cases

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ABSTRACT

The National Institute of Standards and Technology Standard Reference Materials (SRM) 2460 Standard Bullets and 2461 Standard Cartridge Cases are intended for use as check standards for crime laboratories to help verify that their computerized optical imaging equipment for ballistics image acquisitions and correlations is operating properly. Using topography measurements and cross-correlation methods, our earlier results for the SRM bullets and recent results for the SRM cartridge cases both demonstrate that the individual units of the SRMs are highly reproducible. Currently, we are developing procedures for topographic imaging of the firing pin impressions, breech face impressions, and ejector marks of the standard cartridge cases. The initial results lead us to conclude that all three areas can be measured accurately and routinely using confocal techniques. We are also nearing conclusion of a project with crime lab experts to test sets of both SRM cartridge cases and SRM bullets using the automated commercial systems of the National Integrated Ballistics Information Network.

Keywords: Forensic science, ballistics identification, standard bullet, standard cartridge case, topography measurement, confocal.

1. INTRODUCTION

Fired cartridge cases and bullets are marked with characteristic signatures, which are unique to the firearm. Impression marks on the fired cartridge case are caused by impact from the firing pin, breech face, and ejector. Striations on the fired bullet are caused by its passage through the gun barrel. By analyzing these ballistics signatures, firearm examiners can connect a firearm to criminal acts[1]. The procedure of comparing similar cartridge cases and bullets with comparison optical microscopes to determine whether the evidence has been fired from the same firearm is a standard practice for crime labs. Since the 1990's, automated optical systems have also been developed for speeding up the process of ballistics identification[2] in crime labs. The automated microscopes are widely used for acquisition of casing and bullet

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images, which are stored in databases. Correlation software is then used for similarity testing of the stored images to assist in the investigation of gun related crimes. There are several such installations in the United States. The largest of these is the National Integrated Ballistics Identification Network (NIBIN)[3] operated by the Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATF) comprising about 235 imaging stations across the country. Similar systems have been developed in other countries.

Most systems are based on optical imaging comparisons; however, ballistics signatures are 3D geometrical topographies by nature. When a topography feature is observed with an optical microscope, its optical images may show large variations depending on the lighting conditions, such as the intensity and direction of the light, potentially resulting in significant uncertainty in correlations of the acquired images with these systems. In this paper, we discuss the advantages of using topography measurements for correlation of cartridge cases and emphasize topography methods for imaging cartridge cases intended as physical standards in crime labs.

The National Institute of Standards and Technology (NIST) and the ATF have collaborated on the development of physical standards for verification and traceability of the automated optical systems and the associated acquisition procedures.[4] The NIST Standard Reference Material (SRM) 2460 Standard Bullets and 2461 Cartridge Cases are seeing use as check standards for crime laboratories to help verify that their computerized optical imaging equipment for ballistics image acquisitions and correlations is operating properly. These SRM Bullets and Casings are aimed to support the NIBIN, as tools for ballistics measurement quality control, measurement unification, and traceability to standards. Because similarity of surface topography and its appearance is a key factor in firearms identification, the reproduction of identical standards is a key property in this activity. Essentially identical standards are required to demonstrate that different systems across the country are operating the same.

In order to test the topography reproducibility of the SRM Cartridge Cases and Bullets, the cross correlation function maximum CCF_{max} and a NIST proposed parameter called the topography difference D_s are used in the analysis.[5] A topography measurement and analysis system was developed at NIST for calculating these parameters for correlation of both 2D topography profiles for bullets and 3D topography images for cartridge cases. Thus far we have developed and certified Standard Reference Material (SRM) Bullets (SRM 2460) and are nearing completion on SRM 2461 Cartridge Cases. Earlier results for the SRM Bullets demonstrate that the individual units of the SRMs are highly reproducible. The recent topography measurements of the SRM Cartridge Cases also reveal very high similarity among individual units.

Along the way we had an opportunity to evaluate actual test fired casings[6] under a National Academies study on the feasibility of developing a National Ballistics Imaging Database[7]. One conclusion of our work was that direct measurement of surface topography with a research system provided more accurate determinations of cartridge cases fired from the same firearm than a commercial system using optical imaging alone. This result was obtained for both breech face and firing pin impressions on cartridge cases fired from sets of both new and used firearms. Subsequently, we arrived at a similar conclusion for a set of fired bullets[8].

After fabrication of the first sets of the SRM Cartridge Cases, we recently completed a laboratory comparison of both types of standards with the participation of 20 operators on 15 of the widely used Integrated Ballistics Identification Systems (IBIS)[†] currently operating in the NIBIN. The project was called the National Ballistics Imaging Comparison (NBIC) and was a collaboration of NIST and the ATF.

This paper is about the reproducibility of topography images of the new SRM cartridge cases.

[†] Certain commercial equipment, instruments, or materials are identified in this paper to specify adequately the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

2. CONDITIONS OF TOPOGRAPHY MEASUREMENT

Topography images have been taken of firing pin impressions, breech face impressions, and ejector marks on the surfaces of the standard cartridge cases. All topography measurements were taken with a Nanofocus µSurf confocal microscope, which uses Nipkow Disk technology[9] to provide the confocal effect and produce topography images of the surfaces. Important conditions of these measurements include the nominal magnification of the objective lens, its numerical aperture, the lateral pixel spacing, the vertical spacing of the image slices, the total number of image slices, the number of areas that were stitched to form a composite image, and the areas of the composite images. These and other measurement parameters are shown in Table 1.

Table 1. Instrument parameters of the confocal microscope for topography measurements of three regions of the standard cartridge cases

Region Measured	**Firing Pin**	**Breech Face**		**Ejector Mark**
Magnification	20×	10×	20×	20×
Numerical aperture	0.6	0.3	0.6	0.6
Pixel Spacing	1.563 µm × 1.563 µm	3.125 µm × 3.125 µm	1.563 µm × 1.563 µm	1.563 µm × 1.563 µm
Number of pixels in one field of view	512 × 512	512 × 512	512 × 512	512 × 512
Vertical slice spacing (h)	0.15 µm	0.2 µm	0.15 µm	0.25 µm
Typical number of slices (n)	1000	900	987	967
Total vertical travel (h × n)	150 µm	180 µm	148 µm	242 µm
Number of stitched areas	1 field of view	3 × 3	6 × 6	1 × 2
Approx. size of measured area	0.8 mm × 0.8 mm	4 mm × 4 mm	4 mm × 4 mm	0.8 mm × 1.5 mm

3. SRM 2461, STANDARD CARTRIDGE CASES

The cartridge cases are produced by electroforming replicas from a single 9 mm master selected from several test fires at the ATF. The selection criteria for the master were overall clarity of the firing pin, breech face, and ejector mark impressions, the quality of the master casing material, and the potential for long life during the replication process.

The electroforming process is provided by a commercial vendor[10]. Thin replicas of the base of the cartridge case master are produced by the electroforming process. These replicas are then bonded to real cartridge cases to produce standards that have the approximate geometry of a real 9 mm cartridge case but have a slightly larger diameter, partly so that the standards cannot be mistaken for actual fired 9 mm cartridge cases. A photo of several cartridge case SRMs is shown in Fig. 1. The final products are positive replicas, not of the master itself, but of several positive (3rd generation) replicas of the master. Thus far, four sets of cartridge case replicas, about 278 units in all, have been fabricated. Altogether, 250 units of cartridge cases are planned to be measured, certified, and made available as SRM 2461. Each unit will have its surface topography measured by confocal microscopy in the regions of the firing pin impression, breech face impression, and ejector mark. Each unit will also undergo IBIS[11] acquisition of its firing pin impression, breech face impression, and ejector mark.

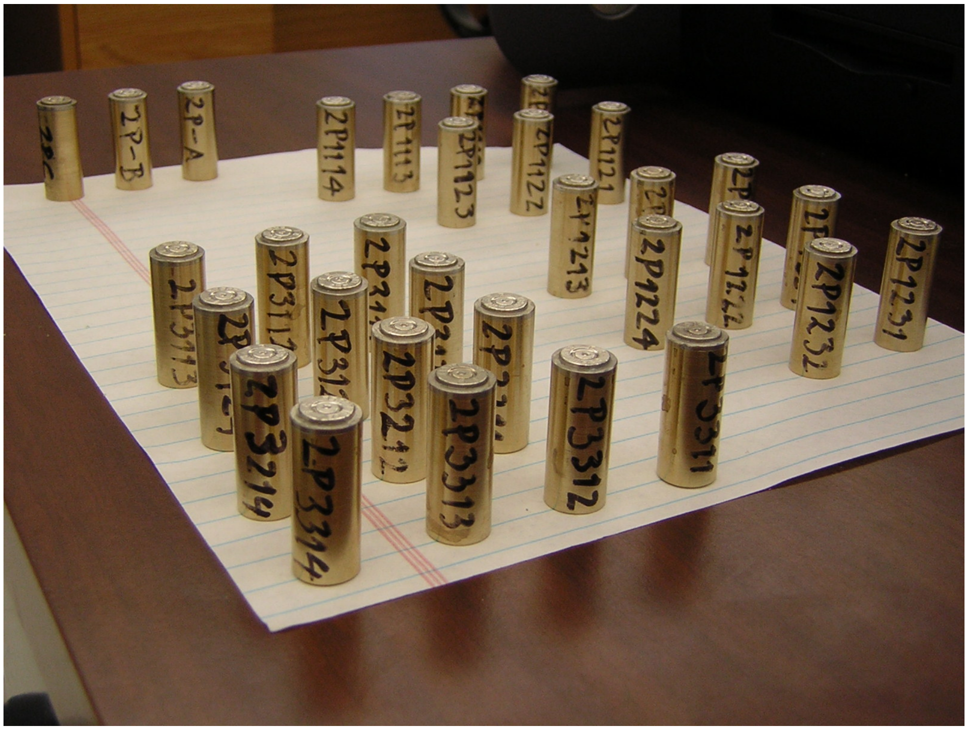

Figure 1. Typical batch of SRM cartridge cases. The buttons on top are the electroformed Ni replicas, which are bonded to turned cylindrical bases. The outer diameter is about 13 mm.

4. TOPOGRAPHY IMAGES OF FIRING PIN IMPRESSIONS

Approximately 150 firing pin impressions have been measured for their surface topography. An example of a topography image is shown in Fig. 2. It has an overall bowl shape upon which are superimposed fine markings, which may be used as identifying characteristics. The correlations so far have been performed with respect to the SRM unit with serial number 007. For each casing, the correlation is done after a high-pass Gaussian filter[12] with 0.25 mm cutoff has been applied to remove the bowl shape. As an example, the correlation of unit #110 with unit #007 is shown in Fig. 3. The upper two graphs are color plots of the unfiltered topography data; the lower two graphs on the left and in the middle are the filtered data and they appear almost identical. The middle graph is shown slightly rotated and translated to produce optimum alignment as determined by a registration program with automated search capability, which calculates the cross-correlation function maximum CCF_{max} between the two topographic images for each rotational and translational position chosen.

If the match were perfect between the two images, the value of CCF_{max} would be unity, or 100 %. The value of 99.6 % obtained here is excellent and shows the high degree of reproducibility of the two casing firing pin impressions.

Figure 4 shows the CCF_{max} results for the first 173 units received when correlated with respect to unit #007. The goal specification is that the value of CCF_{max} be greater than 95 % for all units of the SRM when each firing pin impression is correlated with the firing pin impression for unit #007. So far, nearly all the units have acceptable surface topography. The four units that do not qualify are all seen to have defects or unremovable debris on their surfaces. The presence of these artifacts evidently reduced the CCF_{max} values.

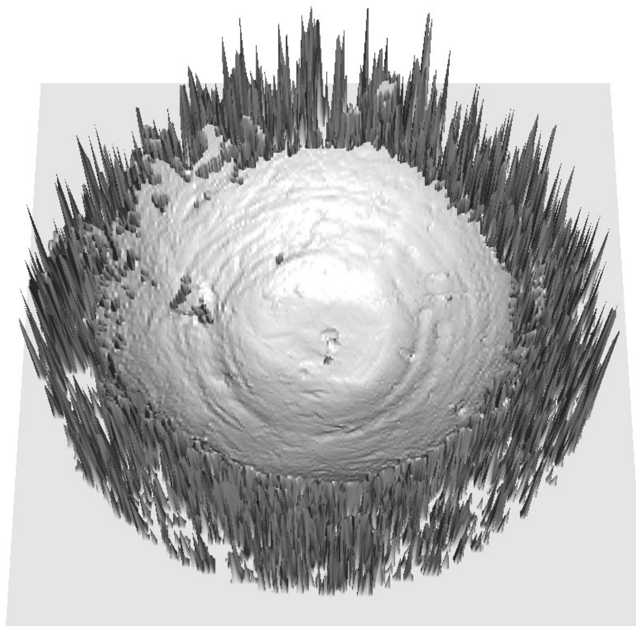

Figure 2. Topographic image of the firing pin impression on SRM 2461, Standard Cartridge Case, Unit #007. The outside border region contains numerous outliers and dropouts, so only the data in the center are used in the analysis.

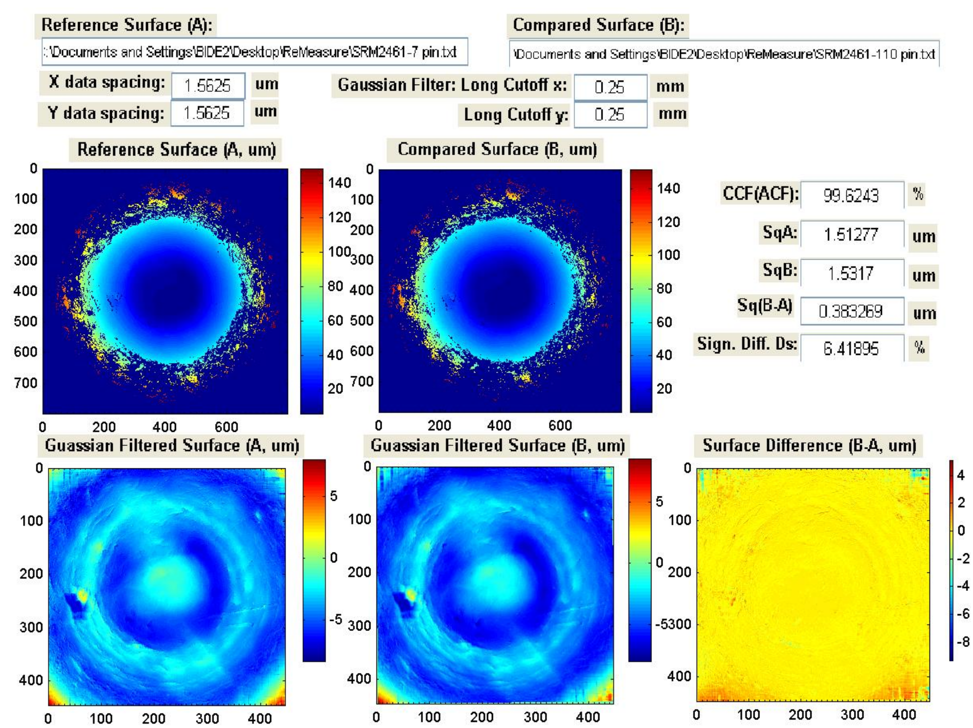

Figure 3. User screen showing the correlation of the firing pin impressions on two units of SRM 2461, the standard cartridge cases reproducibly fabricated by electroforming.

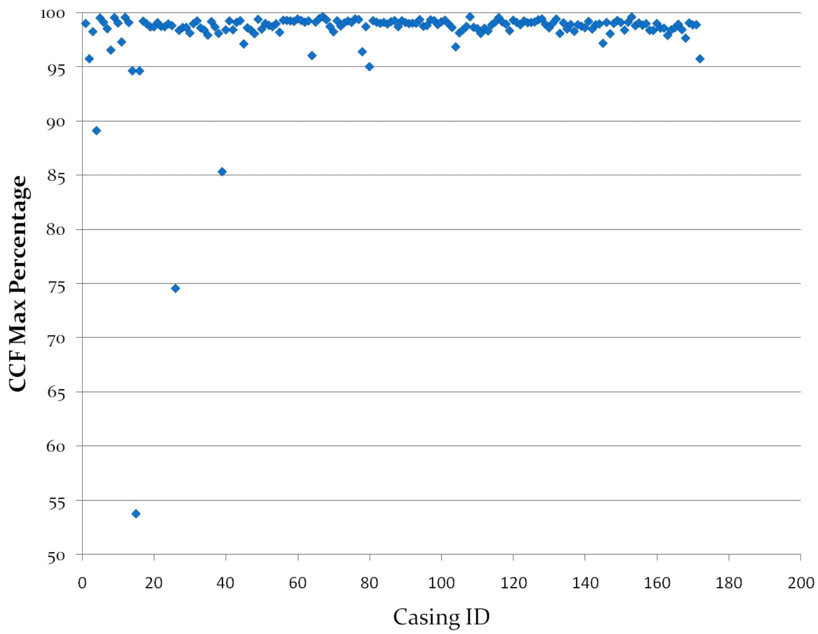

Figure 4. Cross-correlation maxima for the topographic images of firing pin impressions of 173 SRM cartridge cases, using SRM unit #007 as a master.

These excellent results are tempered by the fact that some units of the first two sets of casings reveal a slowly increasing contamination on their surfaces, likely due to the use of solder to bond the thin replicas to the cartridge case substrates. These first two sets will not be distributed as SRMs and the soldering procedure has since been replaced with a gluing process to bond the replicas to the substrates.

5. TOPOGRAPHY IMAGES OF BREECH FACE IMPRESSIONS

Preliminary topography data have also been obtained for the breech face impressions. Here we also see a high degree of reproducibility among the breech face impressions we have tested so far. The preliminary testing has involved the development of a measurement protocol to be used for the production measurements of each breech face impression. The main activity there was to test the trade-off between a 10× objective, which has a field of view of 1.6 mm, and a 20× objective, which has better lateral resolution but a field of view of only 0.8 mm. The surface of the breech face impression, with diameter approximately 3.7 mm, could be measured more quickly with the 10× objective because only nine stitched images would be required, whereas 36 stitched images would be required with the 20× objective. To explore this issue we measured a single breech face impression (SRM 2461, unit #007) with confocal microscopy with both objectives (10× and 20×) at six relative orientations of the cartridge case (0°, 5°, 35°, 45°, 90°, and 105°). Then we used a registration program to locate the positions and rotational orientations of each pair of images and calculated the cross-correlation coefficient at the best matching positions. Two of the data sets are shown in Fig. 5. The data for the 10× and 20× objectives at the same orientation appear quite similar. Figure 6 shows a detailed correlation between two topography images taken with the 10× objective with the casing in two different orientations, ≈0°, and ≈35°. The value of the cross-correlation function at the optimum orientation is 0.95, close to the ideal value of 1.00 for identical data sets. A summary of the cross-correlation maxima is shown in Table 2. The entries show the average CCF_{max} values for correlations of the images measured with the 10× objective, correlations of the images measured with the 20× objective, and correlations between 10× and 20× images. The orientation has little effect, suggesting that there is little distortion in the microscope images. There is a significant but small drop in the correlation value when the images from the two different objectives are compared. This may be due to a slight loss of resolution in the 10× images because the numerical aperture is 0.3, whereas the 20× objective has a numerical aperture of 0.6. In any case, we conclude that there is little loss in image quality with the 10× objective versus the 20× objective and there is a factor of four gain in measurement speed. So we plan to perform all of our subsequent measurements on these SRM breech face impressions with the 10× objective.

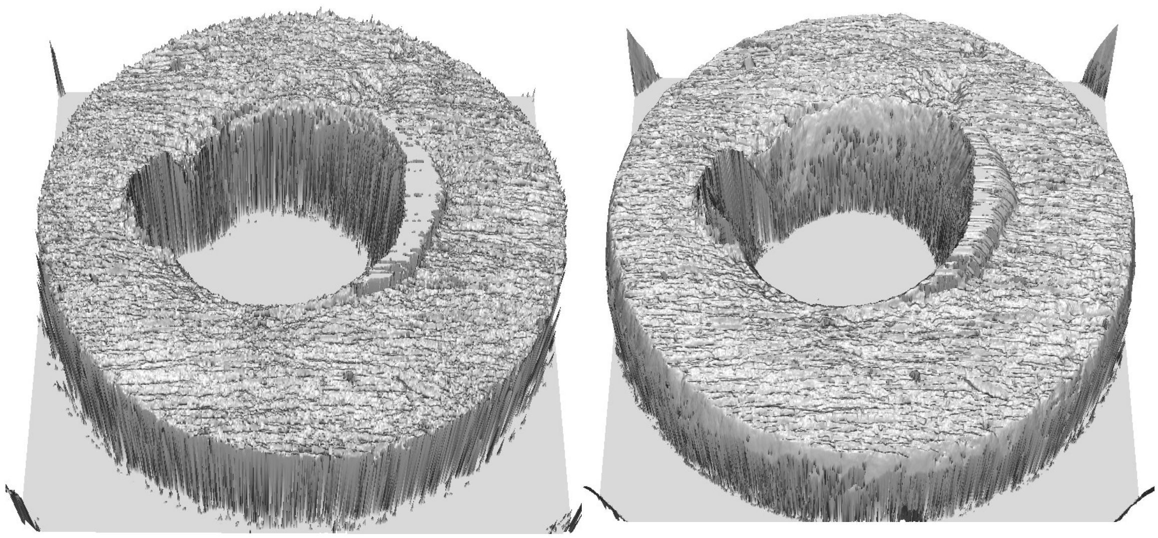

Figure 5. Topographic images of breech face impressions obtained with confocal microscopy using a 10× objective (left) and a 20× objective (right).

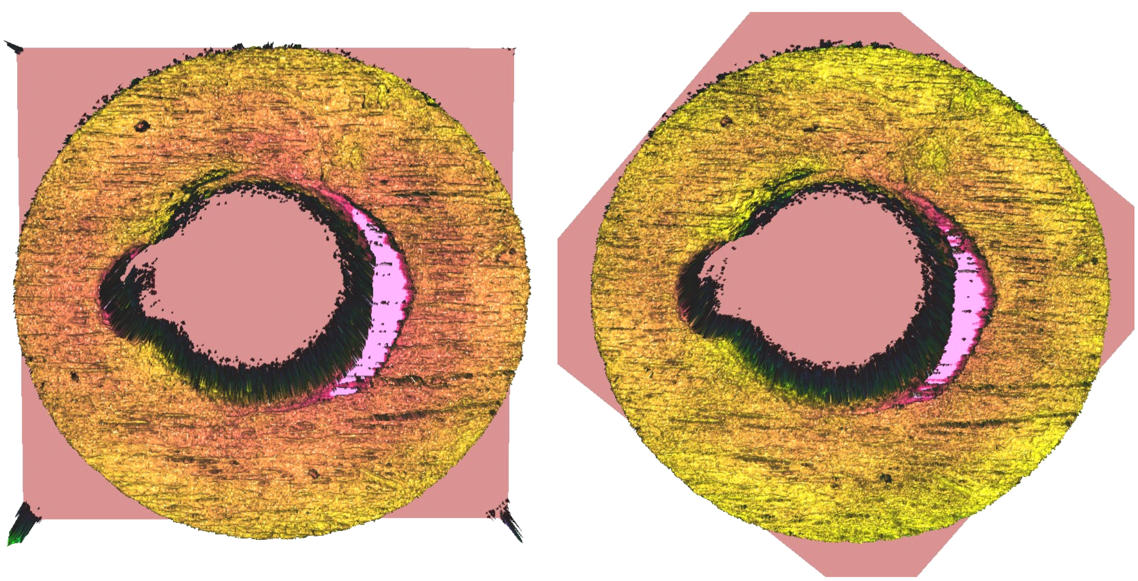

Figure 6. Topographic images of breech face impressions obtained with confocal microscopy using a 10× objective: (left) at 0° orientation and (right) at 35° orientation. The latter image has been rotated manually here to be close to the optimum orientation for correlation. The cross-correlation maximum between the images is 0.95.

Table 2. Summary of the cross-correlation results of topographic images of the same breech face impression acquired with different objectives (10× and 20×) measured in six different rotational orientations (0°, 5°, 35°, 45°, 90°, and 105°). The images were trimmed to remove data points at the edges that are outliers or otherwise not related to the breech face impression itself.

	Microscope Objectives being Compared		
	10× vs. 10×	10× vs. 20×	20× vs. 20×
Number of Pairs	30	72	30
Mean CCFmax	0.941	0.903	0.952
Stdev.	0.018	0.023	0.016

6. TOPOGRAPHIC IMAGES OF EJECTOR MARKS

Initial data on the ejector marks also suggest that they are highly reproducible. Figure 7 shows a comparison of topographic images of ejector marks from two SRM cartridge cases. Comparing these unusual shaped images is difficult to automate. Here the data have been truncated into rectangles, which mask unreliable data at the edges and make the images easier to deal with mathematically. The result is a pair of images that look quite similar and produce a cross-correlation coefficient of 0.965. Because the confocal method is sensitive to low signal-to-noise and because it produces outliers and dropouts at high incident angle, these images were recorded with the cartridge cases tilted so that the principal face of the ejector mark is normal to the optical axis, thus producing a large optical signal and with few dropouts. Figure 8 shows the orientation that was used as well as the normal orientation recommended for inspection on ordinary reflection optical microscopes. This tilted orientation will enable us to demonstrate with topographic imaging whether the ejector mark is highly reproducible from one unit to the next. This orientation is not recommended for viewing with a reflection optical microscope in crime labs. The cartridge case should still be inspected in the normal on-axis orientation when it is in service as a standard in order to demonstrate control of the image acquisitions in crime labs.

7. CONCLUDING OBSERVATIONS

We have developed and certified standard bullets (SRM 2460) for use in crime labs to help demonstrate the quality of image acquisitions by automated microscopes connected to image databases and correlation systems. We are continuing measurements of standard cartridge cases for the same purpose. These cartridge cases will be certified for the reproducibility of their firing pin impressions, breech face impressions, and ejector marks, so that different stations connected to large databases can demonstrate the similarity of their measuring systems and their procedures with different units of the SRM. In related projects we have also shown that topography measurements produced more accurate matches of test fires from the same firearm than the widely used method employing reflection optical microscopy. This was done both for two sets of cartridge cases[6] as well as a set of bullets.[8] If the speed of the acquisition setup and the correlation software can be optimized, the use of topography acquisitions of bullets and casings by optical methods is very promising.

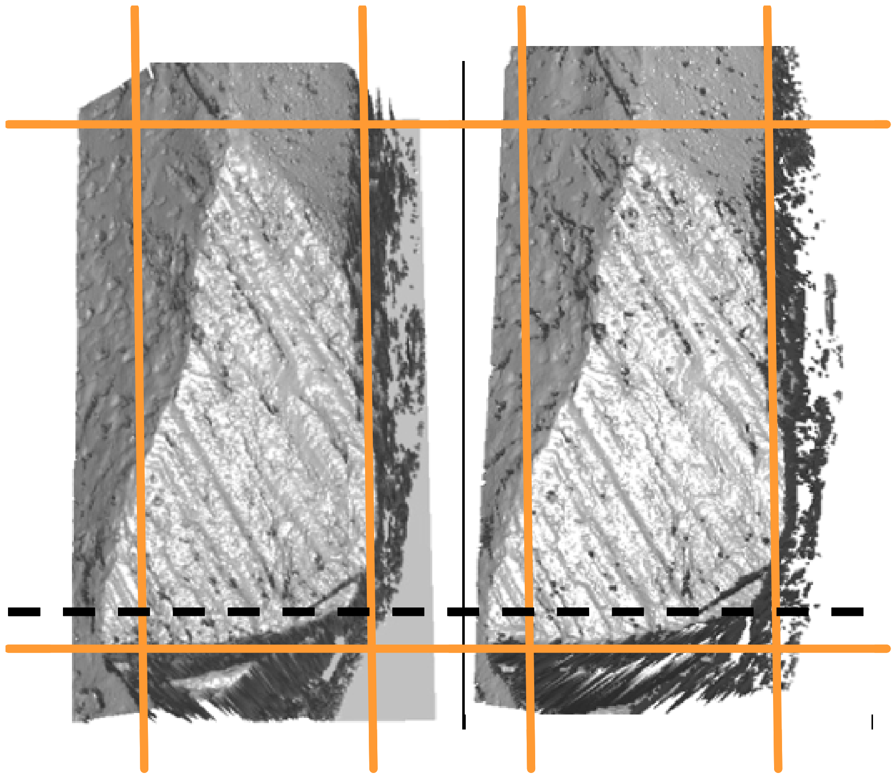

Figure 7. Comparison of ejector mark topography images from two different units of SRM 2461, #001 on the left and #011 on the right. The inner rectangles designate the approximate limits of the areas that were correlated after trimming by the Gaussian filter (solid line) then further trimming of unreliable data points (dashed line).

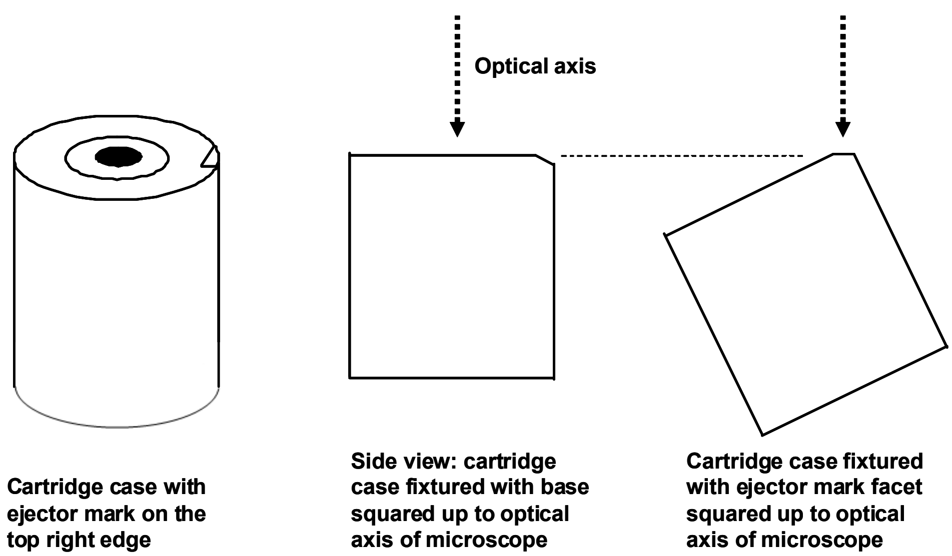

Figure 8. Two orientations for microscopic inspection of cartridge case ejector mark; (middle) customary setup, (right) setup used to optimize the signal-to-noise and minimize dropouts and outliers for measurement of surface topography with confocal microscopy.

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