Optical Methods of Surface Measurement

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Measurement Science and Standards in Forensic Firearms Analysis 2012
NIST, Gaithersburg, MD
July 10, 2012

Contents

- Three optical methods for measuring surface topography:
  - Confocal microscopy
  - Focus variation microscopy
  - Coherence scanning interferometry

- For each method, will discuss:
  - Brief description
  - Documentary standard
  - Some strengths and limitations
  - Applications in firearms examinations and research

- Some comparisons

- Observations on possible research with these methods for firearms

- Will not discuss applications of optical reflection microscopy – already widely known and used

Sources

- John Song, Alan Zheng, T.B. Renegar (NIST)
- ISO Standards and drafts
- R. Artigas, Sensofar
- B. Bachrach, Intelligent Automation, Inc.
- F. Helmli, Alicona
- R. Krueger-Sehm, (PTB)
- P. de Groot, Zygo Corp.
- M. Johnson et al. (MIT)
- K. Garrard et l. (NCSU)
- Nanofocus
- Forensic Technology Inc.
- Pyramidal Technologies

Observation:

Conventional Optical Microscopy vs. Topographic Microscopy

Surface topography (roughness height variation *Z (x, y)*) is likely the primary effect produced by firearms on bullets and casings.

Optical image *I (x, y)* ≠ Topography *Z (x, y)*

Conventional Microscopy:
The optical image contrast
I (x, y) Is primarily a function of:

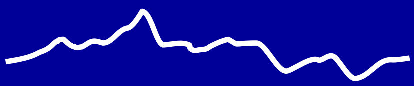
- -Slope,
- -Shadowing,
- -Multiple reflections
- -Optical properties
- -Illumination direction

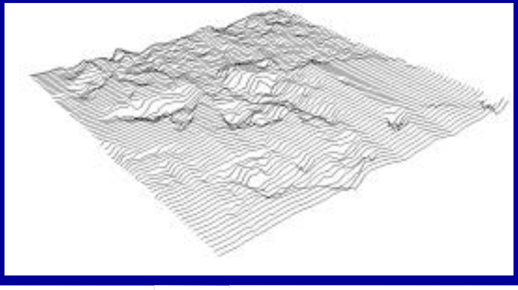
-local height variations, indirectly

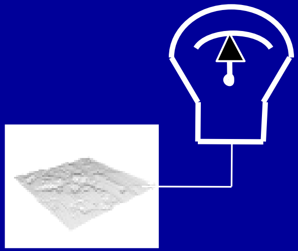
Topographic Microscopy, such as interferometric and confocal microscopy, can measure local height variations *Z (x, y)* directly, independent of illumination and shadowing effects

But there are signal-to-noise issues and data dropouts

From *Classification of Methods for Measuring Surface Texture*, ISO International Standard (IS) 25178-6







Line Profiling,
Senses *Z*(*X*)

Contacting Stylus,
Phase Shifting Interferometry,
Circular Interferometric Profiling,**
Optical Differential Profiling

Areal Topography,
Senses *Z*(*X*,*Y*) or
Z(*X*) as a function of *Y**

Contacting Stylus,
Phase Shifting Interferometry,
Coherence Scanning Interferometry,
Confocal Microscopy,
Chromatic Probe,
Structured Light and Triangulation,
SEM Stereoscopy,
Scanning Tunneling Microscopy,
Atomic Force Microscopy,
Optical Differential Profiling,
Angle Resolved SEM,
Focus Variation Microscopy

Area-Integrating

Total Integrated Scatter,
Angle Resolved Scatter,
Parallel Plate Capacitance,
Pneumatic

***The accuracy of *Z*(*Y*) profiling depends on the method and should be assessed for each method.**

****Relies on circular scanning to produce a *Z*(θ) profile.**

Important Properties of Microscopes for Measuring Surface Topography

- Vertical Resolution
- Lateral Resolution

What can the instruments achieve and what vertical and lateral resolutions are required to resolve important individual characteristics of bullet and cartridge case surfaces?

- Maximum Measurable Slope (Slope Range)

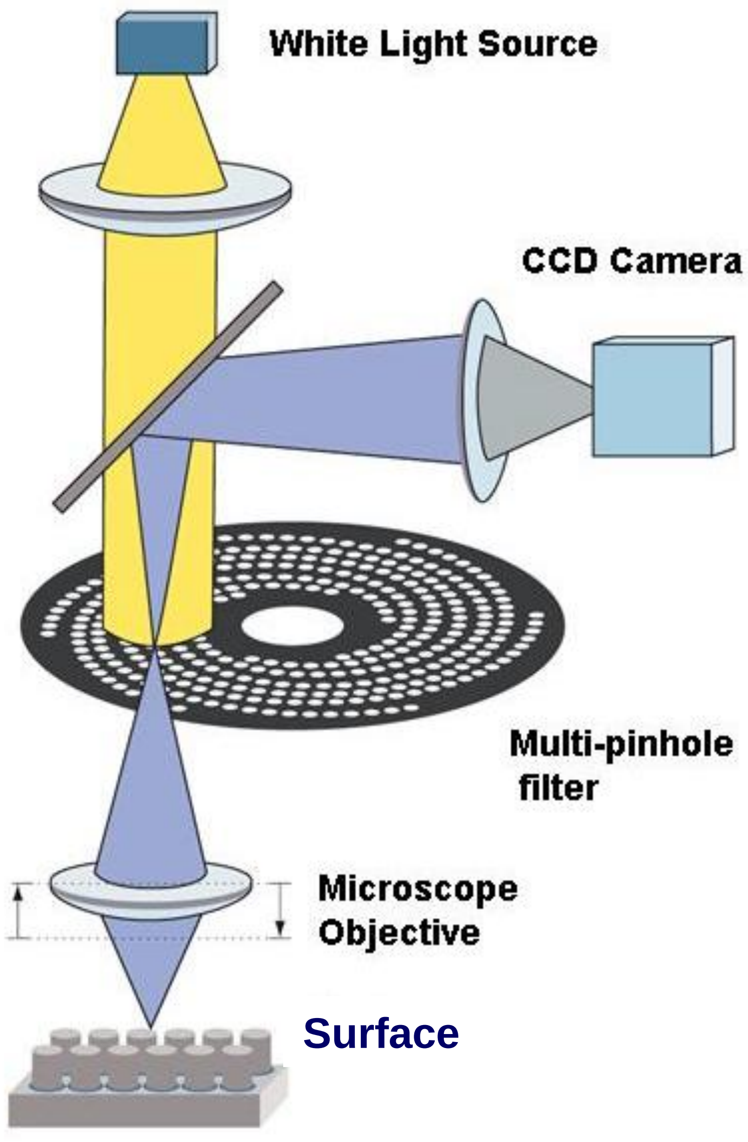
  Important for measuring firing pin impressions

- Cost
- Speed

Confocal Microscopy:

Schematic diagram of a disk scanning confocal microscope

http://www.nanofocus-ag.com/de/html/3dmicro.html

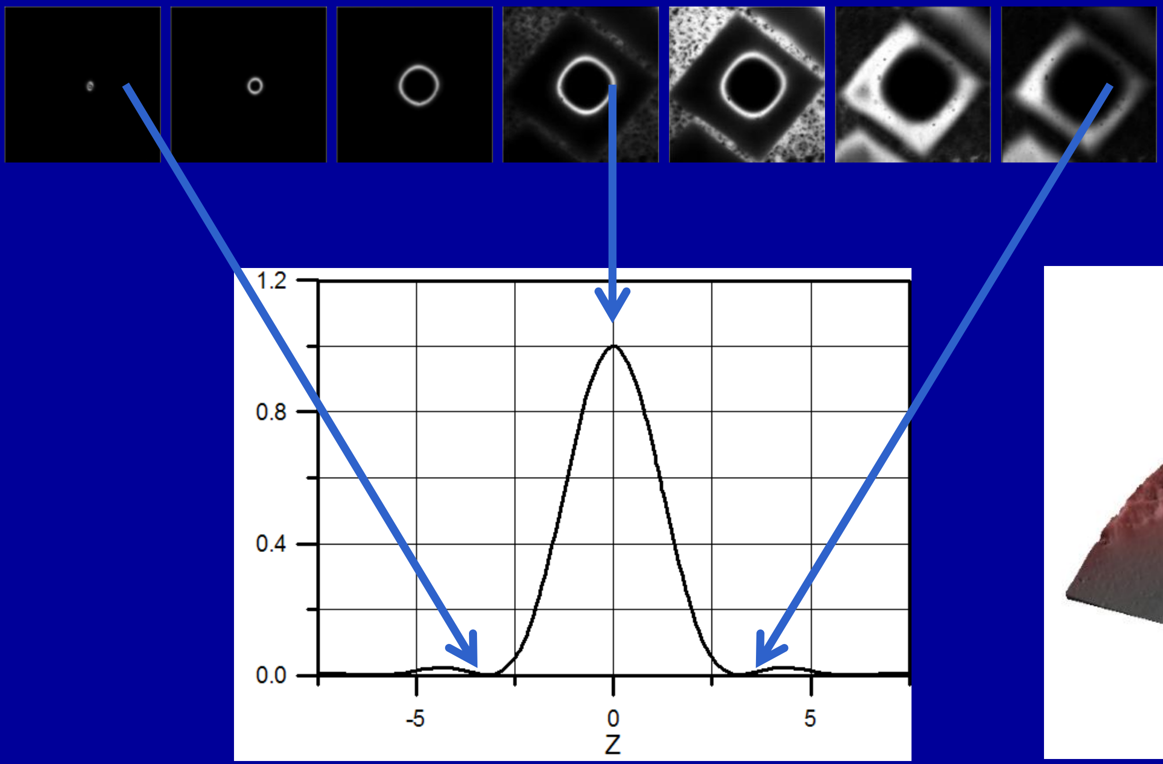


ISO Working Draft 25178-607

ISO/Technical Committee 213/ Working Group 16

Geometrical product specification (GPS) – Surface texture: Areal – Part 607: Nominal characteristics of non-contact (imaging confocal microscopy) instruments

Figure B.1 – A series of confocal images through the depth of focus of a confocal microscope's objective.



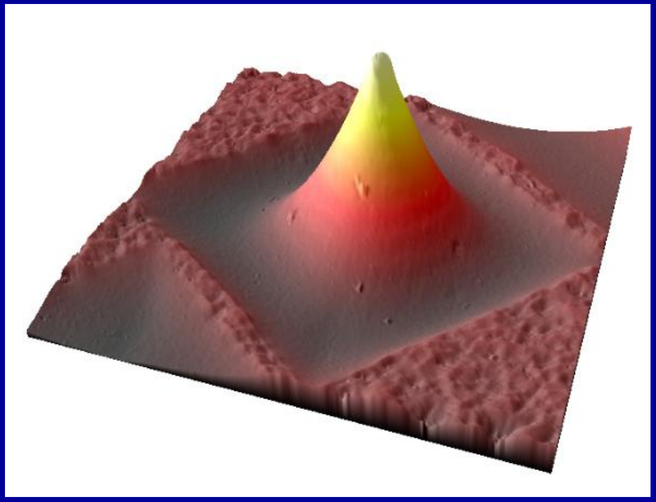


Figure B.2 – Left: axial response of a single pixel along the *z*-direction. Right: the three dimensional surface of the series of images of B.1.

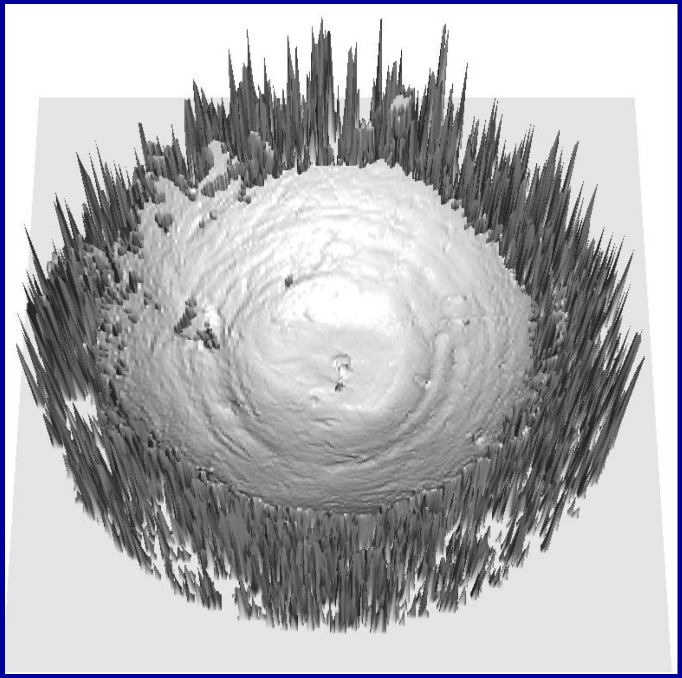
Strength

- Vertical resolution ≈ 3 nm

Lateral resolution ≈ 1 µm (depends on the magnification and the objective, typical for an optical microscope)

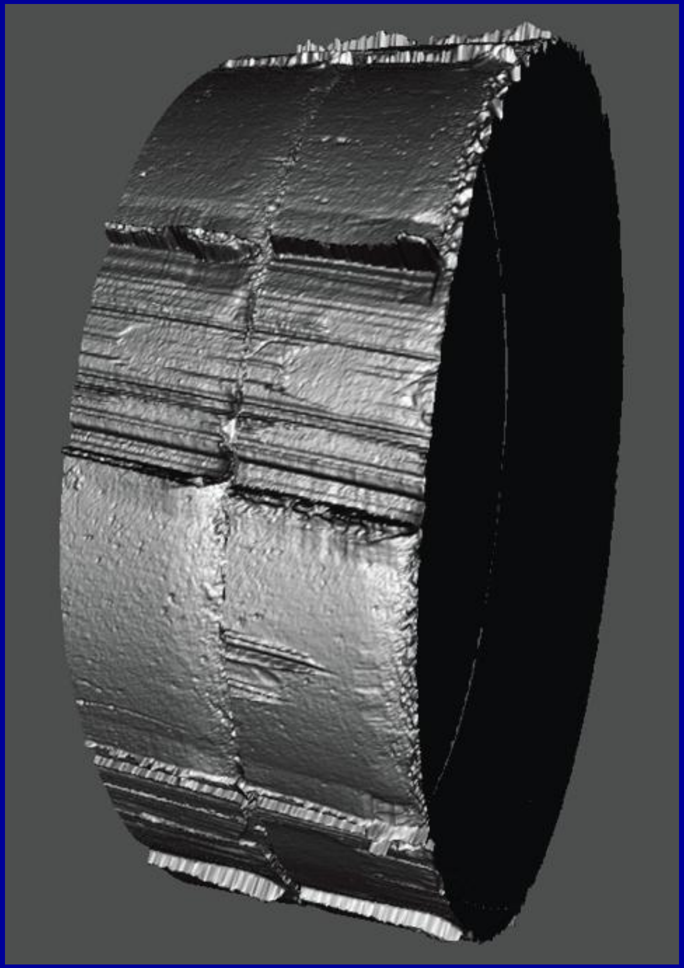
Limitation

- Signal decreases and becomes unreliable for high surface slopes ≈ 15 ° leading to dropouts and outliers



Topography image of a firing pin impression obtained with a confocal microscope

Application of Confocal Microscopy to Firearms Research



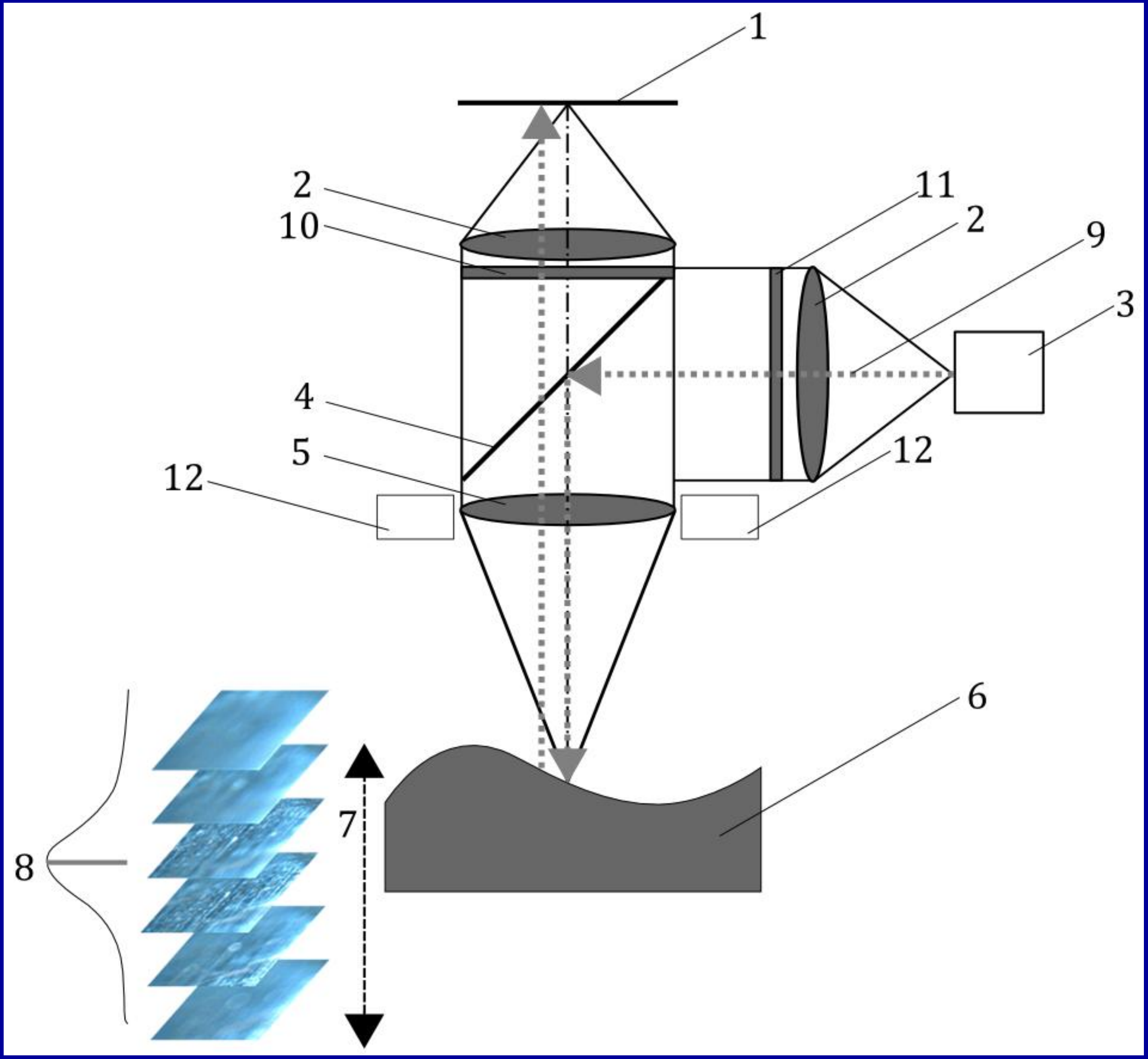
Topography image of a pair of fired bullets

BulletTrax-3D
Forensic Technology, Inc.

From P. Murphy et al., Three-Dimensional Virtual Comparison Microscope for Bullets, http://www.forensictechnology.com/Portals/71705/docs /technote_3dvcmbullets_20100429.pdf (May, 2010)

Focus Variation Microscopy

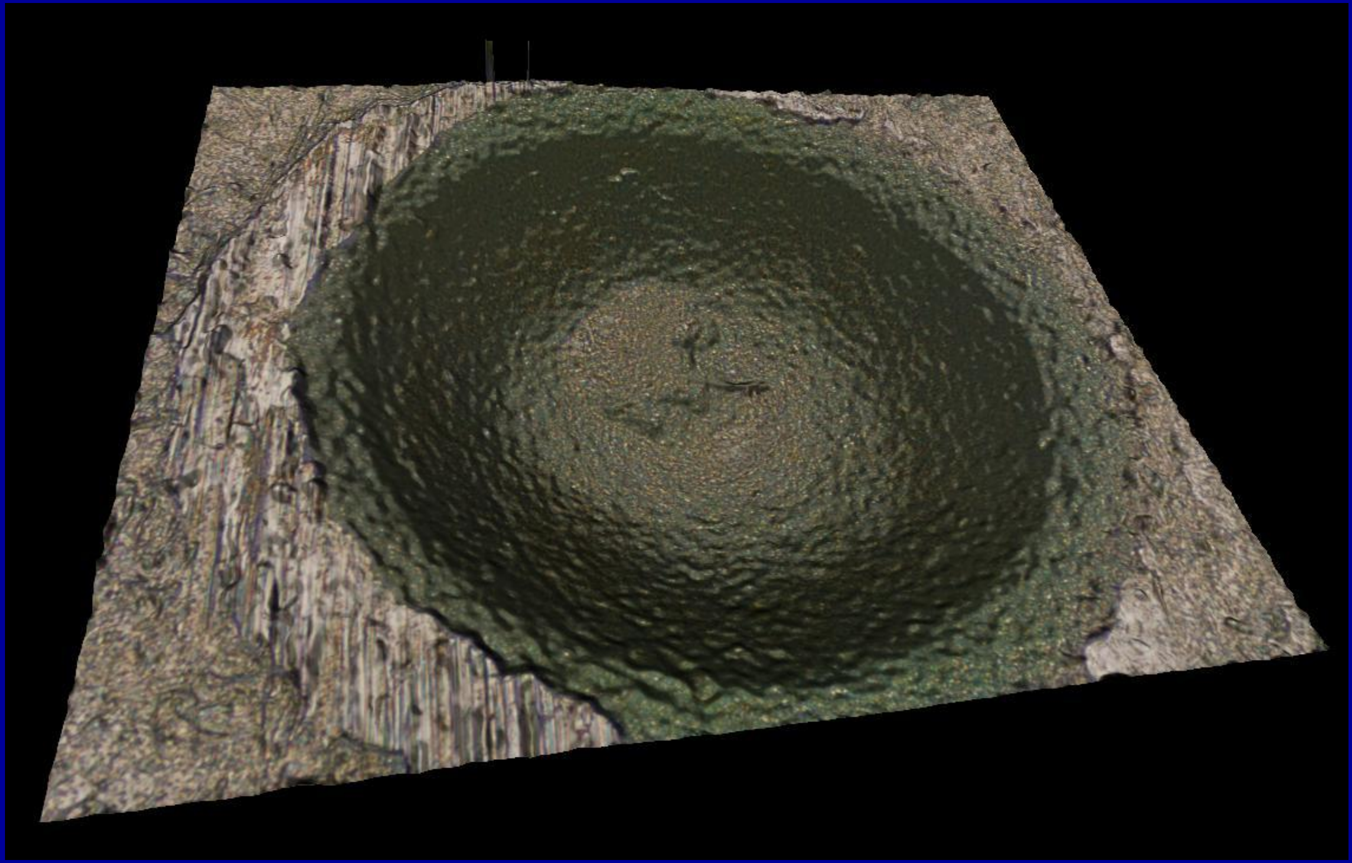
ISO Committee Draft 25178-606 ***Geometrical product specification (GPS) — Surface texture: Areal — Part 606: Nominal characteristics of non-contact (focus variation) instruments,*** **Figure A.1**



Strength of Focus Variation Microscopy

Ability to measure steeply sloped surfaces

Firing pin impression on 9 mm cartridge case measured with focus variation. Overlay of reflectance and topography images.



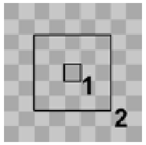
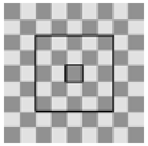
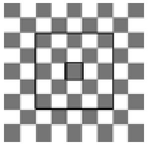
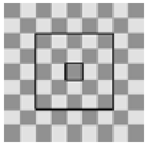
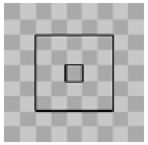
A Limitation of Focus Variation Microscopy

Vertical resolution
≈ 100 nm

Lateral resolution
≈ several pixels

Table A.1
From
ISO DIS
25178—606

Table A. 1 — Calculation of focus information using the standard deviation of the surface image within a 5x5 neighborhood of the point of interest

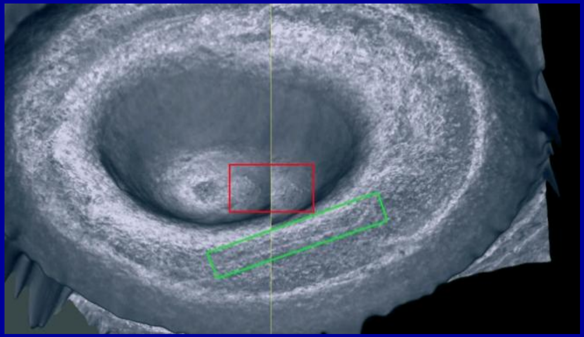
Scan position	Surface image	Standard deviation
Out of focus		10
Almost in focus		20
In focus		50
Almost in focus		20
Out of focus		10

Key

1 point of interest for which the focus information is calculated

2 5x5 neighborhood used to calculate the focus information (standard deviation)

Applications in Forensic Science



- BrassTrax-3D “depth from focus (DFF)”

  http://www.forensictechnology.com/publications/

- Alicona Infinite Focus

- See also review article by R.S. Bolton-King et al. in AFTE Journal 42 (1) , 23 (2010)

Principle of Coherence Scanning Interference Microscopy

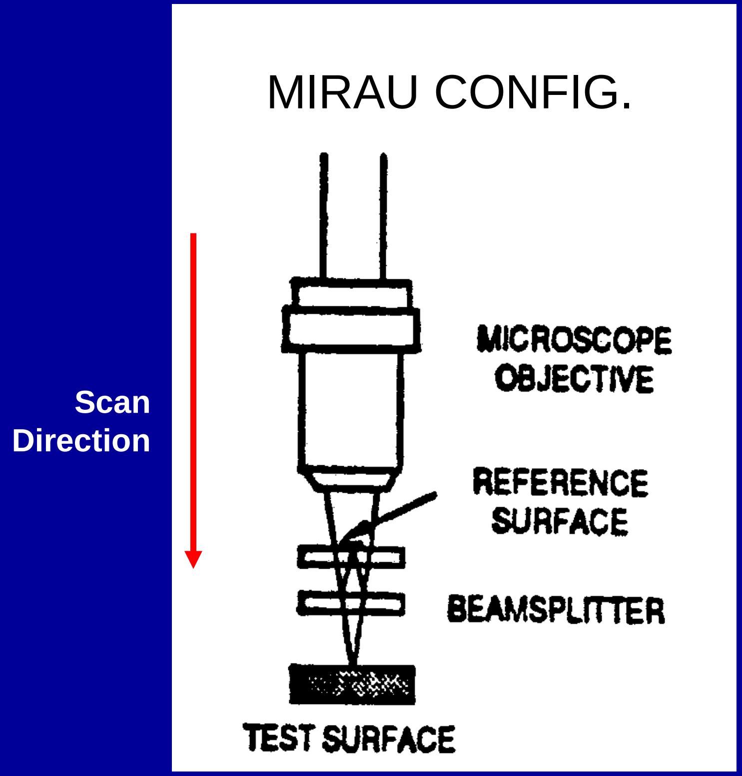
aka:

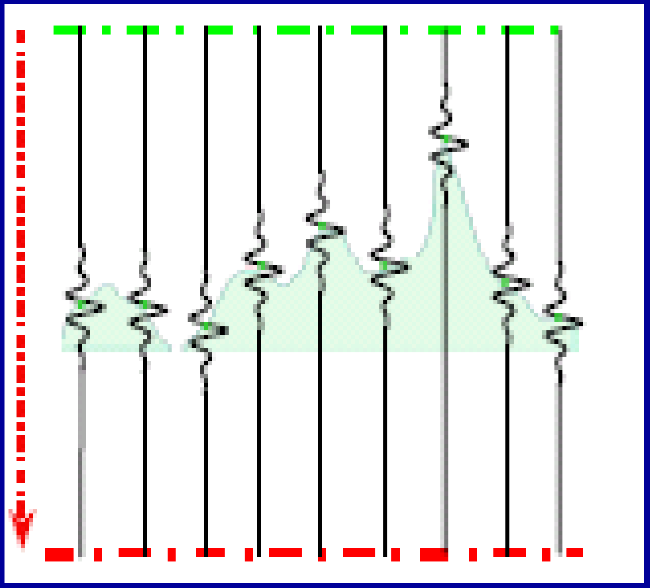
Vertical scanning interferometry,

White light interferometry,

Scanning white light interferometry,

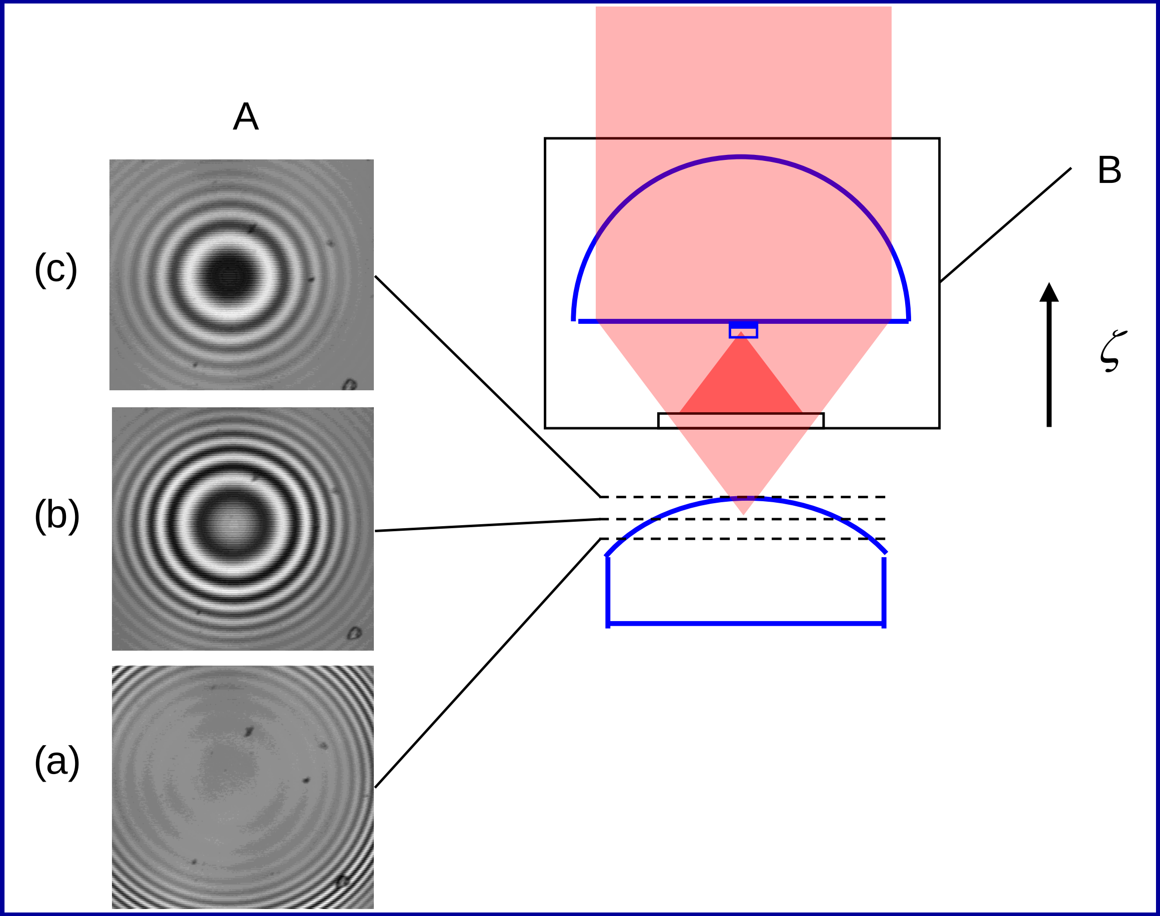
Optical coherence tomography…





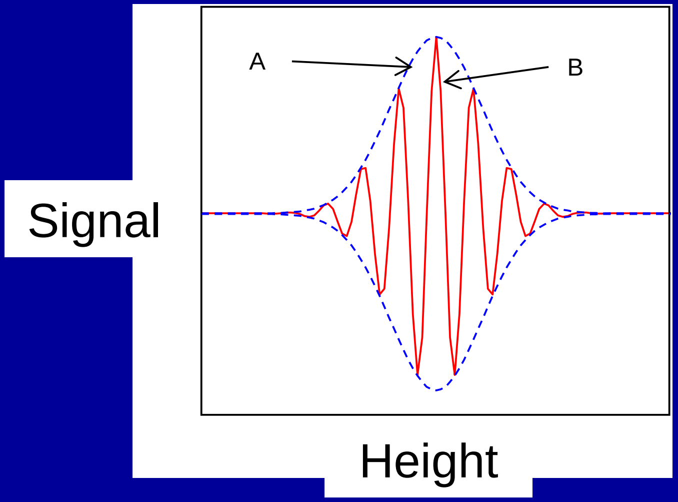
ISO Draft International Standard (DIS) 25178-604
Geometrical product specification (GPS) – Surface texture: Areal – Part 604: Nominal characteristics of non-contact (coherence scanning interferometric microscopy instruments

Fig. B.1



Coherence Scanning Interferometry

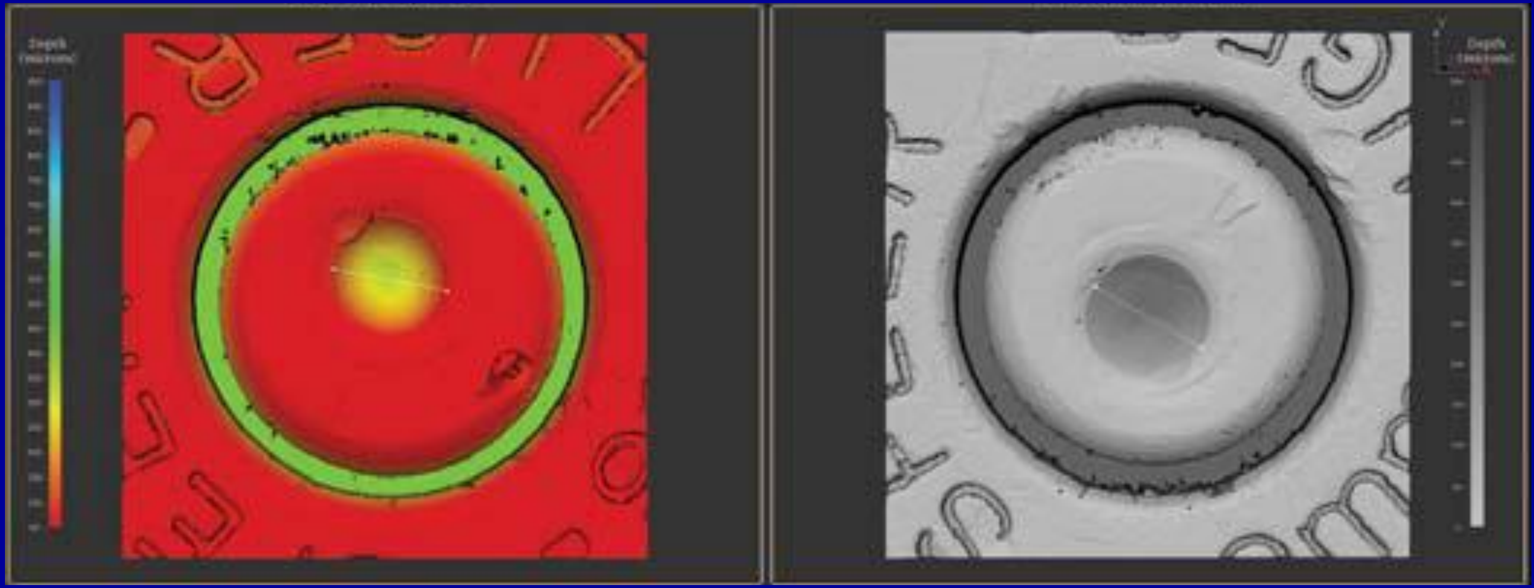
- Strength: Vertical resolution ≈ 3 nm
- Lateral resolution ≈ 1 µm, comparable to confocal microscopy
- Limitation: Has difficulty with steeply sloped surfaces
- Issue: Complex sensor signal



Application in Firearms Research

ALIAS, from Pyramidal Technology in cooperation with Heliotis (Switzerland)

-CSI with high-speed camera



Topographic image of breech face and firing pin impressions.

Contents

- Four optical methods for measuring surface topography:
  - Confocal microscopy
  - Focus variation microscopy
  - Interferometry
  - Chromatic confocal microscopy

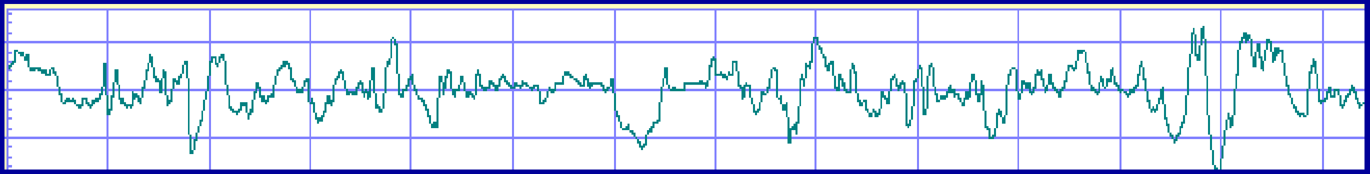
- For each method, will discuss:
  - Brief description
  - Documentary standard
  - Some strengths and limitations
  - Applications in firearms examinations and research

- **Some comparisons**

- Observations on possible research with these methods for firearms

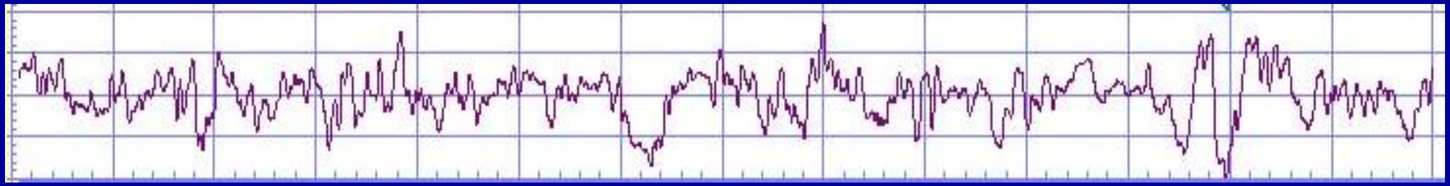
- Will not discuss applications of optical reflection microscopy – already widely known and used

Comparison of 2D Profiles of a Standard Bullet Measured by Four Techniques



Stylus,
Master Profile

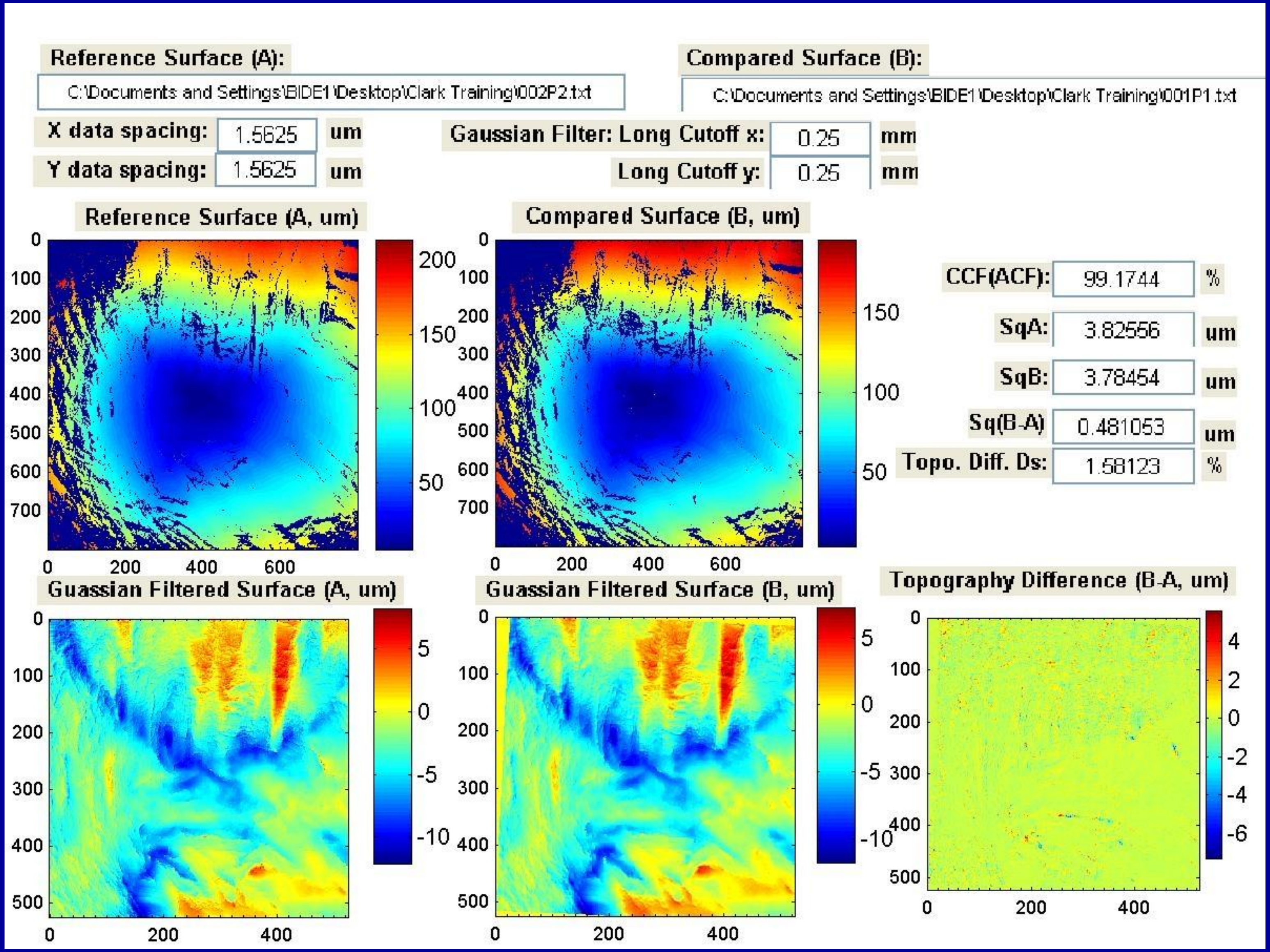
CSI



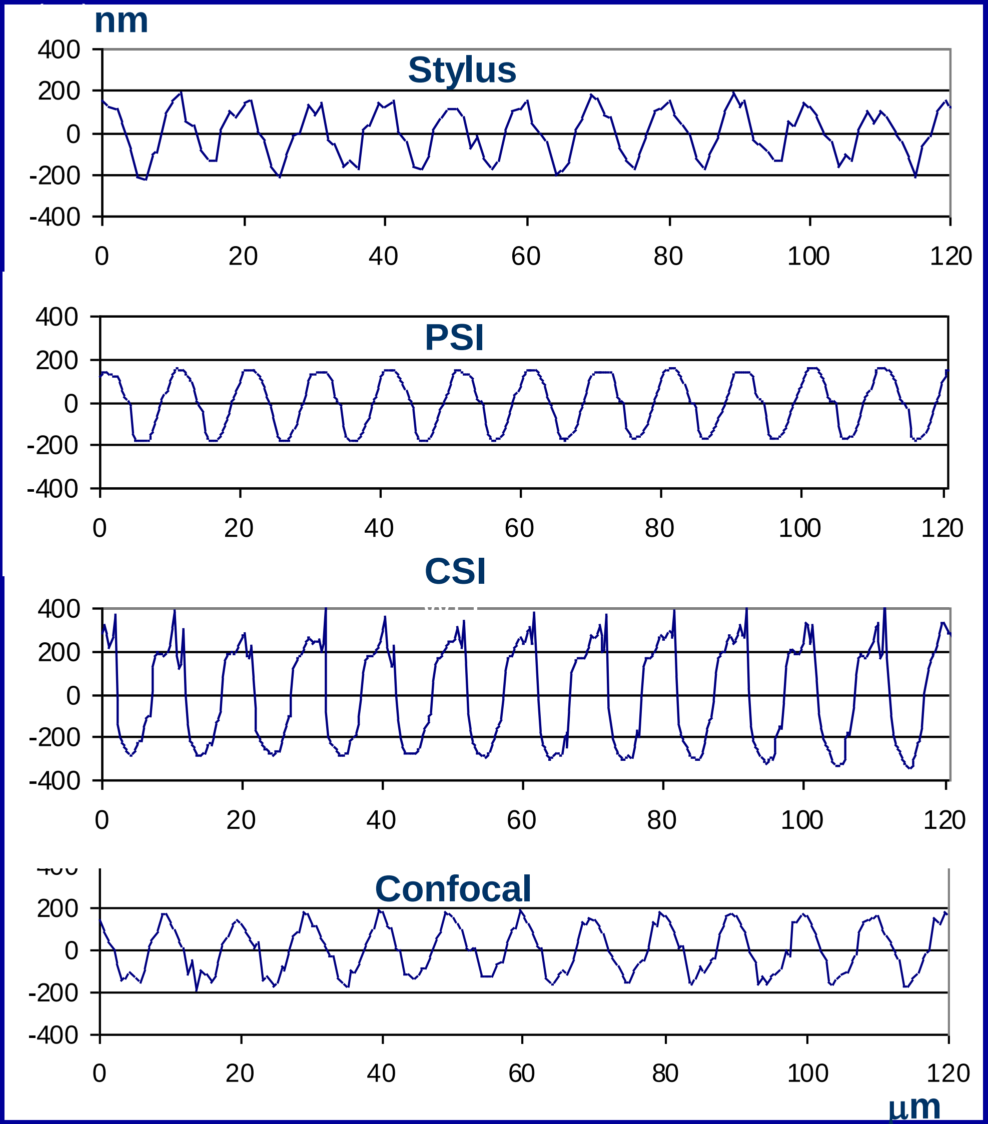
Disc Scanning
Confocal
Microscope

Laser Scanning
Confocal
Microscope

Areal Cross Correlation of Firing Pin Impressions of Two Casing Replicas with Confocal Microscopy



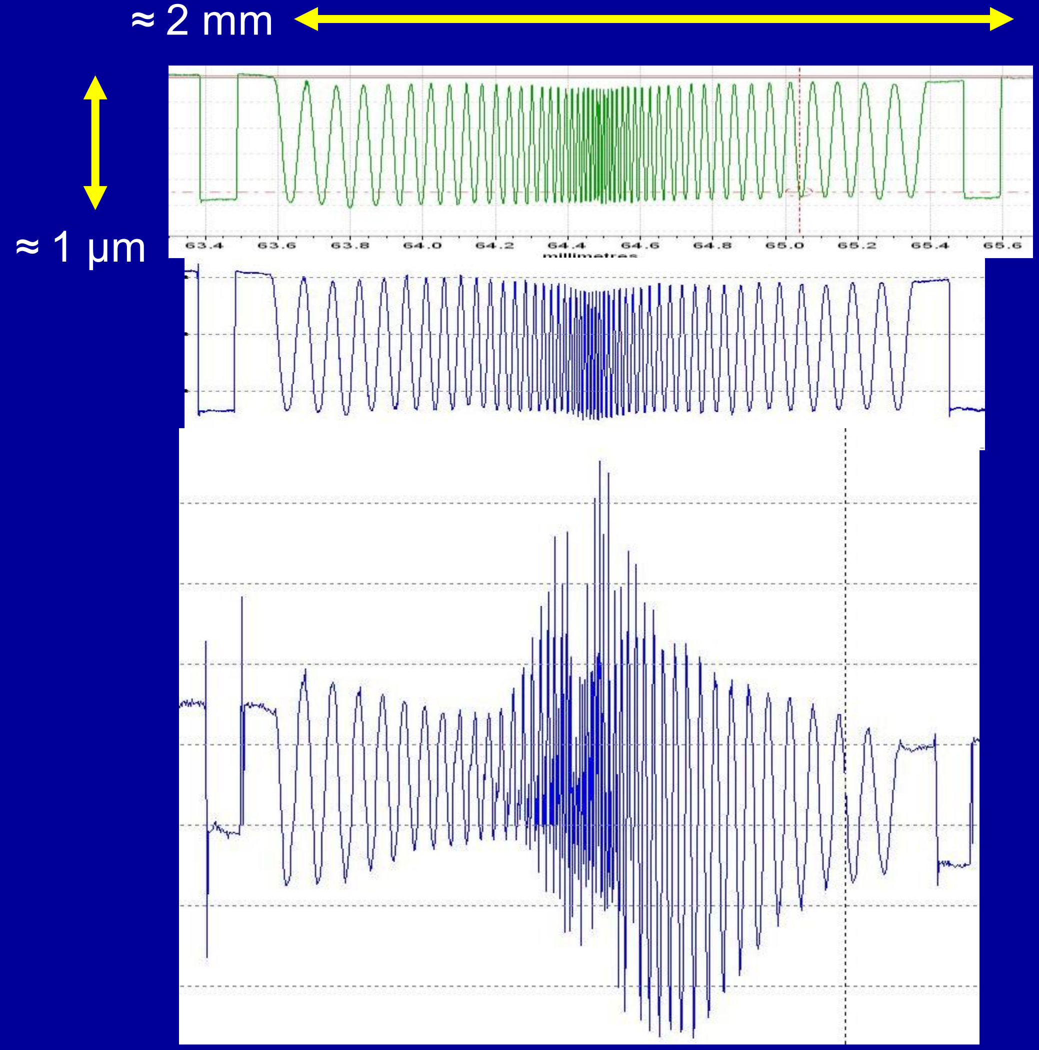
Profiles of a 100 nm *Ra* sinusoidal grating obtained with four techniques



Test of Confocal Microscopy:
Measurement of chirped roughness standard from PTB, Germany

≈ 2 mm

≈ 1 µm



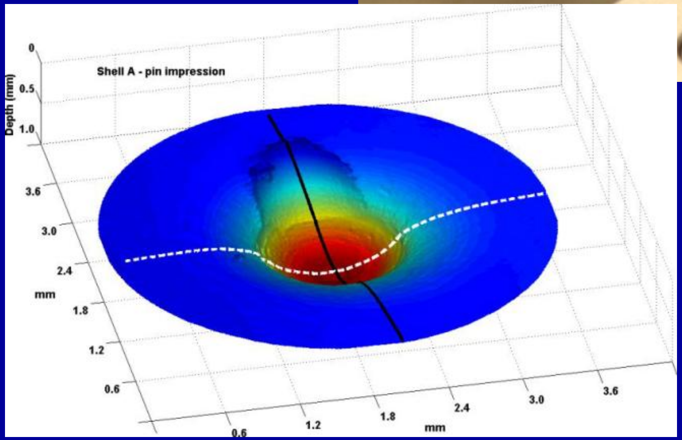
Stylus Profile

Confocal, 50X

Confocal, 10X

Other Methods

Confocal chromatic probe
Polaris – 3D,
K. Garrard et al.,NCSU



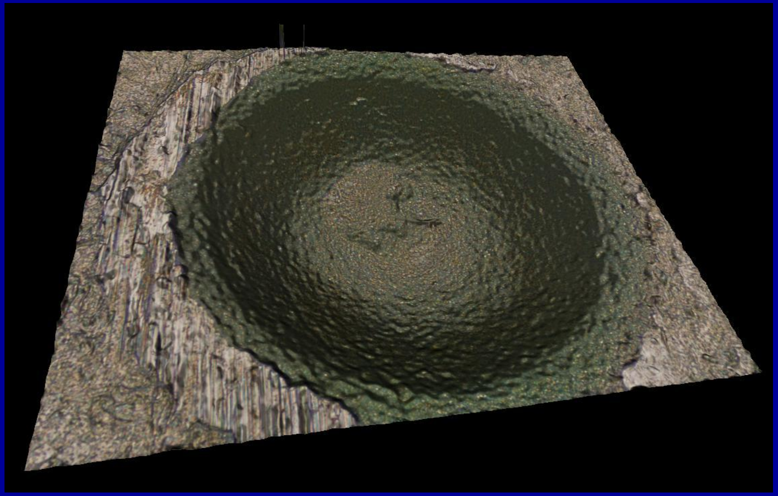
Contacting + Optical Method
Gelsight, M.K. Johnson et al.
MIT

Concluding Observations

- Calibration standards are available for testing different methods
  - Smooth surfaces for assessing vertical resolution
  - Set of periodic surfaces for testing lateral resolution
  - Rough surface standards for testing the algorithms
  - Standard bullet and cartridge case for testing capabilities to measure steep slopes and specific geometries
- Would be beneficial to test vertical and lateral resolution of each method and optimize vs. needs in ballistics identification, speed, and cost → could use a standard set of cartridge cases and bullets (Tulleners-De Kinder Cartridge Cases, NIST Cartridge Cases, IAI Bullets,…)

Concluding Observations

- Data Fusion:
  How best to combine reflection microscopy and topography data quantitatively



- Can apply scanning electron microscopy to obtain images with sub-micrometer resolution (Note: BKA research)