Scanning Probe Microscopy Used for 3D Topography Image Acquisition of Marks on Cartidge Cases in Forensic Ballistics

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Abstract— **In spite of the significance of tool mark analysis in forensic ballistics, the image acquisition and comparison of tool marks remains a difficult and time consuming effort. This work deals with modified scanning probe microscopy applied to examination of marks on the surface of fired cartridge cases. Marks after firing pin are represented by 3-D topography image from measured data and compared according to images taken from confocal microscope and scanning electron microscope.**

Keywords - forensic balistic; scanning probe microscopy; firing pin; cartridge case; marks; 3D; topography.

I. INTRODUCTION

The identifying of the weapon which perpetrator used for shooting includes the basic questions of forensic ballistics. This individual identification is based on the axiom that the components of the weapon which are in the contact with the shot and cartridge case, leave on their surface characteristic marks. They are a unique reflection of micro roughness of contacted surface.

From a historical point of view, one of the earliest references related to the rifling of firearms is in a book by Harold Peterson [1]. In the early part of the 20th century, the science of firearm and tool mark identification was recognized by numerous judicial systems in several countries around the world. Legal recognition was due, in part, to the efforts of several individuals that had conducted research and experiments into the identification of fired projectiles and cartridges cases to the specific firearms.

In the middle part of the 20th century, the science of firearm and tool mark identification continued to evolve. For example, in the United States, the Scientific Crime Detection Laboratory (SCDL) began operations at Northwestern University in 1929, followed by formation of the Federal Bureau of Identification (FBI) Laboratory in 1932. Moreover, many other countries also recognized the requirement to provide this type of forensic analysis and established firearm and tool mark sections either in existing laboratories or as new laboratories. Over the next few years, several laboratories were established and commenced operations, especially in many of the larger cities in Canada, the United Kingdom, and the United States and in Europe.

In 1969, as a result of individual's effort in scientific research in the field of firearm and toolmark identification, Association of Firearm and Toolmark Examiners (AFTE) was founded.

In the last part of the last century, the science of firearms and toolmark identification has continued to evolve with a greater number of forensic scientists being employed as firearm and tool-mark examiners around the world. The science has greatly benefited from the numerous technological advances that have occurred during this period. These advances include innovations in one of the primary tools of the firearm and toolmark examiner — the binocular comparison microscopes. The immense majority of the current comparison microscopes have been equipped with digital cameras and closed circuit television (CCTV) units, which allow for direct viewing on a monitor or instant documentation using digital photomicrography. The most significant advances during this period include the tremendous growth, popularity, and relatively inexpensive cost of computers. The ability to fully utilize the immense potential of computers has allowed science overall, and forensic science more specifically, to take full advantage in development of several useful 'tools' for use within the firearms laboratory. The ongoing development of computers has provided the firearms and toolmark examiner with such useful equipment as the current Integrated Ballistics Identification System (IBIS) from Forensic Technology (Quebec, Canada) which combines a traditional 2D light microscopy image with software for image comparison and database search [2].

In recent years, researchers have started to explore a next generation of techniques for tool mark imaging. These methods produce 3D images of tool marks. Several technologies have been considered, for example, focus-variation microscopy, confocal microscopy, point laser profilometry, atomic force microscopy or scanning interferometry. Mentioned techniques require expensive equipment and often the sample preparation is not trivial. For example, we can mention very fast method called TopMatch GS-3 [3]. It is 3D scan acquisition based on GelSight imaging technology that uses an elastomeric sensor and enhanced photometric stereo [4][5][6][7]. The another novel application of sensing technology, based on chromatic white light, acquires highly detailed topography and luminance

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data of cartridge cases simultaneously [8]. Atomic Force Microscopy (AFM) technique in forensic science was used with combination of Fourier Transform Infrared Attenuated Total Reflectance (FTIR/ATR) spectroscopy in analysis of Gun-Shot Residue (GSR) to test their ability to determine shooting distance and discrimination of the powder manufacturers [9]. Using this method for tool mark analysis is not suitable because regular Scanning Probe Microscopes (SPM) and among them especially atomic force microscope are the best techniques to measure very smooth surfaces. For larger samples, such as cartridge cases, an analogy of scanning probe microscopy was required. This work shows the possibility of the assembled system and also indicates possible trends for the future.

In Section 2, the principle of general scanning probe microscopy and our custom scanning system are described. Section contains series of acquired images from scanning electron, scanning probe and optical microscopy of measured cartridge cases together with their mutual comparison. Section 4 presents a conclusion and an indication of the future work.

II. SCANNING PROBE MICROSCOPY

In general, scanning probe microscopy (SPM) is a technique to examine materials with a solid probe scanning the surfaces. The SPM is relatively new for materials characterization compared with light and electron microscopy. It can examine surface features whose dimensions range from tenth of a millimetre to atomic spacing. The main characteristic of the SPM is a sharp probe tip that scans a sample surface. The tip must remain in very close proximity to the surface because the SPM uses near-field interactions between the tip and a sample surface for examination. This near-field characteristic eliminates the resolution limit associated with optical and electron microscopy because their resolution is limited by the far-field interactions between light or electro waves and specimens. The lateral and vertical resolution of an SPM can be better than 0.1 nm, particularly the vertical resolution. The lateral range of an SPM measurement is up to about 100 μm, and its vertical range is up to about 10 μm. The SPM must operate in vibration-free environment due to atomic proximity between the tip and the sample.

For surface morphology measurement, the mode of SPM using atomic forces is very often utilized. Operation is based on surface scanning using an elastic cantilever with a sharp tip. The tip is moved closer to the surface with a small constant force. The tip height ranges from hundreds of nanometers up to 2 μm and tip curvature radius ranges from 2 to 60 nm. Interaction of the tip and the surface is detected by the reflection of the laser beam from the top of a cantilever on the four-segment photodiode detector.

Every SPM system consists of several basic components: a probe and its motion sensor, scanner, electric controller, computer and vibration isolation system. The scanner controls the probe that moves over the sample in three dimensions in a precise way (1 pm if atomic resolution is required). To achieve this level of precision, a scanner is made of piezoelectric materials. Moreover, the scanner must be well calibrated to eliminate piezoelectric effects (nonlinearity, hysteresis, creep of material). There are four operational modes in the STM: constant current, constant height, spectroscopic and manipulation modes. The most commonly used mode is the constant current mode, where the feedback loop controls the scanner moving up and down to maintain a constant tunnelling current [10].

In case of forensic ballistics, the size of marks (shots, cartridge cases, parts of gun, etc.) is often many times greater than limits of SPM method. It is not possible to use commercial instruments without any physical adjustment of the sample because there is a danger that the sample can be reversibly modified or damaged. For SPM systems, the maximal size of scanned area rarely exceeds 100 μm. Another limitation is the maximal height of the sample, which is often about 1 cm together with surface roughness of the examined sample. From reasons mentioned above, there was a need to modify or design custom scanning systems allowing measuring larger samples with larger roughness of the surfaces.

A. *Custom SPM system*

Our custom scanning system differs in several important aspects from the above described general SPM system. The present configuration of the system can examine only metallic samples. It consists of stationary conductive probe with sharp tip, stage connected to system of servomotors (Mercury M110 1DG) controlled by stepper controllers (Mercury C-862) through the computer and own user software (programmed in MATLAB), it is illustrated in Figure 1. As a feedback, a change in resistivity of the used electronic circuit is employed. This change is caused by the physical contact of the tip and sample; it is measured with multimeter (Hewlett Packard 34401A). Switch SW1 represents contact between the tip and sample. Resistors R_1 = 1 MΩ and R_2 = 100 Ω participate in overall measured circuit resistance. Schema of the electronic circuit can be seen in Figure 2.

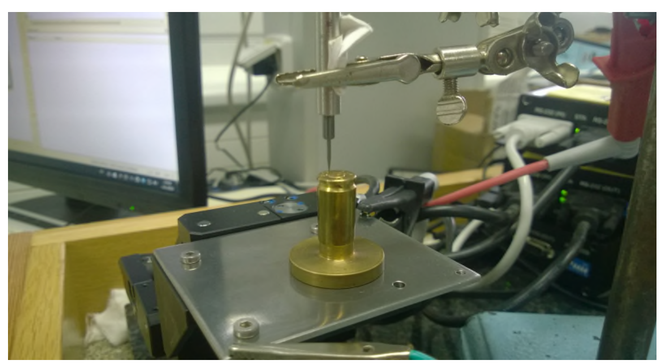

Figure 1. Scanning system with static probe where stage is moved across three axes.

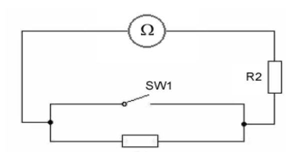

Figure 2. Simple electronic circuit for feedback system.

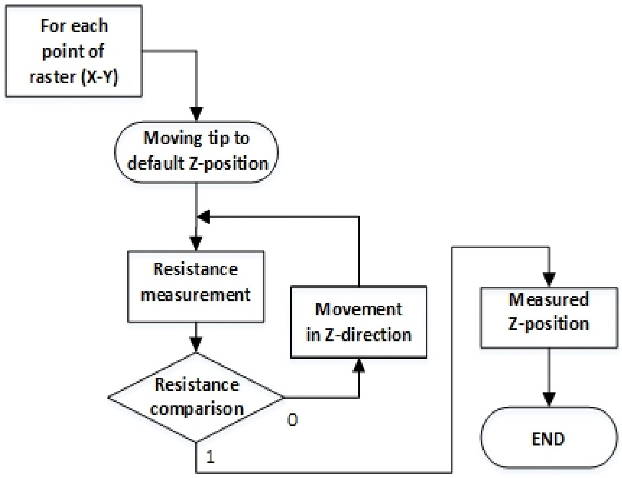

Figure 3. Flowchart of approaching cycle.

This system allows the measurement of larger objects (from few millimetres up to about 5 cm), maximal scanned area is 5 x 5 mm. On the other hand, examined object must be conductive, lateral and vertical resolution are given by chosen scanning raster and limited by curvature radius of the probe and also by used stepper motors. It can be said that the scanning system works in spectroscopy mode. For each point in chosen regular rectangular raster, the approach cycle is successively accomplished to get Z-coordinate which corresponds to topography of the sample, which is illustrated in Figure 3. All three coordinates are stored in common SPM data format for further visualisation and analysis.

The accuracy of the system and the level of details during scanning are dependent on chosen raster size, approaching distance in Z-axis and its velocity. They are inversely related to the total time of scanning process. On the basis of repeated spectroscopy measurement at one single point of the sample it was found out that relative slow approaching velocity of the stage in Z-axis (in range up to 5 µm per second) leads to uncertainty below 0.2 micrometers. On the other hand, velocities over 15 µm per second exceed uncertainty of 1 micrometer. The correct and adequate settings of system parameters is a question of compromise between quality and measurement duration. Lots of important information is shown in main window of the user application during running measurement. It also includes the current 3D graph together with measured topography profile, estimated time of end measurement, information about stage movement and many others.

B. Scanning probe with a sharp conductive tip.

The indispensable part of the scanning system is the tip. Maximal resolution we can reach with this system is given by curvature radius of the tip. The curvature radius of used tip was reached by mechanical sharpening and was measured with optical microscopy and also with scanning electron microscopy. Comparison of these two methods can be seen in Figure 4 and Figure 5, where different determination of curvature radius is obtained. The images from SEM method

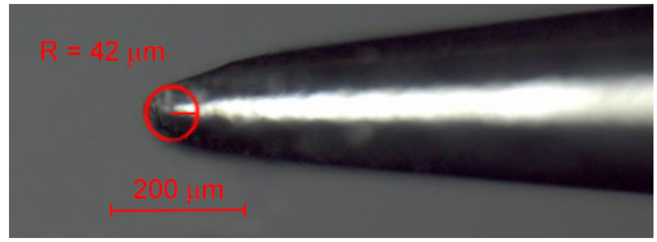

Figure 4. Image of the used sharp conductive tip measured with optical microscope.

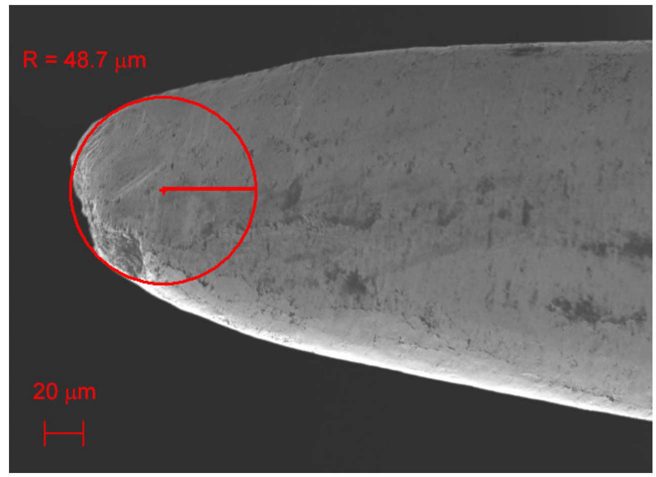

Figure 5. Image of the used sharp conductive tip measured with SEM.

have much better resolution so that measured values are more accurate.

According with this value, the scanning raster is chosen, in our case it was 50 µm. Additionally, the method is based on resistivity change at contact during approach. Regarding to possible physical damage of the tip or sample in case of non-conductive contact (dust, impurity) because stage is approaching the tip until resistivity change of the electronic circuit occurs, tip attachment is also very important. From this reason, the tip has possibility of free movement in Z-axis inside guide conductive casing which is fixed and the tip always get back to the same position.

III. Results and Discussion

For test measurement, two available firearms with different specific marks of firing pin were chosen (Glock 17 and Walther PPQ). For every single gun, several fired cartridge cases were collected and then the marks after firing pin measured and analysed. Two of typical cartridge cases from individual firearms were subjected to measurement with our SPM method. For comparison of obtained topography images to images taken using contemporary method, scanning electron microscopy (SEM) as well as confocal microscopy were used, see Figure 6 – Figure 12.

All cartridge cases were scanned using SPM in the same way, with the same system parameters, raster in both lateral axes was 50 µm, total scanned area from 4000 µm to 3000 µm, depending on size of individual mark. Initial

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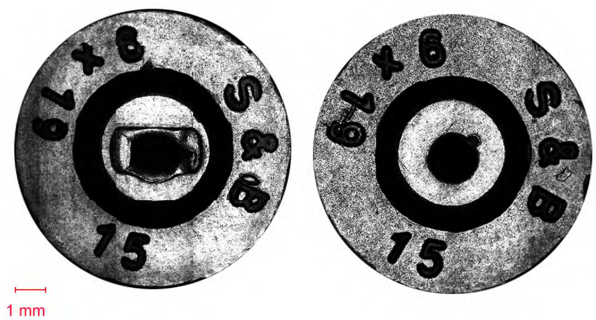

Figure 6. Visualised cartridge cases on primer side using confocal microscope.

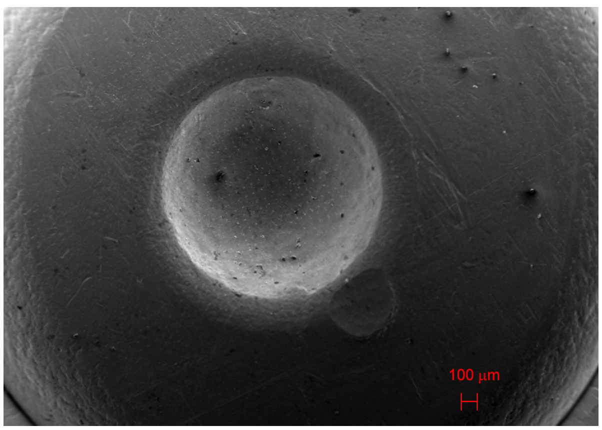

Figure 7. Image of mark after firing pin on cartridge case fired from Walther PPQ measured with SEM.

Figure 8. Image of mark after firing pin on cartridge case fired from Walther PPQ measured with optical microscope.

sample positioning on the stage and the tip distance were manually performed. Approaching speed was set 5 µm/s. The scanning process of one mark took approximately

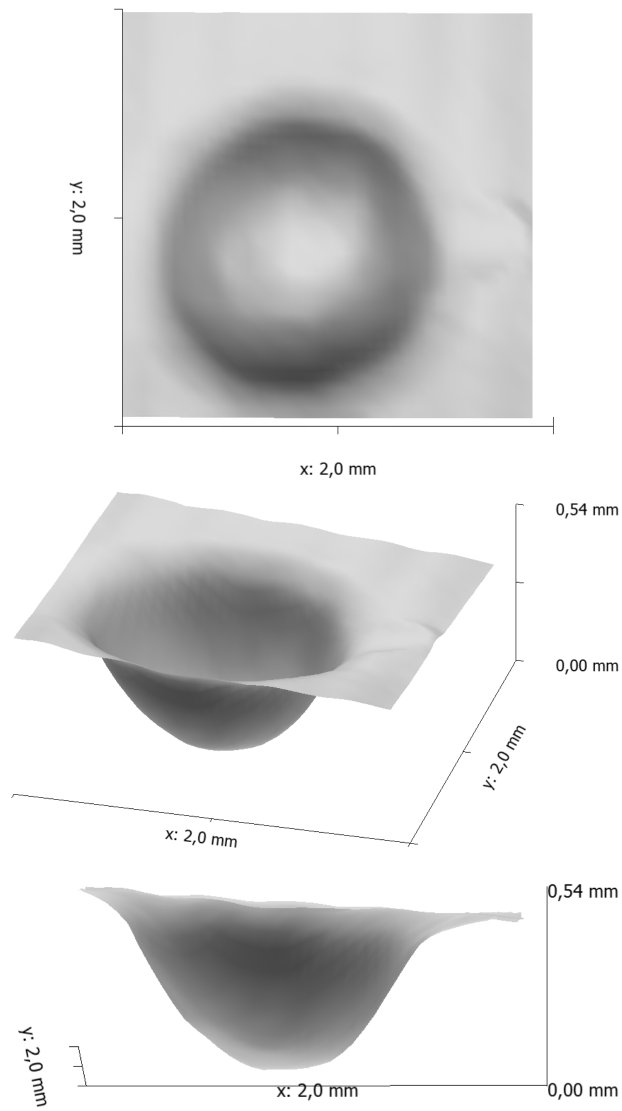

Figure 9. Views on 3D scan of mark after firing pin (Walther PPQ) using our SPM method.

8 hours. All measured data was processed in Gwyddion software [11] which is a modular program for SPM data visualization and analysis [12]. Plane leveling was applied to raw SPM data. The plane was computed from all the image points and was subtracted from the data. The last modification lay in data trimming according to region of interest.

As it can be seen from Figure 9 and Figure 12, the level of detail is very poor, but we have information about spatial penetration of the firing pin, which is another useful information. According to this, we can compare shape of firing pin, its abrasion level so that its possible malfunction can be predictable.

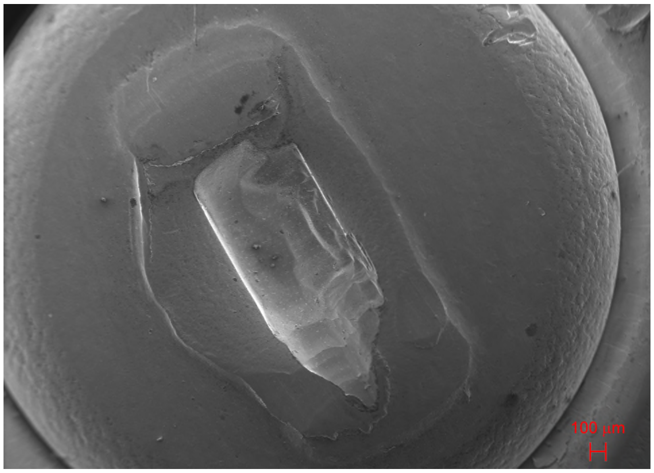

Figure 10. Image of mark after firing pin on cartridge case fired from Glock 17 measured with SEM.

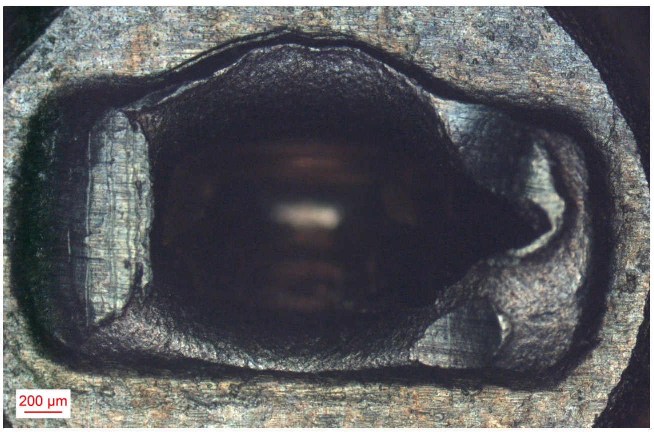

Figure 11. Image of mark after firing pin on cartridge case fired from Glock 17 measured with optical microscope.

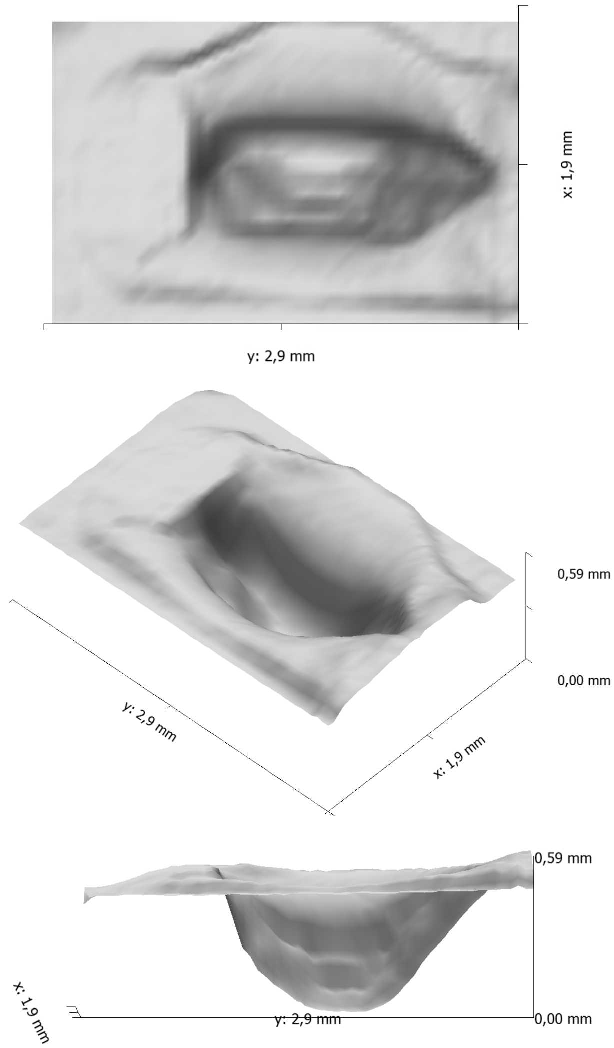

Figure 12. 3D scan using our SPM method of mark after firing pin (Glock 17)

Figure 7 and Figure 10 show SEM images that have, from principal, unique resolution (can reach values of 0.02 nm) and large depth of field (the order of micrometers at 10^4 magnification). We can observe very fine details, images look plastic, but they are still only 2-D images. Moreover, this type of instrument does not belong to common laboratory equipment and its cost is very high.

Figure 6 shows reduced images from confocal microscopy, which provides, except others, non-contact surface profilometry with resolution of 0.15 µm. It can slice clean thin optical sections so that it is able to compose a 3-D topography image. The problem is for surfaces where there is a steep decrease of the material. This represents edge and deep inner part of mark after firing pin on the primer which would be evident from Figure 6 and real comparison of the cartridge case.

For marks after firing pin, STM method can be considered as efficient, especially if the resolution improves. Furthermore, not only topographic images can be the result of this measurement. Another little modification of this method it will lead to simultaneous acquisition of contact potential, which gives us information about homogeneity of metal crystal lattice and its imperfections.

IV. CONLCUSION AND FUTURE WORK

In spite of the significance of tool mark analysis in forensic sciences, the image acquisition and comparison of tool marks remains a difficult and time consuming effort. The comparison, in our case, is based on the fact that microscopic firearm imperfections are transferred to a fired cartridge case.

In this study, we were concerned with marks after firing pin on fired cartridge casings that were measured with custom SPM method. As a result of these measurements, 3-D topography images were acquired. For the verification and comparison of obtained results, images of the same samples were measured with available optical methods (scanning electron microscopy and confocal microscopy).

Using our SMP method, one single cartridge case was scanned in order of hours which is impractical at this moment; but, there are also possibilities and reserves which allows us increasing the scanning time. In future work, construction of near field microwave microscope can be the promising improvement from the point of time consumptions. It is based on impedance change between the tip and the sample in microwave spectra. Additionally, it is non-contact method so that the possibility of tip or sample damage falls behind. The tip is only moved in constant height above the conductive sample within the raster and the resonant curves of coaxial resonator are measured. Image brightness component is arranged according to changes of resonant curves.

The lateral resolution is limited by curvature radius of the tip. By mechanical sharpening we were able to decrease the radius below 50 micrometres which is still not enough to observe details necessary to comparison of tool marks. Using methods like chemical milling of the tip [12] or stretching of the thin wire when heated the curvature radius of the conductive tip can be dramatically reduced. As a consequence of mentioned improvements, 3D scan of measured surface can be taken in much shorter time with better resolution then it is presented here. It is evident, that any SPM method for surface topography measurement is much time-consuming then optical methods. Every method has pros and cons, always it depends what information the user wants to get and what is the worth.

Moreover, every single scanned surface can be mathematically described as a unique vector of numbers; for example, moment characteristics or Fourier descriptors [14] can be utilized in combination of suitable segmentation methods. These complementary aspects can be helpful in tool mark comparison and firearms identification.

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