



Technology Evaluation

Forensic Technology Center of Excellence:
Validation and Evaluation of Magneto-Optical
Imaging Technology for Recovering Obliterated
Serial Numbers in Firearms

FINAL REPORT



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The information shared in this report represents the opinions of the individual practitioners and researchers who participated in the technology testing and evaluation, and not the opinions of their agencies, the FTCoE, or the NIJ. In addition, the individual agents were not part of the agency's technology selection process and have not participated in this project to endorse or protest any technology. All images were provided by Johnson County Sheriff's Department Criminalistics Laboratory or Matesy GmbH. Finally, no individual involved in the testing and evaluation process received any financial or materials support from the manufacturers of the equipment. For more information or questions about this report, visit www.forensiccoe.org, e-mail jerimiller@rti.org or technical contacts.

1. INTRODUCTION

The Gun Control Act of 1968 requires that all newly manufactured firearms produced and imported in the United States bear a serial number. The number must be placed on the frame or receiver and contain a sequence of letters and/or numbers that uniquely identify the firearm. The number must be engraved, cast, or stamped on the firearm in print size no smaller than 1/16 inch and to a minimum depth of 0.003 inch. Stamping, laser etching, and dot/peen marking are the most commonly used serial number application techniques.

When a serial number impression device imprints the identification number, the crystalline structure of the metal is deformed and compacted a short distance beneath the identification number. Two deformation zones result from the impression process: plastic and elastic. The plastic deformation zone is permanent, while the elastic zone is not. If the zone of plastic deformation is still present after a serial number alteration or obliteration (**Figure 1**), it is possible to detect and visualize the serial number. Recovery of an obliterated serial number greatly depends on the material used in the manufacturing of the firearm and the depth of the obliteration.



Figure 1. Tanfoglio Witness pistol with dot pin-applied, and grinding and sanding removed, serial number.

A number of techniques are currently available to recover erased markings in firearms (Klees, 2009). The most commonly used are chemical etching and magnetic particle inspection (MPI). As the discovery of more effective methods is of interest to firearm examiners, an assessment of the technical and nontechnical performance capabilities of magneto-optical (MO) sensor technology was conducted. In Phase I, utilizing stock bar samples, it was found that the MO sensor technology is capable of detecting and visualizing obliterated serial numbers nondestructively and in real time. It was also found that sensor usage was limited to ferrous and paramagnetic metals, and that for the sensor to be successful it requires direct contact between the sensor and the metal (Luyendijk, 2014).

In an effort to validate these findings, a Phase II project was initiated to recover erased markings in actual firearms. MPI was included as the other obliterated serial recovery method to obtain data from the same samples and to compare results. This document reports on the outcome of the Phase II test and evaluation.

2. MAGNETO-OPTICAL SENSOR TECHNOLOGY

MO sensors are a new and innovative tool for observing the structure of magnetic domains in magnetic materials. They can visualize two-dimensional (2D) profiles of magnetic fields with nearly optical resolution in real time using the Faraday effect: an interaction between light and the magnetic field in a sample. For the application to be successful, the sensor must be used in reflective-mode, meaning that it must be in direct contact with the magnetic material of interest. In this project, the MO sensor is used to recover obliterated serial numbers in ferrous and paramagnetic firearms. Other possible MO sensor applications are the recovery of vehicle identification numbers (VINs) in automobiles, the detection and visualization of latent prints on porous and nonporous media using magnetic powder, and in the examination of questioned documents utilizing magnetic ink (Lindner and Koschny, 2012).

2.1 Product

The MO sensor is made up of four functional layers (**Figure 2**). The substrate layer consists of a gadolinium gallium garnet (GGG) with good mechanical, thermal, and optical properties. Next is the MO layer: a single crystalline bismuth and gallium substituted rare earth (RE) iron garnet grown on the GGG substrate by liquid phase epitaxy. A thin mirror to reflect the light passing through the MO layer represents the third layer. The three layers are followed by a diamondlike-carbon (DLC) layer to protect the film and guarantee its durability.

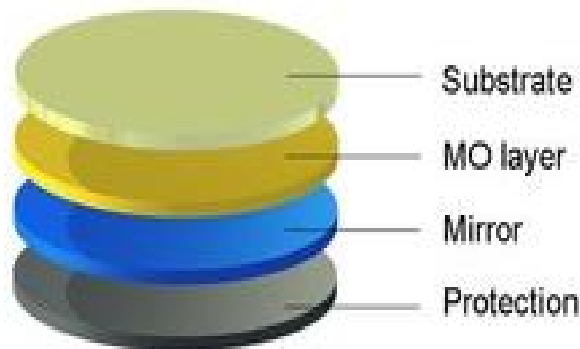


Figure 2. MO sensor configuration showing the four functional layers.

2.2 Operation

To image a magnetic field, the MO-sensor is placed directly onto the magnetic material of interest and illuminated with polarized light. Light passing through the transparent MO-sensor layer is reflected by the mirror coating, causing the light to pass through the MO-sensor once again. When this happens, the plane of polarization is rotated by the magnetic field in the sample. Using an analyzer-polarization filter module, an intensity contrast image is created that is based on the north-south pole components of the magnetic sample (**Figure 3**). Mapping the magnetic properties of the sample object is performed along the x-y plane over the entire sensor size to visualize and analyze both static and dynamic magnetic field changes. The result is an optical image in real time representing a 2D cut through the magnetic stray field of the sample.

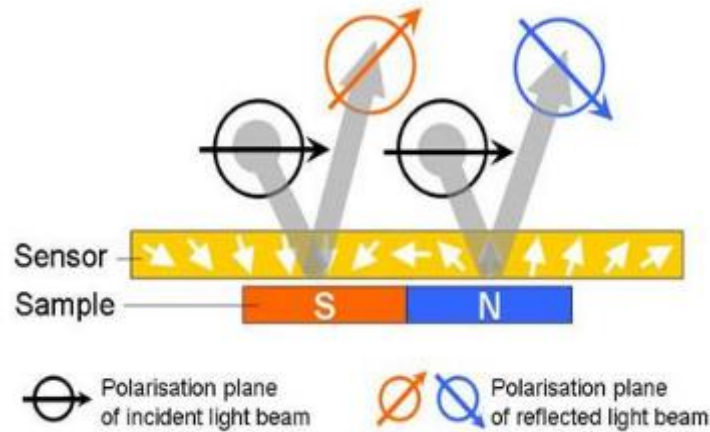


Figure 3. Rotation angle differences caused by the magnetic field's poles of the magnetic material. S and N denote the south-to-north orientation of the sample (source: Matesy GmbH).

2.3 Applicability

MO sensor technology has been used in a number of applications, including automotive (permanent magnet and system analysis), electronics (superconductor quality assurance), material testing (welding seam and crack inspection), and biomedical engineering (magnetic marker monitoring). Recently, application to forensics was demonstrated with regard to restoring erased markings in metals (Weimar and Herrmann, 2011).

2.4 Availability

The MO sensor technology used in this project, as well as the previous project, was developed and manufactured in Jena, Germany, by INNOVENT e.V. and Matesy GmbH, respectively. The sensors are commercially available in the United States through GMW Associates, located at 955 Industrial Road, San Carlos, CA 94070. Depending on the size of the wafer, the sensors can be manufactured in any shape or geometry. Type A sensors (**Table 1**) are currently the most sensitive sensors offered, although INNOVENT is currently developing a Type A+ sensor with a sensitivity from 0.1 to 0.5 kA/m.

Faraday Rotation	$\sim 4^\circ / (\text{kA/m})$
Magnetic Range	0.01 to 2 kA/m
Optical Resolution	10 to 25 $\mu\text{m}/\text{pixel}$
Transmission Range (VIS)	$\lambda > 530 \text{ nm}$
Sensor Size	$\varnothing \leq 70 \text{ mm}$
Sensor Thickness	0.5 mm
Operating Temperature Range	15° to 30° C

Table 1. Type A MO sensor properties.

3. EXPERIMENTAL DESIGN

For Phase II, three objectives were identified. The primary objective was to validate the detection and imaging capabilities of the MO sensor technology for restoring obliterated serial numbers in actual firearms. A secondary objective was to evaluate the added value of the MO sensor technology in light of currently used obliterated serial number restoration techniques. The tertiary objective was to design and develop an MO sensor workstation that can be easily replicated by other forensic facilities interested in using the technology for serial number restoration casework.

Technology validation consisted of testing the MO sensor to ensure that the technology is effective, efficient, consistent, and dependable for detecting and imaging obliterated serial numbers in firearms. Additionally, the technology evaluation compared the results of the tests and nontechnical performance characteristics to those of MPI performed on the same samples. Collectively, the outcomes of these tests provide objective evidence regarding the sensor's ability to successfully detect and recover obliterated serial numbers in steel firearms.

Tests were performed at the Johnson County Sheriff's Office Criminalistics Laboratory (JoCo) in Olathe, KS. JoCo volunteered two forensic firearm examiners for the project. Both are active members of the Association of Firearm and Tool Mark Examiners (AFTE) and have more than 10 years of experience in restoring obliterated serial numbers in firearms. One of the examiners received sensor technology training from the manufacturer and participated in the MO sensor test on stock bar samples (Phase I). The other firearm examiner was trained on MO sensor operation and use by the manufacturer-trained firearm examiner. The MO sensor technology manual served as backup.

Data were collected from firearms obtained from the JoCo reference library (**Figure 4**). Firearms examined were made of ferrous or paramagnetic (stainless) steel, as the Faraday effect is the working principle for the sensor. All firearms had the firearm manufacturer-applied serial number intact to provide the actual key for the MO sensor technology validation study. A total of 67 firearms were selected for study, including pistols, revolvers, rifles, and shotguns. The condition of the specimens ranged from new to slightly used.



Figure 4. Part of the Johnson County Sheriff's Office firearm collection.

Three different serial number application techniques were examined: stamping, dot peening, and laser etching (**Figure 5**). Stamping was selected because it is the traditional marking method for firearm serial numbers, and dot peening and laser etching were incorporated because they are becoming increasingly popular as marking techniques. Stamping and dot peening belong to the class of deforming marking methods because they apply the mark by impact or compression, resulting in a permanent alteration of the physical properties of the material in the marked area. Laser etching removes metal by vaporizing it on contact, leaving no deformation and only a heat-affected zone with little information.



Figure 5. Stamping (A), Dot Peening (B), and Laser Etching (C) applied serial numbers showing differences in quality marks.

Methods used to remove the serial numbers involved physical abrasion techniques, specifically filing, grinding, sanding, and peening. All are techniques commonly encountered in firearm-obiterated serial number casework. Filing, grinding, and sanding methods typically remove the serial number to the base of the metal so that the number is no longer visible. Peening, on the other hand, does not remove the serial number, but defaces it so that it is no longer discernible. If the obliteration does not go deep enough to remove the underlying plastic zone, the obliterated mark may be restored and the serial number recovered (Persi Paoli, 2010). While much is known about the recoverability of stamped markings, very little information is available regarding the recoverability of obliterated dot pin- and laser etch-applied serial numbers on firearms (Kuppuswamy, 2011).

4. MO SENSOR VALIDATION WORKSTATION

The workstation used to validate the imaging and recovery capabilities of the MO sensor technology consisted of a portable desk lamp, a digital camera, a forensic photography stand, a permanent magnet, and a three-piece MO sensor kit (**Figure 6**). The MO sensors used were all of the Type A variety having dimensions of 3 x 3 mm, 17 x 5 mm, and 17 x 15 mm, supplemented by one irregularly cut piece. The desk lamp consisted of a base and a flexible light guide equipped to hold a 150-W fluorescent light bar for diffuse illumination of the sample. The underside of the light (exposed portion) was covered by a film sheet of cut-to-fit linear polarized film. A horseshoe magnet and two small RE magnets were used as needed to induce magnetic fields.



Figure 6. MO sensor kit showing the three sensor sizes used in the project.

A simple point-and-shoot Canon SX40 camera was used to permanently record the recovered marks. A number of exposures were taken and all settings were recorded. The camera had full manual controls and was

equipped with both a Tiffen 58-mm linear polarization filter and a Hoya 58-mm circular polarization filter to serve as analyzers. It was mounted on a portable copy stand for forensic photography. The stand featured an adjustable column to position the camera at the required height and a flexible camera mount to angle the camera to the desired setting. The base of the stand consisted of a rectangular baseboard etched with a 1-inch grid for scaling. Not including the size of the sample, the footprint of the MO sensor technology workstation (**Figure 7**) was approximately 20 x 18 inches or 50 x 45 cm (WxD).



Figure 7. Experimental setup of the MO sensor workstation at the JoCo facility.

5. METHODOLOGY

Tests were performed at the JoCo Sheriff's Office crime lab facility in Olathe, KS, with firearms selected from the JoCo Firearm Reference Library (FRL). Prior to obliterating the serial number, the characters were recorded in a ledger and viewed with the MO sensor technology (**Figure 8**). This was done to confirm the sensor's ability to visualize the unaltered serial number on the firearm and to determine the best location(s) for placement of a magnet. The former was to validate the experimental setup and the method used to recover obliterated serial numbers. It was assumed that if the MO sensor film was unable to visualize the serial number prior to removal, it would be unable to do so after removal as well.



Figure 8. MO sensor methodology confirmatory step showing stamped alphanumeric characters.

Firearms were selected and serial numbers obliterated using four different techniques: filing, grinding, sanding, and peening. For filing, a common metal hand file was used to remove the serial number by scratching the serial number until characters were no longer visible. Similarly, for grinding, a Dremel grinding tool was used to remove the characters to the base, while for sanding, an abrasive paper of grit number higher than 600 and water were used to remove the serial number. Finally, for peening, a center-punch followed by grinding with a Dremel tool was used to deface the characters until they were no longer recognizable.

Serial numbers were removed in a stepwise fashion, meaning that serial number obliteration was performed for about 10 minutes followed by a period of 5 minutes, during which the specimen was allowed to cool off. This process was repeated until the marked characters were no longer visible or legible to the naked eye. This stop-and-go obliteration process was selected to avoid possible over-heating of the metal to the point of disrupting the crystalline structure and/or magnetic properties of the firearm. Once serial numbers were obliterated, samples were placed in a holding area until character recovery tests were performed using the MO sensor.

At the time of testing, specimens were transferred from the holding area to the camera stand and inspected for an area to place the sensor film(s). If the area was scratched or rough and uneven, the Dremel rotary tool with a soft polishing stone was used to polish the affected area until all scratches were removed and a mirrorlike surface was obtained to establish direct contact between the sensor film and substrate. A sensor size selection was then made and the sensor was placed onto the obliterated area. In cases where the serial number was located in curvilinear areas (e.g., barrels), the smallest size sensor film was used first.

JoCo crime lab standard operating procedures for serial number recovery were followed to restore the obliterated serial number to a readable state. Testing followed the criteria identified by the SWGs (SWGFAST, 2010), as well as elements of the National Institute of Standards and Technology (NIST) System, Component, and Operationally Relevant Evaluations (SCORE) framework for the evaluation of emerging technologies (NIST, 2009).

Tests were conducted and results were recorded on a serial number restoration worksheet along with observations made during sample preparation and sample processing. Records were reviewed and interpreted. If all characters were visible and fully identifiable, the outcome was recorded as “full recovery.” Similarly, if all characters were visible but not all fully identifiable, it was documented as “partial recovery.” Finally, if characters were visible but not clearly identifiable, the outcome was documented as “not discernible,” and if none were visible, it was recorded as “nondetectable.”

Digital photographs were taken at the end of the restoration process for permanent record of the restored marks. Several exposures were made by simply adjusting settings on the digital camera. Attempts were made to digitally enhance a number of partially recovered serial numbers to find out if firearm examiners should consider the use of computer software in the restoration of obliterated serial numbers.

Adobe Photoshop CC was selected because it has been used before in serial number restoration (Malikowski, 2004), and in court presentations (People vs. Perez, 2003). Utilizing various noise and visual reduction methods, as well as global and local contrast improvement channels, a process was developed to digitally enhance photographic images of partially recovered serial numbers applied by dot peening, laser etching, and stamping. The stepwise process was converted into a Photoshop serial number restoration methodology, which is described in Appendix A.

6. PERFORMANCE FACTORS

Four technical performance factors were examined to validate the efficiency and effectiveness of the MO sensor for recovering obliterated serial numbers. Another four nontechnical performance factors were validated to determine the usability and implementation potential of the technique. Results and findings were

then compared to those obtained on the same samples by MPI. Technical performance factors included: sensor sensitivity, sensor imaging, sensor durability, and method reproducibility. Nontechnical performance factors included sensor usability, learnability, worker safety, technology cost, technology deployment, and technology mobility. Collectively, they provide the information needed to determine the potential application and use of the MO sensor technology to recover obliterated serial numbers in firearms.

Eight performance factors were used to validate and evaluate the MO sensor technology, described below.

- *Sensor Sensitivity*: Ability to fully detect and visualize the presence of an obliterated serial number or serial number character. In this project, sensitivity is synonymous with limit of detection (LOD).
- *Sensor Imaging*: Ability of the sensor to detect and accurately recognize and visualize a character (letter or numeral) from background noise in a sample.
- *Sensor Durability*: Ability of the sensor to consistently perform its intended use over a relatively long period of time without major defects or breakdowns.
- *Method Reproducibility*: Degree of consistency between the two examiners in yielding the same results for a given sample using the same method and the same equipment.
- *Technology Usability*: Degree of work required to prepare the samples for processing and the time needed to process and analyze the samples.
- *Technology Learnability*: Degree of learning required to successfully operate the technology and to satisfactorily execute the analytical process.
- *Technology Cost*: Economics associated with sample analysis, including the cost of purchasing and operating the equipment (excluding labor).
- *Worker Safety*: Degree to which firearm examiners using the technology are exposed to risk of injury or long-term toxicity associated with sample preparation and analysis.
- *Technology Deployment*: Implementation by the forensic community and application by forensic scientists for its intended use.
- *Technology Mobility*: Ability of the technology to be used in different environmental settings—in the case of the MO sensor technology, in applications internal and external to the crime lab.

7. PERFORMANCE ASSESSMENT

7.1 Sensitivity

In the Phase I project, the MO sensor's performance testing focused on determining the sensor's selectivity and specificity for different materials used in manufacturing firearms. It was found that the sensor's use was limited to firearms made of ferrous and paramagnetic metals. This was not surprising given the fact the sensor's operating principle is the Faraday effect, which is used to measure the distribution of magnetic fields. It was also found that the sensor's detection limit was somewhat different from the one established by the manufacturer. To establish the sensor's true detection limits for the 1018 carbon, 4140 alloy, and 304 stainless steels, and to determine the sensor's sensitivity for serial number recovery in firearms, a request was made to Matesy GmbH to help analyze the samples.

A set of blind samples with obliteration depths beyond Phase I determined LODs was produced for each of the three steels. Samples were prepared by Precision Forensic Testing using the same methodology that was used in Phase I for serial stamping and obliteration. Each sample was given a unique numerical identifier to avoid "cognitive bias" by the examiner analyzing consecutive samples. Serial number obliteration was in 0.003-inch intervals starting at the firearm examiner-established LODs.

Three sets of blind samples (one for each metal) were sent to the manufacturer, requesting examination of the samples using the Type A sensors utilized in the previous experiments. The manufacturer was asked not

to interpret results but instead to take pictures of the outcome of each recovery exercise. Manufacturer-taken pictures were then sent to the firearm examiners participating in this project, requesting that they interpret the results and record the outcome of their analysis.

Table 2 lists the results of the examinations. It was found that the MO limit of detection for the three different metals is not the same, and that certain characters begin to deteriorate sooner than others until they are no longer discernible and eventually undetectable. Down to about 0.016 inch (0.040 mm) below the obliteration depth, the characters for all three steels could be detected and visualized. Below this point, mostly individual characters could be detected and visualized. For the 4140 alloy steel, the last characters detected were at the 0.024-inch (0.061 mm) point. For the 1018 carbon steel, the last detection was reached at 0.040 inch (0.10 mm), and for the 304 stainless steel at 0.037 inch (0.094 mm).

Below 0.040 inch (0.10 mm), no characters could be detected. The fact that below a removal depth of 0.037 inch (0.094 mm) the characters detected grow increasingly faint suggests that the upper limit of detection for the MO sensor is probably near the 0.04-inch (0.10 mm) mark below the serial number obliteration depth. The detection limits differ among the three steels investigated, suggesting that the sensitivity of the MO sensor for the detection of obliterated serial number characters may be impacted by the physical and chemical properties of the metal.

Removal Depth (A)	1018 Carbon Steel	304 Stainless Steel	4140 Alloy Steel	Removal Depth (B)
0.015 inch	6 characters (B)	6 characters (A)	6 characters (A)	0.016 inch
0.018 inch	6 characters (B)	6 characters (A)	5 characters (A)	0.019 inch
0.021 inch	6 characters (B)	3 characters (A)	2 characters (A)	0.022 inch
0.024 inch	6 characters (B)	2 characters (A)	3 characters (A)	0.025 inch
0.027 inch	5 characters (B)	5 characters (B)	0 characters (A)	0.028 inch
0.030 inch	4 characters (B)	6 characters (B)	0 characters (A)	0.031 inch
0.034 inch	0 characters (B)	4 characters (B)	0 characters (B)	0.034 inch
0.037 inch	3 characters (B)	3 characters (B)	0 characters (B)	0.037 inch
0.040 inch	0 characters (B)	1 character (B)	0 characters (B)	0.040 inch
0.041 inch	0 characters (B)	0 characters (B)	0 characters (B)	0.041 inch
0.044 inch	0 characters (B)	0 characters (B)	0 characters (B)	0.044 inch
0.047 inch	0 characters (B)	0 characters (B)	0 characters (B)	0.047 inch
0.050 inch	0 characters (B)	0 characters (B)	0 characters (B)	0.050 inch

Table 2. MO sensor sensitivity results showing six character detection: (A) refers to Phase I results, (B) refers to Phase II results. Depth is the serial number removal depth below stamp depth.

7.2 Reliability

Sensor reliability deals with the question of how well the sensor performs its intended job, in this case the recovery of obliterated serial numbers on firearms. To determine sensor reliability, the recovery rate of characters was determined as the percentage of obliterated serial numbers that can be visualized within the limit of detection for each of the three steels examined. In Phase I, the recovery rate was established within a rather narrow range of detected characters (**Table 3**). It was found to be 52% for 1018 carbon steel, 85% for 4140 alloy steel, and 87% for 304 stainless steel. In this project, the limits of detection were expanded and new MO sensor recovery rates were computed. The lowest recovery rate was for the 4140 alloy steel (50%), followed by the 1018 carbon steel (62%) and the 304 stainless steel (81%). The lower recovery rates are most likely related to the fact that characters and symbols grow increasingly faint and indiscernible near the upper limit of detection.

Detection	304 Stainless Steel	1018 Carbon Steel	4140 Alloy Steel
Initial LOD	87.78%	52.78%	85.56%
Expanded LOD	80.95%	62.50%	50.00%

Table 3. Recovery rate of alphanumeric characters within the MO sensor technology's limit of detection.

7.3 Reproducibility

To determine the consistency of the MO sensor technology, the reproducibility of the sensor technology was examined (**Table 4**). Reproducibility deals with the degree of agreement between two or more examiners analyzing the same sample using the same method and the same equipment. In Phase I, the interreproducibility of the MO sensor was determined using the Kappa-statistic (Sim and Wright, 2005). Kappa is a measure of agreement between observers taking into account the agreement occurrence by chance. It was found that there was moderate agreement between the findings of the two firearm examiners utilizing the MO sensor technology for restoration of obliterated serial numbers.

Examiner Agreement	Kappa Coefficient	Interpretation
Between Labs	0.44	Moderate

Table 4. Interreproducibility of the MO sensor showing firearm examiner agreement.

7.4 Durability

Sensor durability deals with the longevity of the sensor during actual use. At the end of the Phase I MO sensor assessment study, the durability of the sensor was questioned, as the film appeared to scratch easily by the sharp edges of the metal samples. As the sensor film in that project was encased in a box-system, and not placed directly onto the substrate itself, the durability of the sensor film was examined based on sensor placement on the substrate. It was found that although the film scratched during use, and experienced some abuse as it was periodically dropped, it held up well and kept generating workable and useful images of recovered serial numbers. Communication (2015) with Bert Weimar at the Bundeskriminalamt (Federal Criminal Police Office) further revealed that a single MO sensor film has been used in casework in Germany since 2009 (**Table 5**).

Sensor Use	Sensor Film	Operation
Serial number casework	One strip	Since 2009

Table 5. Durability of the same MO sensor film in sensor film longevity.

8. RISK FACTORS

Character recognition is a key component of obliterated serial number restoration and an important factor in the interpretation of MO sensor technology validation and evaluation work. Optical character recognition deals with the ability of the MO sensor to clearly and accurately recover the alphanumeric characters making up the obliterated serial number (Jones, 2013). For the MO sensor technology, character recognition consists of a three-step process: character detection, character visualization, and character identification. In this project, the optical character recognition capabilities of the MO sensor were examined to determine which characters are most likely at risk when recovering obliterated serial numbers in firearms.

8.1 Character Detection

For optical devices, the limit of detection for alphanumeric characters is not the same. Certain characters typically begin to deteriorate sooner than others. For the MO sensor, the limit of detection for 10

numeric characters was examined to determine which numerals are most likely at risk when using the MO sensor for recovering obliterated serial numbers in firearms. Using 1018 carbon steel as a substrate, and stamping as the serial number application technique, it was found (**Table 6**) that the numeral 8 could be detected to about 0.04 inch (0.10 mm) below the obliteration depth, whereas the numeral 5 could be detected at less than half that depth. All other numeric characters had detection limits in between these two extremes.

Numeric Character	Detection Limit
1	0.025 inch
2	0.037 inch
3	0.037 inch
4	0.031 inch
5	0.019 inch
6	0.025 inch
7	0.037 inch
8	0.040 inch
9	0.028 inch
0	0.031 inch

Table 6. 1018 carbon steel detection limits for the 10 numerals examined.

A comparison with the numeric character detection limits established for 304 stainless steel (the metal showing approximately the same range of numeric character detection) revealed that the detection limit for the numeral 5 was similar to the detection limit for the numeral 8 and in line with the detection limits of all other numeric characters that are all over 0.030 inches (**Table 7**).

Numeric Character	Detection Limit
1	0.031 inch
2	0.034 inch
3	<0.037 inch
4	NA
5	0.034 inch
6	0.031 inch
7	0.034 inch
8	0.034 inch
9	0.034 inch
0	0.037 inch

Table 7. 304 stainless steel detection limits for the 10 numerals examined. Note: The numeral 4 was inadvertently excluded from the individual character used to determine stainless steel detection limits.

Tabulating the difference between the two detection limits of the 10 numerals for the two metals, **Table 8** shows that almost all numeric characters have discrepancies of 0.006 inch or less with the exception of the numeral 5, which shows a discrepancy of at least twice that value. This seems to suggest that detection of the numeral 5 was not consistent among the metals and, according to Jones (2013), could be related to inconsistencies in the numeral's depth profile. If true, it could put the numeral 5 at risk of detection by the MO sensor technology.

Numeric Character	Detection Limit Discrepancy
1	0.006 inch
2	0.003 inch
3	NA
4	NA
5	0.015 inch
6	0.006 inch
7	0.003 inch
8	0.006 inch
9	0.006 inch
0	0.006 inch

Table 8. MO sensor detection limit comparison between 304 stainless steel and 1018 carbon steel. NA means unable to establish detection limit discrepancies due to missing data.

8.2 Character Visualization

Character visualization is the next step in the MO sensor character recognition and imaging process. To determine which numeric characters are harder to discern from background noise, the numeric character visualization capability of the MO sensor was examined by reviewing and assessing the discernibility of the numeric characters within the detection limit for each metal. It was found (**Table 9**) that the numeral 7 could be visualized the best, yielding a visualization rate of 100%, and the numeral 1 the worst (50%); these were followed by the numerals 6 (57%), and 5 (60%). All other numeric characters had visualization rates of 80% or higher.

Numeric Character	Discernibility Rates
1	50%
2	80%
3	80%
4	80%
5	60%
6	57%
7	100%
8	83%
9	80%
0	83%

Table 9. MO sensor numeric character discernibility rates.

To determine if character complexity had any bearing on character visualization, a 16-segment character display variation of the better known 7-segment digital numeric character display was used (Maxim Integrated, 2004). Utilizing the alphanumeric data from the MO sensor performance assessment in Phase I of the project, it was found (**Table 10**) that the MO sensor had little difficulty visualizing alphabetic characters but slightly more difficulty visualizing numeric characters. It was also found that simple characters were more challenging than complex ones. This appeared to be true for both alphabetic characters (letter T) and numerals (number 2).

Alphabetic Character	Complexity	Observations w/in LOD	Discernibility
C	4	15	100%
N	6	15	87%
K	4	35	94%
F	4	15	93%
T	3	20	80%
Y	3	20	95%
Numeric Character	Complexity	Observations w/in LOD	Discernibility
1	2	20	70%
2	4	39	81%
3	5	24	79%
8	7	21	86%

Table 10. MO sensor alphanumeric character discernibility.

8.3 Character Identification

Character identification is the last and final step in the MO sensor character recognition process. To determine the risk of not identifying and misidentifying the characters visualized, the character recovery capability of the MO sensor technology was examined. It was found (**Table 11**) that the majority of the characters visualized could be successfully recovered, meaning that they could be positively identified or correctly guessed. The only exception was the numeral 5, possibly because of variances in the depth profile of the mark.

Numeric Character	Recovery Rates
1	76%
2	75%
3	50%
4	50%
5	33%
6	75%
7	75%
8	100%
9	63%
0	70%

Table 11. MO sensor recovery of discernible numeric characters.

Finally, to determine the risk of misidentifying the numeric characters detected and discerned by the MO sensor, the error rate for a limited number of alphanumeric characters was computed at the upper limits of character detection. At this point, displayed characters are inherently faint, with contrast between the character and the background becoming increasingly poor. It was found that for the alphanumeric characters examined, the misidentification of characters was low. Only the uppercase letter K was twice misread as an uppercase letter X, while the numeral 3 was once misread as an uppercase letter S, the numeral 6 for the number 9, the number 2 for the number 8, and the number 8 for the number 5. This finding of misread uppercase letters, uppercase letter and numbers, and plain numerals was not surprising as, according to the Institute for Safe Medication Practices (ISMP, 2009), they are commonly confused in character recognition (**Table 12**).

Uppercase Letter to Uppercase Letter	Uppercase Letter to Numeral <i>cont'd</i>
T and I	U and 0
D and O	Z and 2
C and G	Q and 2
L and I	D and 0
P and B	S and 5
F and R	S and 8
U and O	U and 4
U and V	Z and 7
E and F	Y and 5
V and W	
X and Y	
M and N	
Uppercase Letter to Numeral	Numeral to Numeral
T and 7	7 and 1
F and 7	6 and 8
O and 0	5 and 3
B and 8	5 and 8
G and 6	0 and 8
	3 and 9
	3 and 8
	4 and 9

Table 12. Uppercase letters and numbers commonly confused in character recognition.

9. IMAGE ENHANCEMENT

Adobe Photoshop CC is an image editing application used in forensic analysis (Malikowski, 2004). In this project, it was used to develop a methodology to improve the character recognition of the MO sensor technology and to digitally enhance the image of partially recovered serial numbers. Utilizing a high-resolution image of a partially recovered serial number (**Figure 9A**), with all characters recorded before obliteration, a process was developed to restore the unclear characters until they became fully identifiable (**Figure 9B**). The process consisted of a series of contrast improvement and noise and visual reduction steps (Maini and Aggarwal, 2010). The process was then converted into a methodology (Appendix A) and applied to the partially recovered serial numbers of three different application techniques (laser etching, dot peening, and stamping). This was done to determine the value added of Adobe Photoshop CC image enhancement.

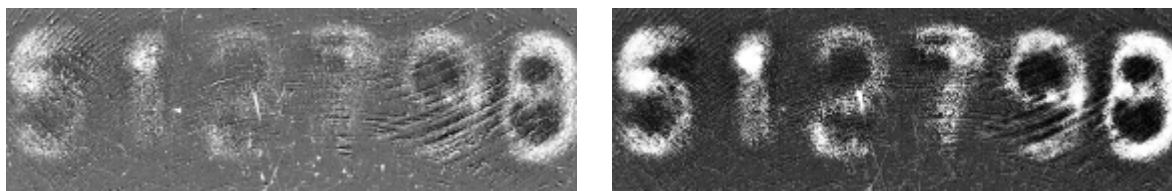


Figure 9. Enhancement of partially recovered numeric characters (A) to a fully recovered serial number; (B) utilizing Adobe Photoshop CC.

Figure 10 shows the results for the partially recovered dot pin-applied and hand-filed obliterated serial number. In the original photograph, the first three numeric characters are visualized as well as the last two. Yet, the two numeric characters in between these two sets are somewhat unclear. Utilizing the Photoshop character restoration methodology, all seven characters were digitally enhanced, leading to full recovery of the obliterated serial number applied by dot peening: 1224960.

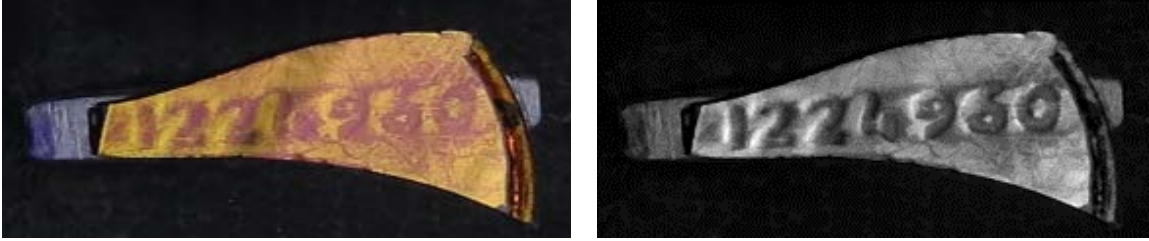


Figure 10. Serial number restoration of dot-peened characters utilizing Adobe Photoshop CC.

Figure 11 shows the results for the partially recovered laser etch-applied and hand-filed obliterated serial number. Like the previous photograph, hand filing of the serial number led to the removal of the serial number, which could be visualized but not clearly identified due to a lack of contrast and clarity. Use of the Photoshop character restoration methodology provided a sharper image and more contrast between the individual characters. The result was full recovery of the original laser etch-applied serial number: RBE0723.

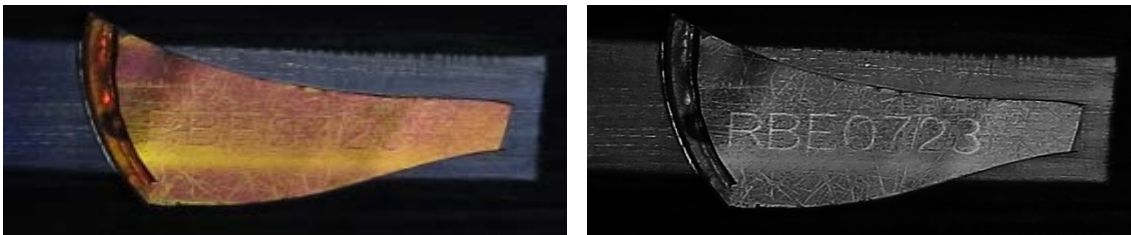


Figure 11. Serial number restoration of laser-etched characters utilizing Adobe Photoshop CC.

Finally, **Figure 12** shows the result for the partially recovered stamping-applied serial number. Although the characters were visible, their images were difficult to identify with certainty. For example, it was unclear if the serial number consisted of seven or eight characters. After an in-depth review of the negative images, it was decided that the serial number consisted of eight characters. Use of the Photoshop character restoration methodology yielded the serial number: LA553849.

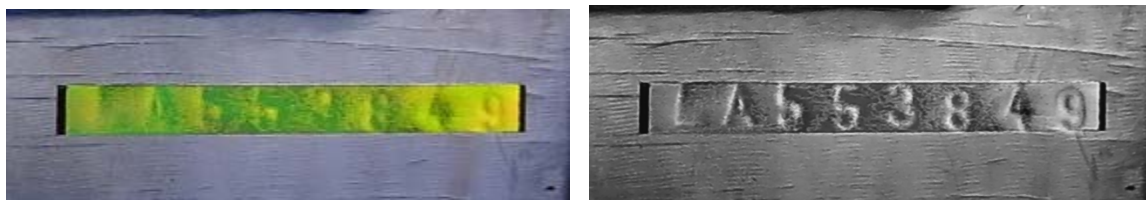


Figure 12. Serial number restoration of stamped characters utilizing Adobe Photoshop CC.

10. PERFORMANCE VALIDATION

For performance evaluation of the MO sensor technology, 67 firearms were selected for testing, representing pistols, revolvers, shotguns, rifles, silencers, and barrels. The performance of the MO sensor technology was validated using three different serial application techniques and four different serial number removal methods.

10.1 Application Techniques

Stamping. In stamping, the serial number is applied by a single stroke of a press or roll marking machine, leaving a clear and deep alphanumeric character on the metal surface. According to the literature (Persi Paoli, 2010) recoverability of the stamped mark (50%) is the highest among serial

number application techniques. **Table 13** shows the results for recovering obliterated stamp-applied serial numbers utilizing the MO sensor. It was found that the technology successfully recovered 60% of the obliterated serial numbers with 45% fully recovered and 15% partially recovered. Of the obliterated serial numbers located on curvilinear substrates (barrels or silencers), the MO sensor yielded 100% recovery, consisting of 75% full recovery and 25% partial recovery.

SN Application	Observations	Full Recovery	Partial Recovery	None Discernible	Not Detected
Stamping	20	45%	15%	15%	25%

Table 13. MO sensor recovery of obliterated stamped serial numbers, showing the relatively high detection and overall recoverability of alphanumeric characters.

Dot Peening. In dot-pin marking, the characters are pressed into the metal surface by applying multiple strokes of a stylus, leaving a relatively low-quality mark. **Table 14** shows the results for recovering obliterated dot-pin-marked serial numbers. It was found that the MO sensor successfully recovered 67% of the obliterated serial numbers, with 62% fully recovered and 5% partially recovered. This recoverability of the dot pin mark by itself is not surprising, as dot peening, similar to stamping, causes permanent plastic deformation of the crystalline structure of the metal. Yet, the high recoverability rate, especially the full recovery rate of obliterated serial numbers, is encouraging, as relatively little has been published in the literature regarding the recoverability of dot pin marks.

SN Application	Observations	Full Recovery	Partial Recovery	None Discernible	Not Detected
Dot Peening	21	62%	5%	14%	19%

Table 14. MO sensor recovery of obliterated dot peened serial numbers showing the relatively high detection and full recoverability of alphanumeric characters.

Laser Etching. In laser etching, a diode-pumped or fiber laser is used to remove material from the metal to create the desired alphanumeric characters. Because of its high precision and the fact that the technique does not require physical contact with the substrate, laser etching can leave a highly precise, high-quality mark at any area of the assembled firearm. **Table 15** shows the results for recovering obliterated laser-etching-applied serial numbers by the MO sensor technology. The MO sensor successfully recovered 50% of the obliterated serial numbers, with 35% fully recovered and 15% partially recovered. Although this recovery rate is somewhat lower than the ones obtained for both the stamped and dot-peened pin-marked obliterated serial numbers, the finding is significant, as very little information is available in the literature regarding the recoverability of laser-etched serial numbers. According to Katterwe (2006), this is because of the rather shallow marking depth of laser etching (0.043 inch), and the fact that lasers generate a heat stress-affected zone that leaves very little information in the substrate (da Silva and Marques dos Santos, 2008).

SN Application	Observations	Full Recovery	Partial Recovery	None Discernible	Not Detected
Laser Etching	20	35%	15%	5%	45%

Table 15. MO sensor recovery of obliterated laser-etched serial numbers, showing the relatively low detection but excellent recoverability of alphanumeric characters detected.

10.2 Obliteration Method

Filing. Filing is one of the most commonly used methods to remove serial numbers in firearms. In this project, a hand file was used to remove the serial number to the base of the metal so that the number could no longer be read. **Table 16** shows the results for recovering the hand-filed obliterated serial numbers by the MO sensor. It was found that 56% of the filed-off serial numbers could be recovered, of which 43% were fully recovered and 13% partially recovered. Of the partially recovered serial numbers, one was located on a curvilinear surface.

SN Application	Observations	Full Recovery	Partial Recovery	Not Discernible	Not Detected
Filing	30	43%	13%	13%	30%

Table 16. MO sensor recovery of filed-off serial numbers, showing good detection and recoverability of characters.

Grinding. Grinding is one of the other most commonly used serial number obliteration methods. In this project, a Dremel tool was used to remove the serial number. Similar to filing, the number was removed to the base of the metal. **Table 17** shows the results for recovering the Dremel-tool-obliterated serial numbers by the MO sensor. It was found that 61% of the filed-off serial numbers could be recovered, of which 52% were fully recovered and 10% were partially recovered.

SN Application	Observations	Full Recovery	Partial Recovery	Not Discernible	Not Detected
Grinding	31	52%	10%	10%	29%

Table 17. MO sensor recovery of grinding obliterated serial numbers showing good detection and full recoverability of detected characters.

Sanding. Like filing and grinding, sanding is another serial number removal method that involves physical abrasion. In this project, coarse (600 grit upwards) sandpaper was used to remove the serial number. This was a very time-consuming and labor-intensive activity that was performed only once due to project time constraints. Serial number recovery by the MO sensor yielded a partial recovery.

Peening. Unlike filing, grinding, and sanding, peening does not remove any of the serial number. Rather, the serial number is defaced so that it is no longer discernible. In this project, a center punch was used to hammer into the markings of six different firearms. Due to the destructive nature of this technique, the peening process was followed by grinding to obtain the flat surface necessary for the MO sensor to contact the substrate. Attempts to recover the center-punched serial numbers after grinding yielded no results. It is believed that peening of the serial number damaged, and grinding removed, the plastic deformation zone, thereby preventing the serial numbers to be detected by the MO sensor. The only marks recovered were those of the center punch.

11. PERFORMANCE EVALUATION

Technical and nontechnical performance data were compared to those of MPI obtained from the same samples and by the same two firearm examiners. The evaluation was conducted to help determine the validity, reliability, and usability of the MO sensor technology for obliterated firearm serial number restoration. MPI was selected because MPI, like the MO sensor, is a nondestructive assessment technique that does not permanently alter the sample being examined. It is commonly used in forensic engineering and is a standard for erased markings restoration in firearms.

11.1 Magnetic Particle Inspection

MPI examines the properties of a material by using magnetic fields and small magnetic particles to detect and visualize surface and subsurface discontinuities in the ferromagnetic materials of the firearms sampled. In this project, it was performed right after examination by the MO sensor technology. To prepare the samples for MPI, each sample was polished with a mild abrasive compound and cloth wheel. It was then placed on a horseshoe electromagnet and sprayed with an aerosol (MPI-80 black magnetic particle bath) to attract the magnetic particles in the spray to the magnetic properties of the characters. After the spray bath, samples were examined and a determination was made regarding the visibility of the characters. If determined invisible, the sample was placed back on the electromagnet, and the process was repeated. The process ended when all characters were either legible or determined illegible. Once the determination was made, photo documentation completed the testing process.

11.2 Technical Performance Comparison

In Phase I of the project, the sensitivity, selectivity, specificity, accuracy, and precision of the MO sensor technology was compared with MPI using stock bar samples and a 2 x 2 contingency table. Results indicated (**Table 18**) that besides sensitivity, which was in favor of the MO sensor technology, the selectivity, specificity, accuracy, and precision were largely compatible. This is not surprising given the fact the operating principles of both the MO sensor technology and MPI are based on the magnetic properties of the materials investigated.

Technical Performance	MO/MPI
Sensitivity	0.98
Selectivity	0.63
Specificity	0.43
Accuracy	0.67
Precision	0.55

Table 18. Technical performance comparison (using stock bar samples) between the MO sensor technology and MPI: values close to 0.00 favor MPI, while values close to 1.00 favor the MO sensor technology. Values close to 0.50 indicate no favorite.

In this project, the obliterated serial number recovery potential of the MO sensor was examined and compared with that of MPI using actual firearms. Using the data displayed in Appendices A-D, **Table 19** shows the results organized by outcome for the MO sensor and MPI, and the three different serial number application techniques. It can be seen that both techniques were capable of recovering the obliterated laser etch-, stamp-, and dot pin-applied serial numbers, and that both techniques yielded similar recoverability results. Combining partial and full recovery results, the highest recoverability rates were obtained for dot pin-applied serial numbers and the lowest recoverability rate for laser etch-applied serial numbers. The recoverability rate for stamp-applied serial numbers was in between these two. For the MO sensor, recoverability rates were over 50% for all three application techniques.

SN Application	Recovery Method	Full Recovery	Partial Recovery	Nondiscernible	Not Detected
Laser Etched	MO sensor	35%	15%	5%	45%
	MPI	35%	10%	10%	45%
Stamped	MO sensor	45%	15%	15%	25%
	MPI	40%	20%	15%	25%
Dot Peening	MO sensor	62%	5%	14%	19%
	MPI	75%	5%	5%	19%

Table 19. Obliterated serial number detection and recovery comparison by application technique for MO sensor technology and MPI. Results show identical detection and similar recovery outcomes.

Comparing serial number recovery results for filing and grinding (**Table 20**) shows that both methods yield recoverability rates of at least 50%. This suggests that the MO sensor and MPI are equally well suited in recovering filed-off and ground-down serial numbers in firearms.

SN Application	Recovery Method	Full Recovery	Partial Recovery	Nondiscernible	Not Detected
Hand Filing	MO sensor	44%	13%	13%	30%
	MPI	43%	10%	17%	30%
Dremel Grinding	MO sensor	51%	10%	10%	29%
	MPI	55%	13%	3%	29%

Table 20. Obliterated serial number recovery comparison between the MO sensor technology and MPI. Results show identical detection, slightly better MO sensor technology recovery of hand filing obliterated serial numbers, and slightly better MPI recovery of Dremel grinding obliterated serial numbers.

Non-Technical Performance

Sample Preparation: The criterion used to determine the MO sensor technology and MPI ease of use was the effort needed to prepare the sample for actual sample processing. It was found (**Table 21**) that very little if any sample preparation was needed for the MO sensor, and samples could be processed upon receipt. In only a few instances did the samples require polishing to remove deep scratches. MPI, on the other hand, required polishing for all samples examined to create the flat surface needed to apply the oil suspension for sample processing. For both the MO sensor technology and MPI, a Dremel tool was used for polishing.

Sample Preparation	Effort
MO sensor technology	Polishing sometimes needed
MPI	Polishing required

Table 21. MO sensor and MPI sample preparation comparison showing somewhat less sample preparation for the MO sensor technology.

Sample Processing: The criterion used to compare the efficiency of the MO sensor technology and MPI was the time required to perform the task of recovering the obliterated serial number. Once the sample was prepared, it was transferred to the workstation to apply the film (MO sensor) or the oil

suspension (MPI). Both techniques did not damage or alter the sample to recover the obliterated serial number. Both techniques obtained results instantaneously in a few minutes (**Table 22**).

Sample Processing	Execution
MO sensor technology	Nondestructive, real time
MPI	Nondestructive, real time

Table 22. MO sensor and MPI sample processing comparison showing identical execution.

Required Skillset: The criterion used to determine the learnability of the MO sensor technology and MPI was the skillset required to operate the equipment. Both MO sensor and MPI are simple and straightforward technologies requiring little instruction (**Table 23**). A brief introduction to the operating principles of the technology and proper execution of sample processing typically suffice. Access to a user's manual and a help desk in case of technology-related questions is preferred, but not required.

Technology Learnability	Required Skillset
MO sensor technology	Minimal training
MPI	Minimal training

Table 23. MO sensor and MPI technology learnability comparison showing identical skillset requirements.

Health and Safety: Worker health and safety are important aspects of new technology application and use in forensic labs. Comparing health and safety aspects of the two techniques (**Table 24**), it was found that the MO sensor poses few concerns or issues. The sensor is picked up by a pair of tweezers and moved to the sample, where it is placed directly onto the affected area. A weak permanent magnet normally is applied to create the magnetic field necessary for the Faraday effect. MPI periodically requires the use of an electromagnet, which can pose potential hazards for individuals with implanted electronic devices.

Worker Health & Safety	Interference
MO sensor technology	None
MPI	Electronic device

Table 24. MO sensor and MPI technology health and safety comparison, showing the potential for interference with electronic devices by MPI.

Technology Durability and Cost: Technology durability and cost are important factors in determining the usability of a new product or technology. In comparing the durability of the MO sensor technology and MPI, it was found both are simple technologies that require little to no maintenance, having been used in casework for years (**Table 25**). Cleaning of the sensor film with a soft lens-cleaning fabric is the only task required to keep the MO sensor in workable condition. Sensor film scratches are a concern because they can interfere with interpreting serial number recovery results. Yet, a single sensor film has been used by BKA in casework since 2009 without any major issues (Weimar, 2015).

Technology Durability	Casework Use
MO sensor technology	Multiple years
MPI	Multiple years

Table 25. MO sensor and MPI technology durability comparison showing casework use.

A cost comparison between the MO sensor technology and MPI shows that the two technologies are cost comparable (**Table 26**). The MO sensor requires a capital investment of \$2,360 to purchase the MO sensor kit. No additional materials and supplies are needed to use the technology with the exception of a soft leans-cleaning fabric. MPI requires a capital investment of about \$900 to purchase a unit. Special equipment, like benches and yokes, may increase the purchasing cost. In addition, the use of suspension fluids may require the periodic purchase of MPI supplies.

Technology Cost	Equipment, Materials, Supplies
MO sensor technology	Capital (\$2,360), no operating, no accessories
MPI	Capital (\$900) + operating + accessories

Table 26. MO sensor and MPI technology cost comparison, showing comparable costs.

Technology Deployment: A comparison between the versatility of the MO sensor and MPI technologies (**Table 27**) shows that the use of MPI is limited to firearm and tool mark examination. The MO sensor technology has the benefit that besides firearm and tool mark examination, it can be also used by other forensic disciplines. In latent print, for example, the sensor can be applied to detect and visualize prints on both porous and nonporous media when using conventional or nanoparticle-based magnetic powders. Also, in questioned document examination, the MO sensor can be used in the authentication of currency and official documents utilizing magnetic ink. Finally, in crime scene investigation, the MO sensor technology can be used to detect and recover evidence, including latent prints on immovable objects.

Technology Use	Versatility
MO sensor technology	Multiple applications and uses besides firearm and tool mark examination
MPI	Firearm and tool mark examination

Table 27. MO sensor and MPI technology use comparison, showing MO sensor versatility and potential for multiple forensic applications.

Technology Mobility: Although this project validated and evaluated the use of MO sensor technology in the lab, it must be stated that the Type A sensor is also available in a portable device. This device (Magnetic Eye) was not tested and validated in Phase II. However, given the sensor's capability to recover obliterated serial numbers in ferrous and paramagnetic metals, its use should be considered by law enforcement dealing with stolen cars and erased VIN marks.

12. LESSONS LEARNED

The following subsections summarize the validation and evaluation test results as well as firearm examiner observations regarding the MO sensor's ability to recover obliterated serial numbers in firearms. For the purpose of this section, the information obtained is supplemented by information provided by Bert Weimar of the Bundeskriminalamt (BKA) in Germany on field use of the technology.

12.1 Validation Outcomes

Nondestructive. The MO sensor technology does not damage or alter the physical or chemical properties of the specimen examined, thereby allowing other obliterated serial number recovery techniques to be used in combination with the MO sensor technology. In the case of tandem use with destructive methods (e.g., chemical etching), the MO sensor method should be used first.

Real Time Detection. The sensor film requires direct contact with the substrate to obtain information. When placed on the sample substrate, the sensor processes and displays the information obtained in a matter of seconds at the lower limit of detection and minutes at the upper limit of detection. If characters are not detected instantaneously, the sample should be polished and the process repeated for a few minutes.

Excellent Sensitivity. The federal requirement for serial number application is engraving, casting, or stamping to a minimum depth of 0.003 inch. With the MO sensor's detection limit established at 0.020 inch below the serial number application depth, the sensor's sensitivity for obliterated serial number detection is more than 5x the required application depth for the firearm marking. This significantly increases the chance of erased markings recovery in ferrous and paramagnetic firearms.

Good Recovery. Serial number recovery rates, measured as the percentage of obliterated serial numbers visualized within the MO sensor established limit of detection, are in the order of 50% to 80%. This is in line with, and somewhat higher than, other serial number recovery techniques (Persi Paoli, 2010).

Extensive Application: The MO sensor technology is capable of recovering obliterated dot-pin and laser-etch applied markings. As such, it provides a new tool for forensic scientists to recover obliterated serial numbers in firearms. This is a significant discovery because, to date, very little has been published in the literature regarding the successful recovery of obliterated dot-peen- and laser-etch-applied serial numbers, even though the two techniques are becoming increasingly popular among firearm manufacturers.

Basic Image Quality: The MO sensor creates images with character attributes that can easily be enhanced to provide input for digital image processing techniques. Techniques like Adobe Photoshop can generate visual images of obliterated markings that are more suitable for serial number recovery than the original ones. The rapid advancement of digital image processing, coupled with the increased power and sensitivity of optical character recognition, make these techniques invaluable tools for the restoration of obliterated serial numbers in firearms and their presentation in courtrooms.

12.2 Evaluation Findings

- *Low Learnability.* MO sensor application and use require very little training. The manufacturer train-the-trainer program was successfully implemented in both this project and the previous project. A user's manual and a sensor technology helpline complemented the training. No major challenges or issues were encountered during use of the technology. No calls were made to the helpline requesting technical assistance.
- *Easy to Use.* The MO sensor technology is easy to use. In most cases, the sensor film can be placed directly onto the substrate without any sample preparation. For some rough substrates, some sample polishing is needed. This typically requires a few minutes and is achieved using a Dremel tool with a soft polishing stone. Although no health problems were observed during technology use, some worker safety concerns were noted because the MO sensor is made of very thin crystalline material with sharp edges.
- *Low Risk.* The MO sensor displays excellent character recognition. Alphanumeric characters can be detected and visualized with good precision and accuracy. The overall majority of numeric characters can be recovered in over 50% of cases within their detection limit. Only the numeral 5 shows lower recoverability. Misidentification of both alphabetic and numeric characters is low but does occur in the form of uppercase letters, uppercase letters and

numerals, and numerals. The biggest risk for character misidentification is at the upper limit of character detection when characters become faint.

12.3 Implementation Potential

- *Commercially Available.* The MO sensor technology is manufactured by Matesy GmbH in Jena, Germany, and is distributed in the United States through GMW Associates, located at 955 Industrial Road in San Carlos, CA. The sensor film is available in three different sizes but can be customized to fit any application or use.
- *Field Tested.* The MO sensor technology has been used in casework at the Bundeskriminalamt in Germany since 2009. The technique is typically the first method used in the recovery of obliterated serial numbers from ferrous and paramagnetic firearms. According to Bert Weimar (personal communication, 2015), the MO method is in 10% of the cases the only method needed and, in some cases, the only successful method.
- *Limited Use:* The operating principle for the MO sensor is the Faraday effect, which depends on the magnetic properties of the material examined. Use of the MO sensor method is restricted to paramagnetic materials and ferrous metals and their alloys.
- *Little Value Added.* Very little difference exists between the technical performance of the MO sensor and MPI: both are nondestructive, target ferrous metals and their alloys, and recover obliterated serial numbers in real time at nearly identical detection and recovery rates. The only difference noted between the two relates to nontechnical performance: The MO sensor is easy to use, requires little to no sample preparation, needs no supplies, and is not messy.

13. CONCLUSION

Magneto-optical (MO) sensor technology is a nondestructive testing technique with excellent sensitivity and imaging capability. The technology is suitable for use by firearm examiners interested in detecting and imaging obliterated serial numbers in real time. It is fast, easy to learn and use, and requires little to no sample preparation. The technology has been successfully applied in serial number restoration casework and, in some cases, was the only successful method. The method can be used as a standalone technique, although more often than not the method is used in combination with other serial number recovery methods. In cases where the MO sensor is used in combination with a destructive method, the MO sensor technology should be used first. The technology is very similar to magnetic particle inspection (MPI), yields comparable performance results, but requires little to no sample preparation, needs no supplies, is less messy, and is safe to use in the presence of electronic devices. The value added of MO sensor technology is its potential application in other forensic disciplines besides firearm examination.

14. BIBLIOGRAPHY

Da Silva, L. and Acioly Marques dos Santos, P. 2008. Recovering obliterated laser engraved serial numbers in Firearms. *Forensic Science International*, 179 (2-3), 63-66.

ISMP. 2009. Misidentification of alphanumeric symbols in both handwritten and computer generated information. *ISMP Medical Safety Alert*, 14 (13), 1-2.

Jones, E.D., 2013. Forensic investigation of stamped markings using a large-chamber scanning electron microscope and computer analysis for depth determination. Thesis and Special Projects. Paper 1237. Western Kentucky University, Bowling Green, KY.

- Katterwe, H. 2006. Restoration of serial numbers. In: Eric Stauffer, Monica Bonfanti (Eds.), *Forensic Investigation of Stolen–Recovered and Other Crime-Related Vehicles*, Elsevier, UK.
- Klees, G. 2009. The restoration or detection of obliterated laser-etched firearm markings by scanning electron microscopy and x-ray mapping. *AFTE Journal*, 41 (2), 184-187.
- Koschny, M. and Lindner, M. 2012. Magneto-optical sensors accurately analyze magnetic field distribution of magnetic materials. *Advanced Materials and Processes*, 170 (2), 13-16.
- Kuppuswamy, R. (2011). Metallographic etching of aluminum and its alloys for restoration of obliterated marks in forensic science practice and investigations. (pp. 331-352). Rijeka, Croatia: InTech. DOI: 10.5772/576.
- Luyendijk, R. 2014. Performance evaluation and utility assessment of magneto-optical sensor technology for detecting and visualizing obliterated serial numbers in firearms. Final Report, Department of Justice, National Institute of Justice, Washington, DC.
- Maini, R. and Aggarwal, H. 2010. A comprehensive review of image enhancement techniques. *Journal of Computing*, 2 (3), 8-13.
- Malikowski, S. 2004. The restoration of an obliterated serial number and barcode using digital photography and Adobe Photoshop. *AFTE Journal*, 36 (2), 237-238
- Maxim Integrated. "[Application Note 3212: Driving 16-Segment Displays](#)". 2004.
- National Institute of Standards and Technology. 2009. *System, Component, Operationally Relevant Evaluation (SCORE)*. U.S. Department of Commerce (<http://www.nist.gov/el/isd/ks/score.cfm>).
- Persi Paoli, G. The Method Behind the Mark: A Review of Firearm Marking Technologies, Small Arms Survey, 2010.
- Sim, J. and Wright, C. 2005. The kappa statistic in reliability studies: use, interpretation, and sample size requirements. *Physical Therapy*, 85 (3), 257-268.
- SWGFAST. 2010. *Standard for the validation and performance review of friction ridge impression development and examination techniques*. Document # 17. (http://www.swgfast.org/documents/validation/121124_Validation-Performance-Review_2.0.pdf).
- Weimar, B. and Herrmann, D. 2011. A simple magneto-optical method for the restoration of erased markings in metals. *Forensic Science International*, 207, 119-121.
- Weimar, B. 2015. Personal communication.

Appendix A: Adobe Photoshop Serial Number Restoration Methodology¹

The following methodology was developed by a technical team member to enhance the photographic images obtained by the MO sensor technology. The methodology is not unique to the MO sensor images and can be used by anyone interested in improving the quality of the digital image. This is not a “user’s guide”. It is meant to be a tool for firearm examiners who are familiar with Photoshop or are interested in using the software for firearm examinations, like serial number recovery. A number of training courses are currently offered targeting the same features and application of Adobe Photoshop as presented. It consists of a series of steps, along with a brief textual explanation. The first four steps target the basic setup to edit the image; the rest of the steps deal with improving the quality of the digital image.

Step 1: Open Photoshop and select the image of interest. Photoshop will load the image into a layer called “background.”

Step 2: Unlock the background layer (double click it), rename the layer (e.g., Original) and select “OK.”

Step 3: Use the “Crop Tool” to reduce file size, and area of focus. Drag edges to fit the dimensions of choice. Make sure the check box “Delete Cropped Pixels” is deselected. Press “Enter.”

Step 4: Select “image -> image size” and check size and resolution (for image enhancement, area of focus ideally should be 1,500 pixels or more in width), and change value (if necessary).

Step 5: Convert the image to grey scale. Although this step is not necessary, viewing the image can be useful to more easily identify bright and dark spots. To convert the image to black and white, locate the “Adjustment” panel and select “Black and White.”

Step 6: Select image layer and use the “Dust and Scratches” filter (Filter -> Noise -> Dust and Scratches) to reduce noise and to clean up the image. Set the “Threshold” to 0 and increase the “Radius” until the largest gashes are no longer visible. Increase “Threshold” until small details return that were lost and larger gashes remain hidden. Click “OK.”

Step 7: Use the “Levels and Curves” filter to adjust the shadows, highlights, and midtones of the image.

To use “Levels” go to the “Adjustment” panel and select “Levels.” Drag the Black Point slider (left) and the White point slider (right) inward until they touch the left-hand and right-hand edges of the histogram, respectively. This compresses the tonal range and allows for adjustments in the midtone range to be made through use of the Grey Slider (middle) and moving it to the right (dark) or left (light).

¹ This simple method can be used with older versions of Photoshop as newer features are not needed to process pictures. All original photos are preserved. In Photoshop, the original image is imported and a Photoshop “master file” is created. The AP enhanced image is saved in the master file as a “revised” image. The “revised” image can then be exported and compared to the original, if necessary. AP enhanced images are currently being used, and accepted, in court presentation.

Use “Curves” to control contrast if there is a wide range of grey tones in the image. To use “Curves,” go to the Adjustments panel and “Curves.” This will open a panel with a diagonal line. Click the middle of the line to create a central control point and to control contrast in the midtones of the range. Drag down on the lower part of the line to work on shadows and drag up on the upper part of the line to work on the highlights. Create an S-curve to improve image contrast, as steeper slopes add more contrast.

Step 8: Set up “History Brush” to take a screen shot and create a history point (Window -> History). Select the icon mimicking a camera to create a saved state image for History Brush to be used. Scroll to the top of the History Panel and click the checkbox next to “Snapshot 1” to set it as the active image for the History tool.

Step 9: Use “Dodge and Burn” to improve contrast. From the Tools palette, select the Dodge tool and set the Range to “Highlights” and Exposure to “15%” (lowering the exposure reduces the strength of the effect and allows stacking of the effect with multiple passes). Select the desired brush size and start painting the areas to be lightened.

To darken desired areas of the image, click the “Dodge” tool and select “Burn” from the side menu. Set the Range to “Shadows” and Exposure to “15%”. Similar to “Dodge,” select the desired paint brush size and start painting the areas to be darkened.

For images that do not possess enough contrast, set the “Dodge” and “Burn” tool’s range to “Midtones.”

As the “Dodge and Burn” tools are destructive, the History Tool (set in step 8) can be used to restore certain sections of the image if necessary.

Step 10: In addition, the “Zoom Out” (View -> Zoom Out) and “Invert” steps might be beneficial to minimize visual noise. The “Zoom Out,” for example, can be used to control focus and to draw the eye to specific points in the image. Inverting the image, on the other hand, creates a negative of the image that can be useful for enhancing white or grey detail embedded in the dark regions of the image. To invert an image in Photoshop, go to the “Adjustment” panel and select “Invert.”

Step 11: When all image enhancements and improvements have been made, select “File” and save the image as both a .psd file for future edits with Photoshop, and as a .png file for use outside of Photoshop.

Appendix B: Recovery of Stamp-Applied and Hand-File and Dremel-Tool Removed Serial Numbers

FRL #	Serial Number Application Method	Obliteration Method	MO Sensor Film Results	MPI Results
2064	Stamped	Hand filing	Full recovery	Full recovery
1154	Stamped	Hand filing	Not discernible	Not discernible
1067	Stamped	Hand filing	Full recovery	Recovery with one character unclear (8 vs 9)
1279	Stamped	Hand filing	No detection	No detection
Frame	Stamped	Hand filing	Full recovery	Full recovery
1903	Stamped	Hand filing	Not discernible	Not discernible
0571	Stamped	Hand filing	Not discernible	Not discernible
0737	Stamped	Hand filing	No detection	No detection
0044	Stamped	Hand filing	No detection	No detection
0594	Stamped	Hand filing	Partial recovery (curved surface)	Slightly less recovery due to curvature
0756	Stamped	Grinding	No detection	No detection
1151	Stamped	Grinding	Full recovery	Full recovery
0596	Stamped	Grinding	Full recovery	Full recovery
0474	Stamped	Grinding	No detection	No detection
Barrel	Stamped	Grinding	Full recovery	Full recovery a little harder due to curvature
1789	Stamped	Grinding	Partial recovery	Partial recovery
1756	Stamped	Grinding	Full recovery	Full recovery a little harder due to curvature
0887	Stamped	Grinding	Full recovery	Full recovery
1180	Stamped	Grinding	Full recovery	Full recovery a little harder due to curvature
1905	Stamped	Grinding	Partial recovery	Partial recovery

Appendix C: Recovery of Dot-Pin Applied and Hand-File and Dremel-Tool Removed Serial Numbers

FRL #	SN Application	Obliteration	MO Results	MPI Results
0234	Dot Peening	Grinding	Not discernible	Full recovery
1288	Dot Peening	Grinding	Full but faint recovery	Full recovery
1334	Dot matrix/pin stamped	Grinding	No detection	No detection
0209	Dot matrix/pin stamped	Grinding	No detection	No detection
1697	Dot matrix/pin stamped	Grinding	Full recovery	Full recovery
1717	Dot matrix/pin stamped	Grinding	Full recovery	Full recovery
2071	Dot matrix/pin stamped	Grinding	Full recovery	Full recovery
1394	Dot matrix/pin stamped	Grinding	Full recovery	Full recovery
1076	Dot matrix/pin stamped	Grinding	Full recovery	Full recovery
1612	Dot matrix/pin stamped	Grinding	Full recovery	Full recovery
1997	Dot matrix/pin stamped	Grinding	Not discernible	Partial recovery
1838	Dot matrix/pin stamped	Hand filing	Not discernible	Not discernible
1973	Dot matrix/pin stamped	Hand filing	Full recovery	Full recovery
1117	Dot matrix/pin stamped	Hand filing	Full recovery	Full recovery
1885	Dot matrix/pin stamped	Hand filing	No detection	No detection
2077	Dot matrix/pin stamped	Hand filing	Partial recovery	Full recovery
1274	Dot matrix/pin stamped	Hand filing	Full recovery	Full recovery
1962	Dot matrix/pin stamped	Hand filing	Full recovery	Full recovery
0451	Dot matrix/pin stamped	Hand filing	No detection	No detection
1557	Dot matrix/pin stamped	Hand filing	Full recovery	Full recovery
1149	Dot matrix/pin stamped	Hand filing	Full recovery	Full recovery

Appendix D: Recovery of Laser-Etch Applied and Hand-File and Dremel-Tool Removed Serial Numbers

FRL #	SN Application	Obliteration	MO Results	MPI Results
0478	Laser etched	Grinding	Full recovery	Full recovery
1358	Laser etched	Grinding	Full recovery	Full recovery
1430	Laser etched	Grinding	No detection	No detection
2068	Laser etched	Grinding	No detection	No detection
0968	Laser etched	Grinding	No detection	No detection
2044	Laser etched	Grinding	Full recovery	Full recovery
1958	Laser etched	Grinding	Not discernible	Not discernible
1146	Laser etched	Grinding	Partial recovery	Partial recovery
0620	Laser etched	Grinding	No detection	No detection
1904	Laser etched	Grinding	No detection	No detection
0900	Laser etched	Hand filing	Full recovery	Full recovery
1397	Laser etched	Hand filing	Full recovery	Full recovery
1979	Laser etched	Hand filing	Partial recovery	Not discernible
1280	Laser etched	Hand filing	No detection	No detection
2108	Laser etched	Hand filing	Partial recovery	Partial recovery
0135	Laser etched	Hand filing	No detection	No detection
1217	Laser etched	Hand filing	No detection	No detection
0148	Laser etched	Hand filing	No detection	No detection
1447	Laser etched	Hand filing	Full recovery	Full recovery
1504	Laser etched	Hand filing	Full recovery	Full recovery

Appendix E: Recovery of Center-Punch Removed Serial Numbers

FRL #	SN Application	Obliteration	MO Results	MPI Results
0129	Stamped	Center punch then grinding	Only recovered punching marks	Only recovered punching marks
2063	Stamped	Peened/punched then grinding	Only recovered punching marks	Only recovered punching marks
1499	Stamped	Peened/punched then grinding	Only recovered punching marks	Only recovered punching marks
1735	Dot Peened	Peened/punched then grinding	Only recovered punching marks	Only recovered punching marks
1453	Laser etched	Peened/punched then grinding	Only recovered punching marks	Only recovered punching marks
1921	Dot Peened	Sanding	Partial recovery	Partial recovery

Appendix F: Expanded MO Sensor Detection and Visualization

Oblit. Depth in Inches	4140 Steel	1018 Steel	304 Stainless Steel
.019		415836	
.022		167903	
.025		468617	
.028	847361	534907	512798
.031	128954	070246	671028
.034	670851	478391	512798
.037	372598	473251	031698
.040	423670	620581	092547
.041			190563
.045			403859
.048			549106
.051			275304
.052			512798

Note: Characters highlighted in “gray” were not detected by the MO sensor technology. Those highlighted in “darker blue” were detected and correctly identified by the firearm examiner. Characters highlighted in “green” were detected and visualized by the MO sensor technology, but identification of the correct character posed a challenge. The firearm examiner made a correct guess. Finally, characters highlighted in “lighter blue” were detected and visualized by the MO sensor technology. Like the green colored characters, the identification of the character posed a challenge to the firearm examiner. The attempt to identify the correct character was unsuccessful.