Automated bullet-identification system based on surface topography techniques

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Abstract: Every firearm has individual characteristics that are as unique to it as fingerprints are to human beings. When a firearm is fired, it transfers these characteristics – in the form of microscopic scratches and dents – to the fired bullets and cartridge casings. The rifling of the barrel of the firearm marks the bullets travelling through it, and the firearm's breech mechanism marks the ammunition's cartridge casing. Characterising these marks is the critical element in identifying firearms.

Traditionally the comparison of ballistic evidence has been a tedious and time-consuming process requiring highly skilled examiners. In the past decade, engineers have created automated ballistics identification systems that meld traditional comparison microscopes with digital cameras, computers, huge databases, and image analysis techniques. This kind of system can help investigators to link crimes by automatically finding similarities among images of bullet but suffering significant drawbacks and minimal matching.

More recently, approaches based on 3D digital representations of evidence surface topography have started to appear, both in research and industrial products. Potentially the introduction of 3D surface topography measurement can overcome the limitations of digital imaging systems by making the bullet surface measurement reproducible and reliable. A 3D quantitative approach for bullet identification is proposed in this paper. In this system the surface topography of the whole bullet can be acquired for analysis and identification. Primary researches have been done by applying advanced surface topography techniques for bullet marks' characteristics extraction. A variety of 2D and 3D visualization graphics have also been provided to help firearm examiners to make final decisions.

Keywords: Surface topography; Bullet-identification; Surface segmentation; Visualization technique

1. Introduction

Bullets are intentionally made wider than the gun barrels through which they are fired. The hard barrel compresses the relatively soft metal of the bullet as the exploding gunpowder hurls the projectile down the barrel. The size difference compresses the bullet slightly, enabling about a half-dozen spiral grooves cut along the barrel's inner wall to “grab” the bullet and make it spin which stabilises the bullet's flight. Between the spiral grooves are the so-called lands where the barrel is the narrowest. These areas, which typically have unintentional microscopic scratches (striations) on them from their manufacture and usage, squeeze the bullet the most and leave a signature of their scratches on its surface. To check whether a bullet from a crime scene was fired from a specific gun, firearms examiners typically test-fire a bullet from the suspect gun and then compare the scratches on its land impressions to those on the crime-scene bullet. Alternatively bullets can be compared to those obtained from other crime scenes to establish linkages.

The first use of the microscope as an advanced tool in firearms identification was around 1925. This was a single-eyepiece instrument similar to the microscope used today. The next advance was the dual eyepiece ballistics microscope (comparison microscope) which is still the primary technique used in the UK today. Automated ballistics identification systems are currently in use by a number of police forces around the world. These systems do not provide conclusive results. Rather, a list of potential candidates are presented that must be manually reviewed. The most widely used automated ballistics identification systems encompass IBIS and CONDOR, etc. IBIS is an automated, computerised forensic firearms identification system that integrates cartridge case and bullet analysis, as well as electronic firearms reference libraries, on a single computer platform. Those automated systems are based on acquired grey scale digital images, image analysis and processing techniques. It implies an inevitable loss of information if compared with direct observation of the real specimens through a microscope, where viewpoint, lighting conditions, orientation, magnification, etc., can be changed during observation. In turn, the reduced amount of information available from digital images places intrinsic limitations to the capabilities of any identification/comparison technique based on such an approach.
More recently, approaches based on 3D digital representations of evidence surface topography have started to appear, both in research, Kinder and Bonfanti [1], Fernado [2], and Bachrach [3] and as industrial products, such as BulletTRAX-3D system by Forensic Tech. Inc. [4]. The introduction of 3D surface topography measurement can solve the limitations of digital imaging system by making the bullet surface measurement reproducible and reliable.

2. A proposed measurement solution for bullet marks

The proposed measurement system is based on a Talyrond 365 roundness/cylindricity system. Fig. 1 shows the schematic diagram of this measurement solution. The Talyrond 365 system incorporates a bi-directional precision roundness testing rotary stage with absolute positioning capabilities, providing highly accurate positioning, roundness and roughness measurement [5]. A special chuck is also designed for mounting the measured bullet. Starting from about 1 mm from the bottom of the measured bullet (Fig. 2), 100 circles along the bullet axis will be scanned, the sample spacing is 0.05 mm. Each circumference scan consists of 9000 points. In total, the bullet surface topography includes 100×9000 points.

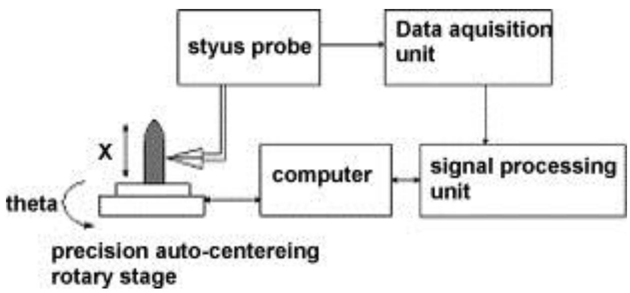


Fig. 1. Schematic diagram of the measuring system.

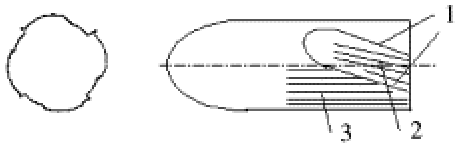


Fig. 2. Single land impression on bullet surface: 1, land impressions; 2, striations in land impressions; 3, forcing cone marks.

Compared with other 3D measurement systems, this proposed system has following advantages: (1) the rotary stage allows full 3D surface topography information to be collected as well as form deviation such as roundness and diameter; (2) this system can measure the inside of gun barrels and cartridge casings using a smart stylus sensor, as the stylus tip is very small and the shape of stylus can be changed. In some cases, it is very useful to compare the bullet surface with the gun barrel which imprints the fired bullet, and the cartridge casing which was connected with the fired bullet. Currently no automated bullet-identification systems can provide such measurements because the optical sensor or digital camera is too big to allow access to gun barrel or a cartridge casing.

3. Feature extraction of bullet marks based on surface topography techniques

Firearm identification is concerned with two types of characteristics of firearm: class and individual. Therefore bullet marks consist of class and individual characteristics. Class characteristics are those characteristics imparted to a bullet that represents a family of firearms and usually are limited to a group of manufacturers. In firearm identification, class characteristics can be used to eliminate or include bullets from the search and hence are useful for reducing a large database down to a more manageable level. For fired bullets, the lands, grooves, and diameter of the barrel impart the class characteristics (Fig. 3). Individual characteristics are those marks, including striations and other imperfections, which make a particular fired bullet unique and serve as the basis for a conclusive identification to a particular firearm (Fig. 4). The unique marks that identify a bullet to a particular barrel are usually located in the land impression areas.

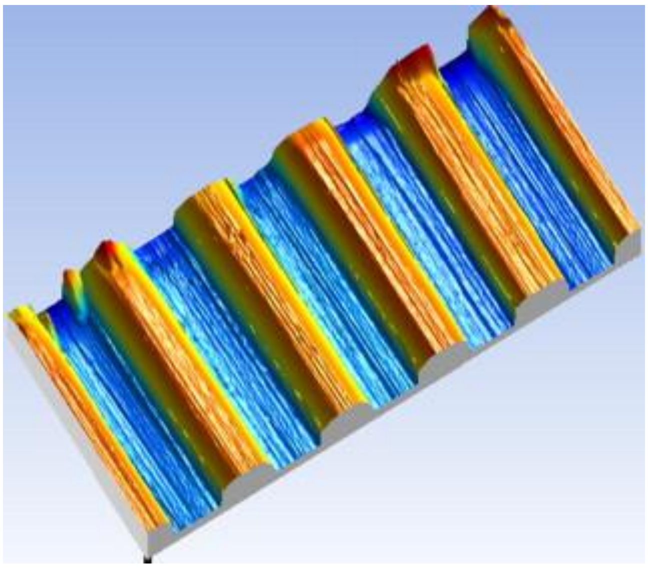


Fig. 3. 3D “Benelli” bullet surface topography.

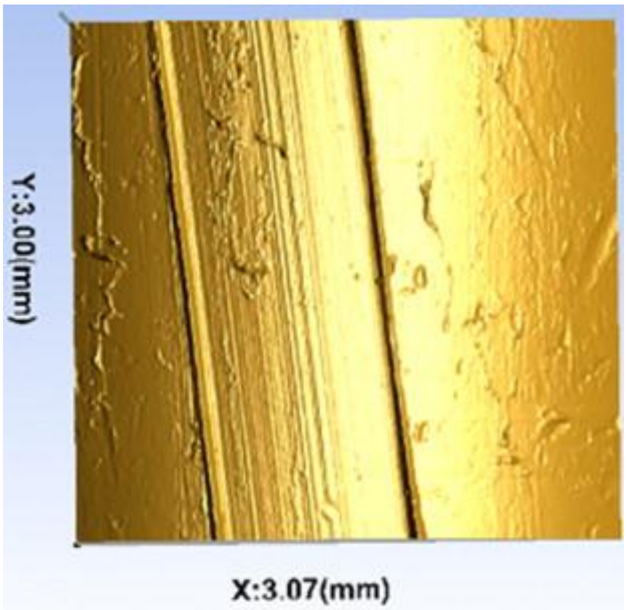


Fig. 4. Single land impression on bullet surface.

3.1. Class characteristics extraction

The surface segmentation technique based on morphological analysis has been well developed for analysing microstructure featured surfaces [6]; [7] ; [8], and it presents great potential for the extraction and characterisation of markings on a bullet surface. Surface segmentation analysis divides a landscape into regions consisting of hills and regions consisting of dales. By definition the boundaries between hills are course lines, and the boundaries between dales are ridge lines. So a scale limited surface can be organized by networks of critical points: peaks, pits and saddles points, and critical lines: ridge lines, course lines (Fig. 5). Furthermore, height and area pruning methods of surface networks are used for combination and removal of insignificant feature primitives. Fig. 6 shows a surface segmentation result on a steel sheet surface.

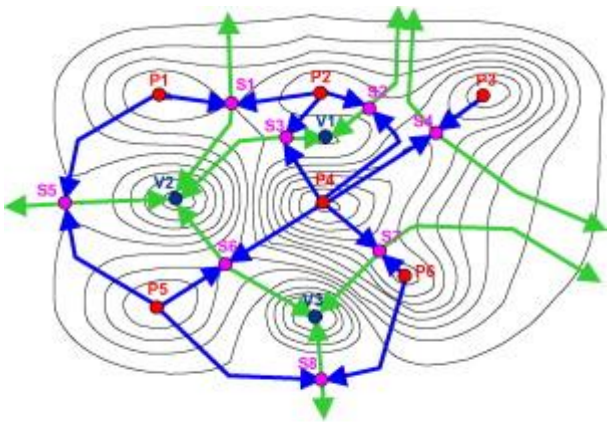


Fig. 5. Primitives—critical points, lines and areas. P, peak; V, pit, S, saddle point. Ridge lines connect peaks to saddle points, course lines connect pits to saddle points.

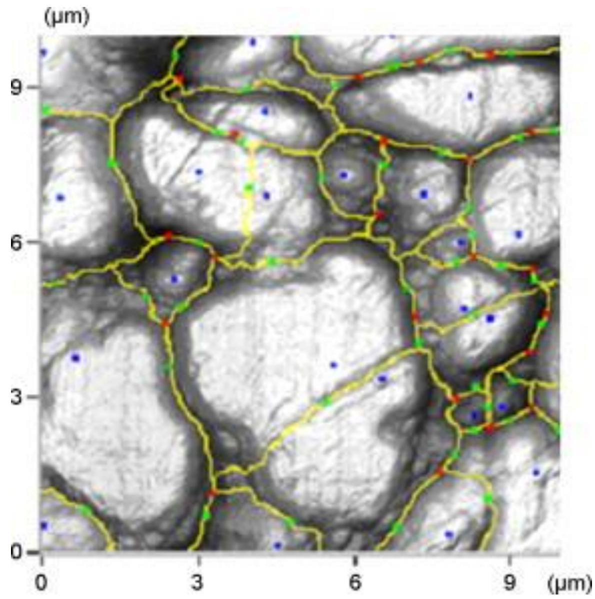


Fig. 6. Surface segmentation demonstration.

Likewise surface segmentation analysis can be applied for bullet surface segmentation. Fig. 7 shows that the bullet surface is effectively separated into different regions, e.g. the groove impression and land impression regions. Thus, the number of land regions, and each region's dimensional information such as region width, depth, twist spiral direction and angle, can be calculated as bullet class characteristics. The region depth information may not be stable and be affected by other factors, such as the composition and diameter of bullet. The rifling number and twist spiral direction are essential elements for gun type classification. The region width and twist angle are reference for gun classification, however, their variation may be helpful in identifying a specific gun.

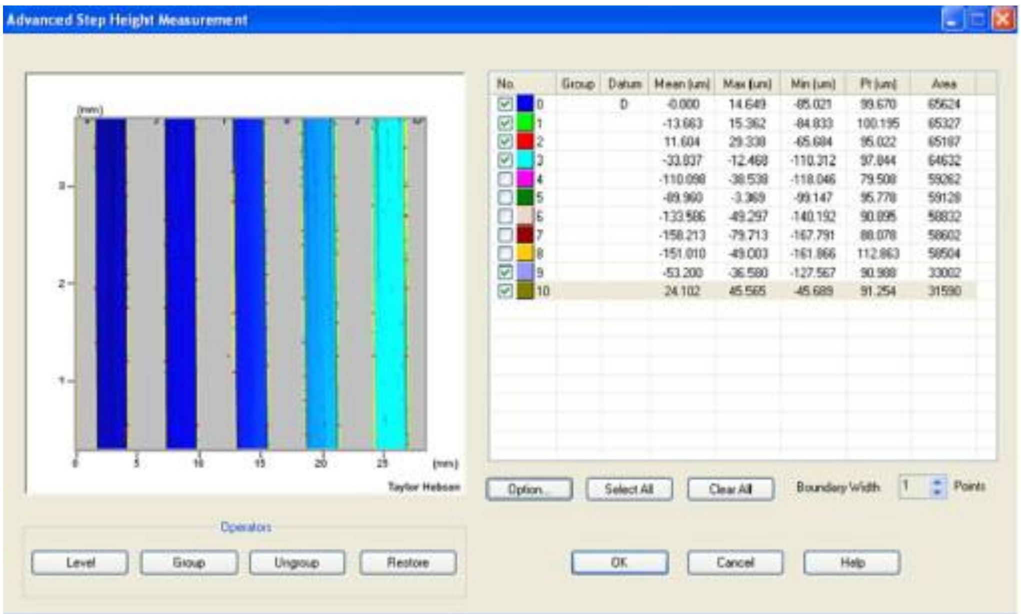


Fig. 7. Bullet surface segmentation and class.

3.2. Individual characteristics extraction

The individual characteristics of a gun are the most important with matching a bullet to a gun. But the measured bullet surface is mixtures of signals consisting of class characteristics and individual characteristics, and cannot be used for directly comparison and correlation. Therefore, the separation of class characteristics and individual characteristics is crucial for bullet identification. The strategy for individual feature extraction consists of following data process steps:

(1) Surface abstraction. As individual characteristics in the barrel of a gun are transferred onto the bullet surface along with the twist angle averaging of surface data along this direction can enhance useful information and suppress disturbances. Projecting the bullet surface along rifling twist direction results a 1D signal [9]. The resulting 1D signals provide a compact, faithful representation of bullet surface, which contributes to efficiency of comparison (Fig. 8(a)). The key issue in this stage is the calculation of the twist angle. The angular spectrum in surface topography analysis integrates spectral energy in a number of given angular directions and is very useful in identifying the directionality of surface lays. Corresponding ISO parameter Std (texture direction of the surface) which is the maximum value of the angular spectrum can be used for determining the average twist angle and direction of rifling.

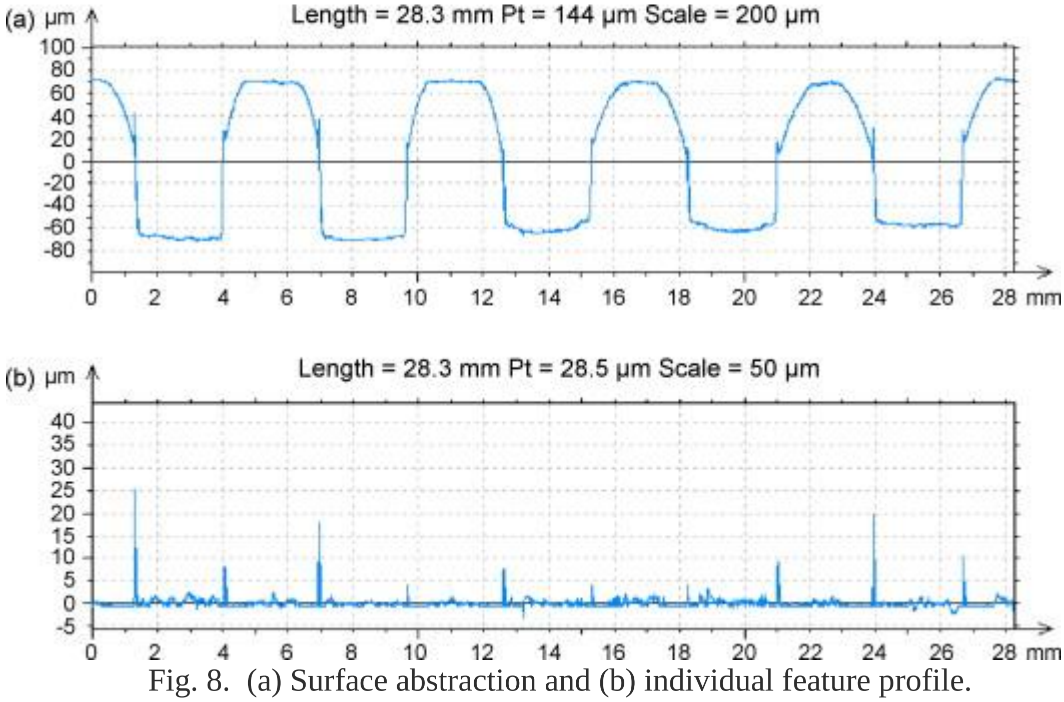


Fig. 8. (a) Surface abstraction and (b) individual feature profile.

(2) Wavelet filtering. The 1D representation of a bullet surface consists of class characteristics and individual characteristics and accurate separation of these features is the key issue for matching. These line features of the bullet marks are also elaborate in both time and frequency domains. Traditional filtering methods designed in either time or frequency domains are not effective in processing such signals, and there is no means to break it down into frequency bands of interest. Multi-scale analysis including wavelet analysis has been a powerful tool in analysing signals when high precision in both time and frequency domains are needed [10]. By applying wavelet

high-pass filtering, a feature profile only composed of individual characteristics can be acquired (Fig. 8(b)).

(3) Comparison. The comparison between two bullets can be transferred to the comparison between two feature profiles. The cross-correlation function is a powerful tool in finding the similarity between two signals. The maximum value of the CCF is used as a quantitative parameter of the similarity. For multiple bullet comparison, this parameter should be recorded and sorted in particular sequence.

4. Visualization technology

The automated bullet-identification system provides the initial identification of the bullet, and the final decision will be verified by firearm examiners based on the suggested "best matches" list. So a 3D virtual comparison microscopy is proposed. A variety of 2D and 3D visualization graphic tools have been developed to help firearm examiners in reaching the final decision. Visualization technology has been widely used for reconstructing 3D measured data in surface metrology area. Fig. 9 is a composite visual software tool which allows the side-by-side observation and comparison of the microscopic characteristics present on different bullets. Fig. 10 is a zoom view which allows the user finds the details in bullet marks.

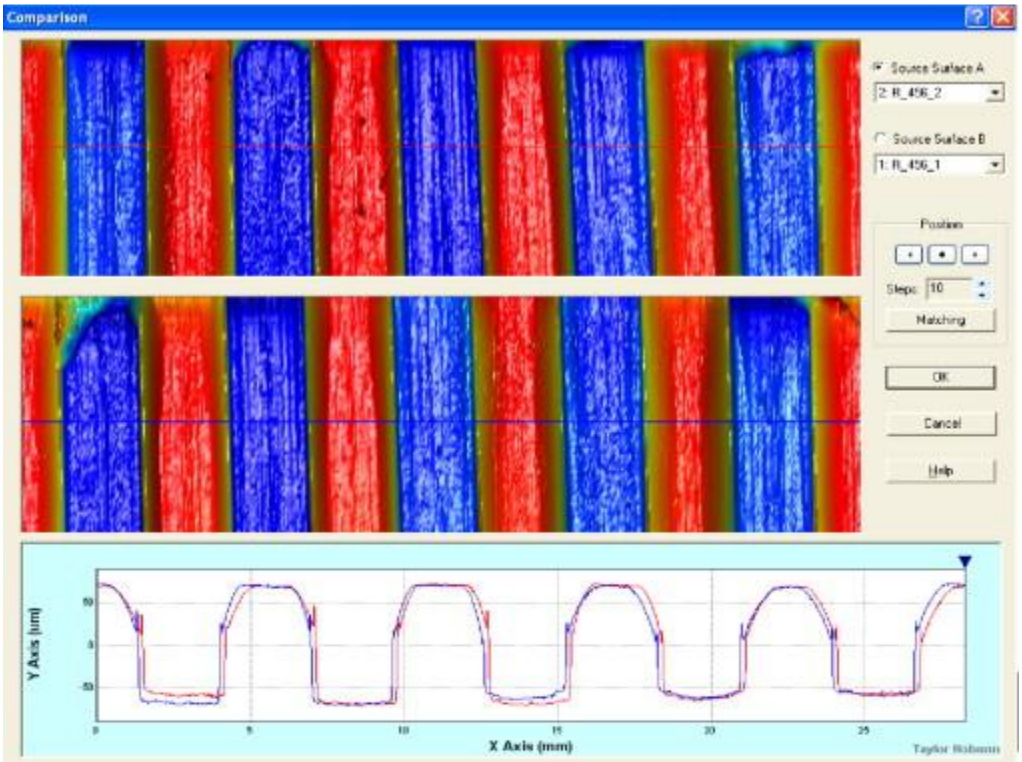
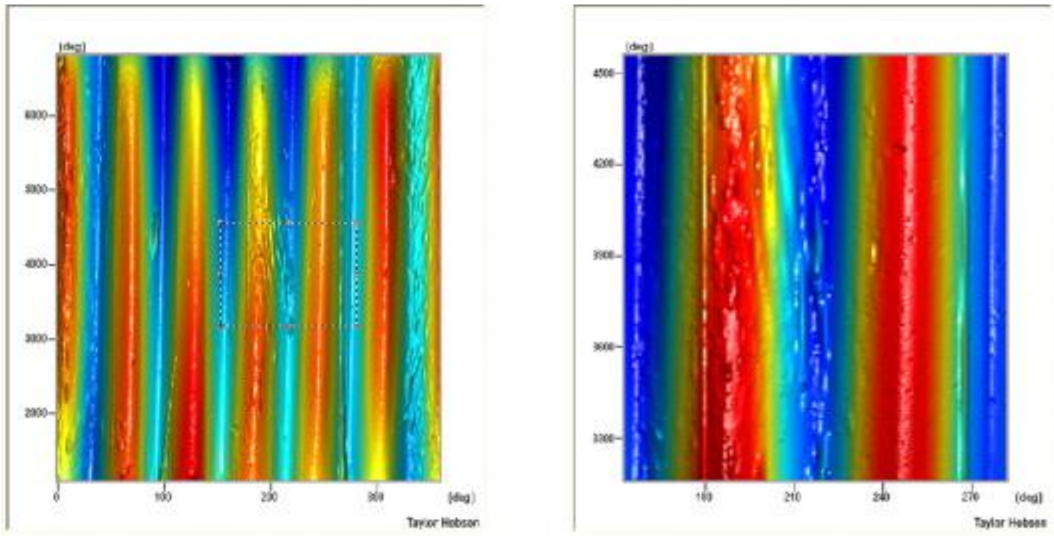


Fig. 9. Composite visualization comparison module.



UNIT	LEFT	RIGHT	TOP	BOTTOM	X Length	Y Length
Points	153	282	990	591	130(359)	400(1632)
deg	153	282	4557	3160.5	129(359)	1396.5(5712)

Fig. 10. Zoom view module.

5. Conclusion and future works

In this paper, an experimental automated bullet-identification system based on surface topography techniques has been presented. In this system, complete and accurate bullet surface topography data can be acquired for analysis and identification using the proposed bullet measurement solution. By applying advanced surface topography analysis, such as surface data segmentation techniques, the class characteristics and individual characteristics are effectively extracted to improve firearm identification. This system can be used as a complement for those commercial systems. The identification capacity and validity need further research by using a large number of bullet samples in the future.

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