Applications of 3D measurements in the study of marks on cartridge cases

PhD project
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Problematic

- Regarding firearms investigation some highlighted issues are summarized below:
  - The validity of the fundamental assumptions of uniqueness and reproducibility has not yet been fully demonstrated.
  - More researches would be needed to quantitatively characterize the probability of uniqueness.
  - There is a lack of objectivity during the identification process.
- This research tries to address some of these issues.

Aim of the PhD research

To quantify and to use the similarity between molded marks to help firearm experts making decisions regarding common origin of questioned cartridges cases.

- To do that an automatic comparison system based on 3D technology has been developed.

Marks to be analyzed

- Breech Face Mark
- Firing Pin Mark
3D measurement
Confocal detection profiler
μsurf of Nanofocus®
Resolution: 2 μm

3D comparison
- Preprocessing of 3D measurement
  - Primer cup segmentation.
  - Firing pin mark and breech face mark separation.
  - Global shape suppression (to cut the biggest frequencies).
- Alignment of marks
  - ICP (Iterative Closes Point) – Firing pin marks.
  - Optimization algorithm – Breech face marks.
- Error metric calculation after alignment
  - Quantify the similarities et/or differences between two marks.

Primer Cup Cutting
Automatic segmentation of the primer cup taking advantage of normal vectors

Marks separation
Automatic separation of the marks taking advantage of normal vectors
Global shape suppression

Largest frequencies cutting

Firing pin alignment

Ceska Zebrojovka Sample A
Ceska Zebrojovka Sample B

Alignment

Breech face alignment

SIG Sauer Sample A
SIG Sauer Sample B

Scores

Similarities quantification
Correlation index
Euclidean distance
Normal vectors difference

“Scores”
Results Interpretation

**Likelihood ratio (LR)**
- The LR is a value that represent the ratio between the probability to observe the comparison results under two different hypothesis:
  - \( H_1 \): The cartridge cases are fired by the same firearm
  - \( H_2 \): The cartridge cases are fired by different* firearms
- If \( LR > 1 \)
  \( \rightarrow \) The comparison results provide support for \( H_1 \) compared to \( H_2 \)
- If \( LR \) is between 0 and 1
  \( \rightarrow \) The comparison results provide support for \( H_2 \) compared to \( H_1 \)

\* With the same class characteristics

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Within vs. Between

- **Within**
  - 1 weapon
  - \( M \) cartridges

- **Between**
  - \( N \) weapons
  - \( N \) cartridges

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LR extrapolation – One dimension

\[
LR = \frac{p(d \mid H_1)}{p(d \mid H_2)}
\]

\( p(d \mid H_1, I) \)
\( p(d \mid H_2, I) \)

Score

1.2
1.3
More than one score

- If we have more than one score to describe one comparison? It could be the case when we have scores coming from the firing pin mark and scores from the breech face mark.

Monovariate distribution (KDE)

1D - Probability density function

- Within
- Between

More than one score

- If we have more than one score to describe one comparison? It could be the case when we have scores coming from the firing pin mark and scores from the breech face mark.

- PCA (Principal Component Analysis) is performed:
  - Reduce the number of dimensions keeping the more discriminative.
  - Fusion between firing pin scores and breech face scores.
  - Reduction until two dimensions.
    - Bivariate distributions (estimated by kernel density estimations or normal distributions).
Bivariate distribution (KDE)

2D - Probability density function

LR extrapolation – Two dimensions

LR > 1

Between

Within

LR < 1

Between

Within

Results on SIG pistols

- Test have been performed with SIG Sauer 9 mm Luger pistols
  - Within distribution
    - 2 weapons
    - Just one presented – similar results
  - Between distribution
    - 84 weapons model SIG P226, P228 and SIG Pro.
    - Weapons used by policemen's, during training period.
Tippett Plot

- For each comparison used to build the within (H₁) and between (H₂) distributions one LR is calculated. The result is two sets of LRs.

- These distributions are illustrated using a Tippett plot that shows one minus the cumulative distribution for respectively the LRs computed under H₁ and H₂.

- The Tippet plot allow also to show the rates of misleading evidence.
  - RMED: rate of \( LR < 1 \) if the cartridge cases are fired by the same weapons.
  - RMEP: rate of \( LR > 1 \) if the cartridge cases are fired by two weapons.

Tippett Plot - Weapon A - Firing pin

Tippett Plot - Weapon A - Breech Face

Tippett Plot - Weapon A - Fusion
Conclusions

- An automatic comparator system based on 3D technology has been developed.
  - The promising potential of 3D technology has been demonstrated.
  - These results have been obtained using the same ammunition (Geco SX). Several difficulties were met when different ammunitions are employed (not shown here).
- A bivariate model to calculate Likelihood ratios has been set up
  - Allow to evaluate the amount of similarities (or differences) between two marks.
  - Allow to take in account the marks separately or together.

Conclusions

- The most important points coming out from this research are the followings:
  - This is an objective and repeatable procedure to evaluate similarities between moulded marks.
  - It allows the quantification of relevant error rates (RMED, RMEP) and a quantification of “inconclusive” cases (low LRs).
  - Regarding the criticism raised by the NRC report on strengthening forensic science in the United States (2009). This research represents a move towards transparency and objectivity.
  - The operational constraints of this approach will be explored in collaboration with the Netherlands Forensic Institute (2010-2011).

Within – Same weapon

THANK YOU for your patience
Between – Different weapons