# *Forensic Topography at NIST: Ballistics and Associated Toolmarks*

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# NIST Focus Area: Ballistics and Associated Tool Marks

## Goals:

- Metrology infrastructure for objective forensic firearm and tool mark identification.
- Scientifically justified protocols that yield objective determinations of identification with well-characterized error rates.

## Objectives:

- Metrics, procedures, **quantitative error rates and uncertainties**.
- Metrology, quality assurance, and standards.
- Scientific knowledge base for similarity of marks and tool mark variability.

## Motivation: 2009 NRC Report[1]

- *"..the decision of the tool mark examiner remains a subjective decision based on unarticulated standards and no statistical foundation for estimation of error rates."*[1]

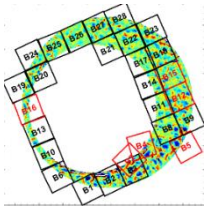
[1]National Research Council, "Strengthening Forensic Science in the United States: A Path Forward," National Academies Press, 2009

# *Major Collaborators:*

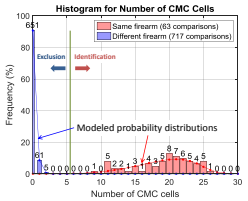
- **U.S. Law Enforcement:** DoJ/NIJ, ATF, FBI, State and local crime labs
- **Universities and forensic institutes:** John Jay College, University of Central Oklahoma, Iowa State University, UC Davis, RTI International, Netherlands Forensics Institute, National Institute for Criminalistics and Criminology (BE), California Criminalistics Institute.
- **Industry:** Cadre Research (Gelsight), Alicona, X-wave Innovations, Leeds Forensic Systems, Leica, Intelligent Automation Inc., Sensofar.
- **Forensic Organizations:** AFTE, IAI, AAFS, CAC, ENFSI, OSAC

# *Ballistics and Toolmarks: Major Efforts*


1. Quality assurance, reference artifacts, documentary standards

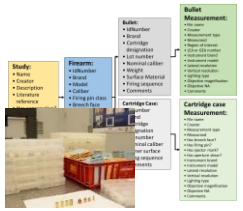


2. Metrics and algorithms for objective identification



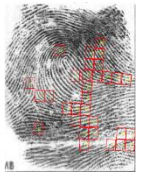

3. Quantitative uncertainty evaluation

4. Ballistics tool mark database for research and validation

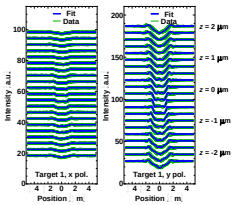


5. Tool mark identification for non-firearm tools

6. Applications to forensic pattern matching



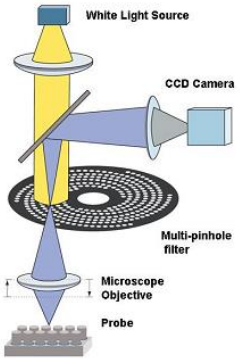
7. Optics research, Fourier methods, E&M modeling

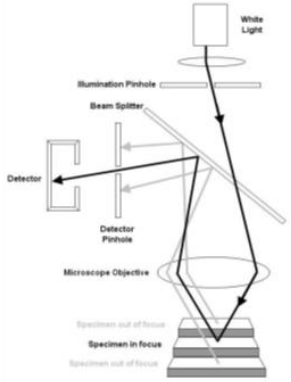


# Hardware Platforms: 3-D Topography

**3-D optical measurements:** Repeatable, more information, variety of techniques.

## Confocal – out-of-focus light rejected

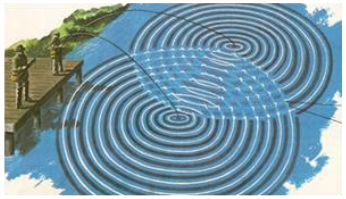


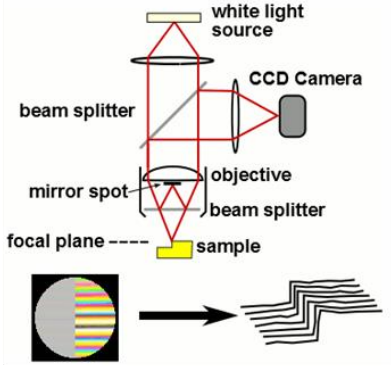

ASME B46-2009

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

## Interferometric – light interference

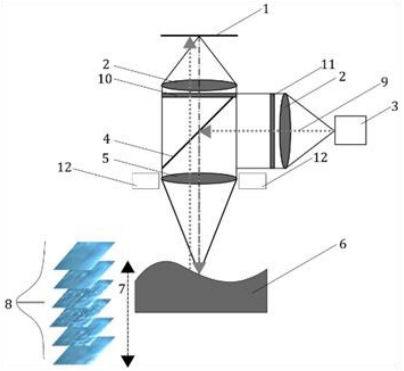


http://www.daviddarling.info/images/interference_water_waves.jpg



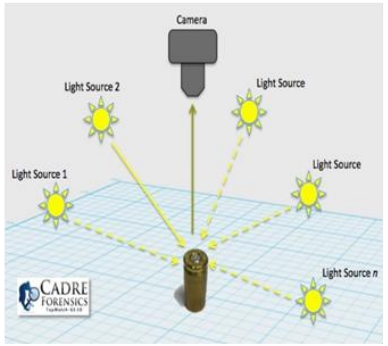

ByStigmatellaaurantiacaatEnglishWikipedia,CCBYSA3.0, https://commons.wikimedia.org/w/index.php?curid=20155972

## Focus Variation – pixel vs neighbors




| 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 |

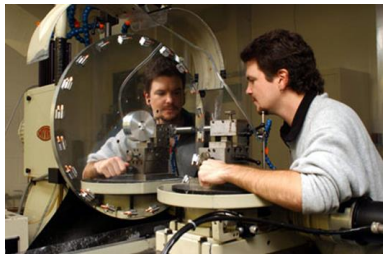
## Photometric Stereo – illumination or viewing angles



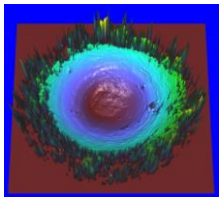

# Standards for Quality Control

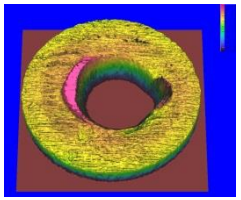
Physical standards for ballistic measurement traceability and quality control.

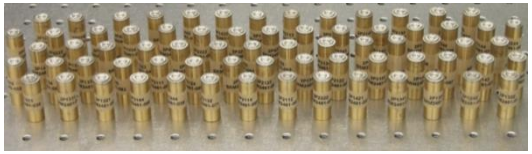
- SRM 2460 Standard Bullet
  - Machined from pure copper
  - 9 mm diameter
  - 6 land impressions

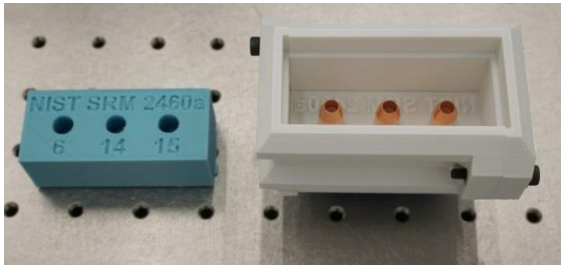
- SRM 2461 Standard Casing
  - 9 mm cartridge case
  - 3 measurement regions
    - firing pin
    - breech face
    - ejector mark





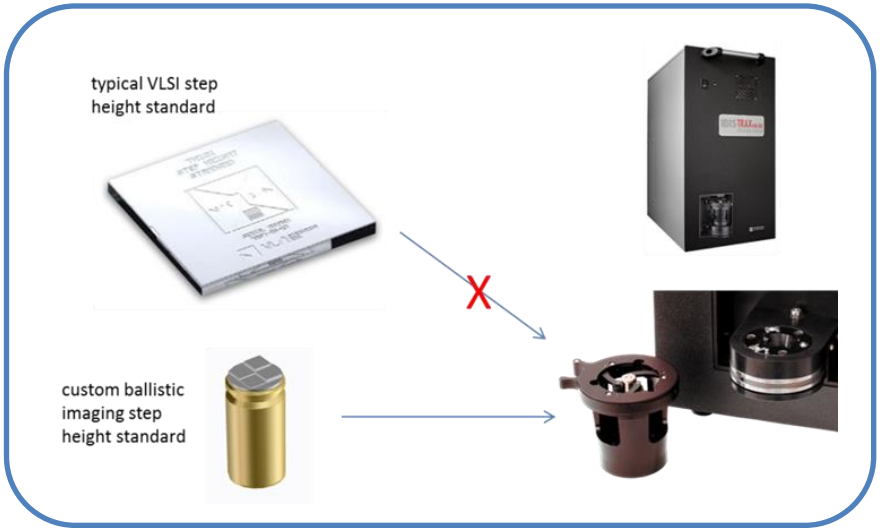
- SRM 2460a (in development)
  - Uses polymer replication process
  - Gold coated for durability
  - High quality, but economical

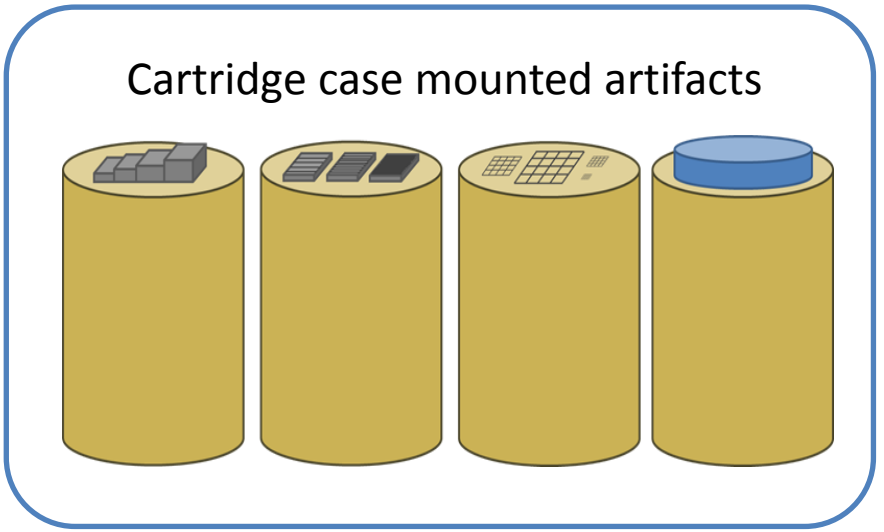


# A Metrology Foundation for 3D Ballistic Imaging

(Recent NIJ funded project.)

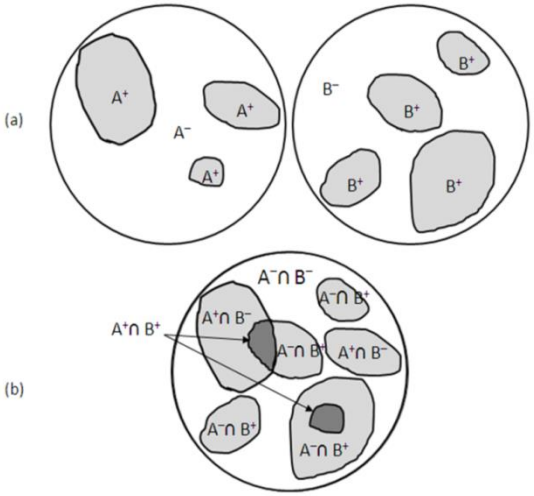
1. Performance Evaluation Standards
   - Specifications for instrument-to-instrument comparisons
2. Ballistics-oriented Reference Standards
   - Standards in cartridge case format (step height, resolution targets, etc.) with dimensions suitable for calibrating 3D instruments
3. Standardized quality assurance methods
   - Provide necessary detail for implementing 3D ballistic imaging measurement assurance system



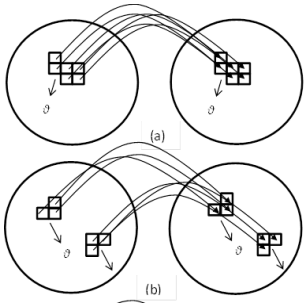



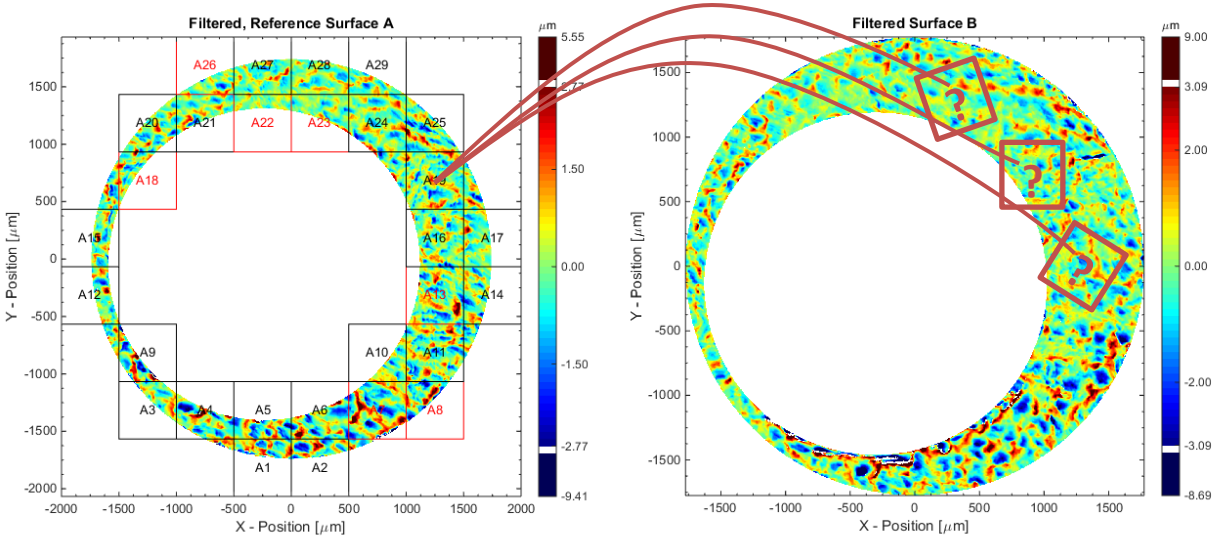
# New Algorithms: Congruent Matching Cells (CMC) Method

- Congruent Matching Cross-sections (CMX) for firing pins
- Congruent Matching Profile Segments (CMPS) for Bullets
- Congruent Matching Features (CMF) for complex features




Less bias from areas of poor impression




**If *CMC* ≥ 6 → Match,**
**If *CMC* < 6 → Non-match.**

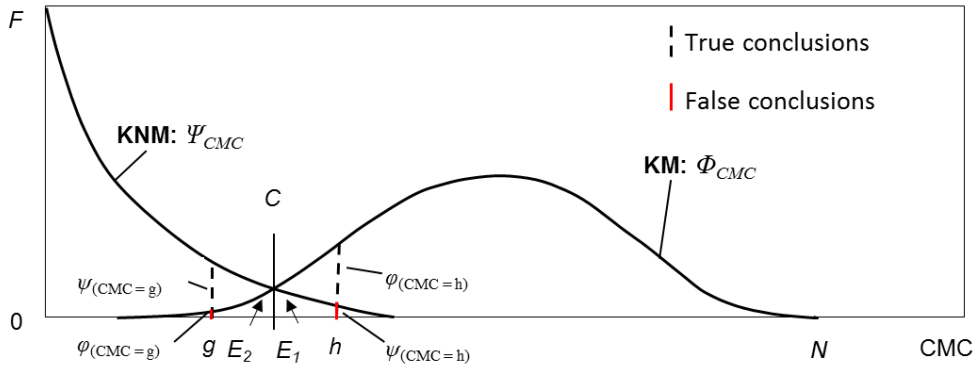
J. Song, "Proposed NIST Ballistics Identification System (NBIS) using 3D Topography Measurements on Correlation Cells", AFTE Journal, 45 (2), 184-194, 2013.

- **Registration position *x*, *y*, threshold $T_x$, $T_y$**
- **Registration angle $\theta$, threshold $T_\theta$**
- **Correlation value $CCF_{max}$, threshold $T_{CCF}$**

# Error rates, uncertainty procedures, and likelihood ratios

**Key challenges:**

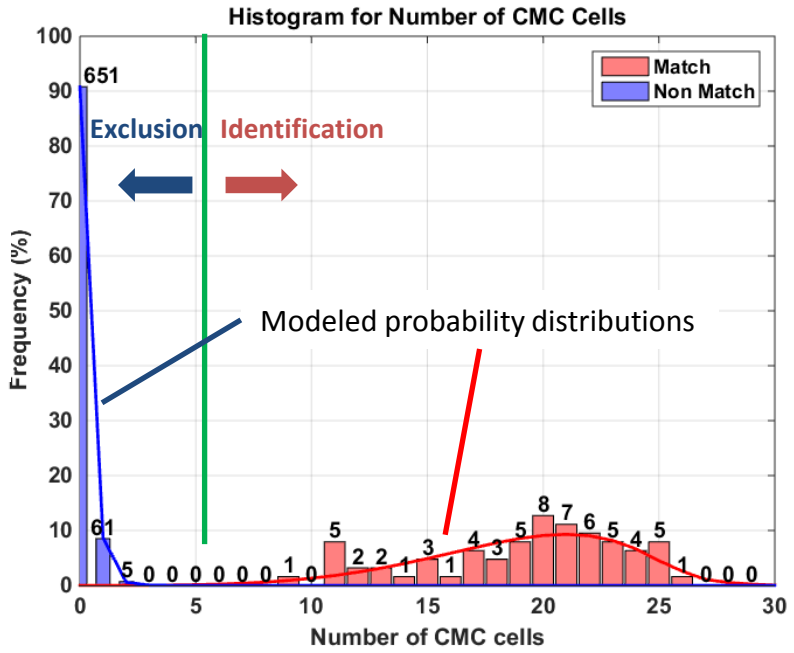
- Reliable uncertainties require accurate models for tails of the probability distributions with limited data and an understanding of dependencies. We are now developing new test data sets and population models.




Cumulative false positive error rate.

$$E_1 = \sum_{CMC=C}^{CMC=N} e_{1(CMC)} = e_{1(CMC=C)} + e_{1(CMC=C+1)} + \cdots + e_{1(CMC=N)}$$

$$= \psi_{(CMC=C)} + \psi_{(CMC=C+1)} + \cdots + \psi_{(CMC=N)}$$




**Observed and modeled CMC score distribution for 780 image comparisons from 10 pistol slides.**

**We can express the reliability of the forensic test using a likelihood ratio.**

$$\text{Likelihood Ratio} = \frac{\text{True positive rate}}{\text{False positive rate}}$$