Israel Police, Division of Identification and Forensic Science.

- Toolmarks and Materials Lab.
- Hadassah Academic College, Dept. of Computer Science
- Hebrew University, Dept. of Statistics.

The Israeli research team started 15 years ago, after a European “scale committee” was established.
A small cut (1 mm) in the sole, how significant can it be?

97/3 point 1
It is not the size...

Changing angle

Is it a 1, 3 or 5 component?

2 mm
- it’s amount of information...
Characterizing Shoeprints –
From Class Characteristics
To Accidental Marks

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1) Toolmarks and materials lab. DIFS, Israel police
2) Hadassah Academic College, Dept. of Computer Science, Jerusalem.

SAMSI workshop September 1st 2015

Technical Report TP-3211, Submitted to the U.S. Department of Justice, NIJ.
How do we Identify shoes?
Fingerprints vs. Shoeprints

Fingerprints

• Can’t be changed.
• Consistent throughout whole life.
• Typical pattern.
• Minutiae consist of two basic types.
• Spatial configuration of minutiae determines individuality.
Fingerprints vs. Shoeprints

**Shoeprints**
- Life span several years.
- People own several pairs.
- Changes with wear.
- Unlimited patterns.
- Unlimited accidental shapes.
Connecting shoe to shoeprint

Class characteristics
- Pattern
- Size
- Wear

Accidental characteristics
- Cuts
- Nicks
- Tears
- Foreign objects

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Pattern

Pattern is not brand!
Size

7.5

9

10.5

12
Wear

Slight wear

Intermediate wear

Extreme wear
Accidental characteristics / Randomly acquired characteristic

A feature ...resulting from random events including, but not limited to: cuts, scratches, tears, holes, stone holds, abrasions and the acquisition of debris. The position, orientation, size and shape of these characteristics contribute to the uniqueness of a footwear outsole or tire tread.

(SWGTREAD - Standard for Terminology Used for Forensic Footwear and Tire Impression Evidence)
Sampling process – Case work

Suspect shoe

Crime scene print

Same pattern?

Yes

Test impressions

Same size & wear?

No

Exclusion

Same accidentals appear on print & shoe?

Exclusion

Determine level of certainty
Creating test impressions
Shoe

Same pattern? Yes → Test impressions

No → Exclusion

Print

Same accidentals appear on print & shoe? Yes → Determine level of certainty

No → Test impressions

Same size & wear? Yes → Exclusion

No → Test impressions

Exclusion
Comparison process
Comparison process

• Very high quality prints – can see accidentals without shoe.
• Most cases – See accidentals with overlaid test impression.
• Very low quality prints – look at shoe to identify what to search for on print.
Sampling process – Case work

1. **Shoe**
   - Same pattern?
     - Yes: **Test impressions**
     - No: **Exclusion**

2. **Print**
   - Same pattern?
     - Yes: **Test impressions**
     - No: **Exclusion**

3. **Test impressions**
   - Same size & wear?
     - Yes: **Exclusion**
     - No: **Same accidentals appear on print & shoe?**

4. **Same accidentals appear on print & shoe?**
   - Yes: **Determine level of certainty**
   - No: **Exclusion**
Determining level of certainty

Identification

Can’t be eliminated

Possible

Probable

Highly Probable

Negative

SAMSI
September 1st, 2015
From case work to research

- Class characteristics not very discriminative.
- Shoe-sole patterns change often.
- Tearing behavior of shoe-sole material similar for most shoes.

Focus on accidentals!
Database consisting shoes of various patterns

✓ A universal system for any possible pattern.
✓ Enables creating large database.
✓ Most shoe soles made of similar material, hence tear in similar way.
✗ Only contact areas can contain accidentals.
✗ Week points based on pattern.
Sampling process – Creating database of accidentals

- Creating test impressions.
- Scanning test impressions.
- Semi-Automatically marking accidentals.
- Finding shoe aligned coordinate system.
Scanning test impressions

- 600 ppi.
- Color.
- JPG or TIFF files.
Semi-Automatically marking accidentals

Marking the area of the accidental

Automatic marking of borders

Fine tuning the threshold

Cleaning excess markings
Three Criteria to evaluate an accidental
All the assumptions used are initial assumptions and further investigation into them is required!
The probability of having an accidental in a specific location

**Basic assumptions:**
We divide the test impression into grid cells and assume no more than one accidental in each cell.

The size of each grid cell is the size of the error in locating the accidentals.

Error \( \approx (5 \text{ mm})^2 = 0.25 \text{ cm}^2 \).

The area of a shoe is \( 30 \times 10 \text{ cm}^2 = 300 \text{ cm}^2 \).

Assuming a **uniform distribution** of locations:

\[ p = \frac{1}{1200} \]

Average of 30 accidentals per shoe:

\[ P = 30 \times \left( \frac{1}{1200} \right) = \frac{1}{40} \]

Ref: Yoram Yekutieli, “Challenges in image analysis of shoeprints”, Tomorrow 9:45
The probability for a specific accidental orientation

Basic assumptions:

- The orientation of a shape is the angle of its major (longer) axis relative to the X axis of the shoe aligned coordinate system.
- Error rate is determined by degree on elongation.
- The distributions of orientations are largely uniform.

Ref: Yoram Yekutieli, “Challenges in image analysis of shoeprints”, Tomorrow 9:45
The probability of having an accidental with a specific shape

Accidental shape compared against all the accidentals in the database.

Ref: Yoram Yekutieli, “Challenges in image analysis of shoeprints”, Tomorrow 9:45
The probability of having an accidental with a specific shape

- For each comparison calculating its matching error.
- Counting how many comparisons had a matching error value lower than the threshold.
- Assuming 500 out of the 10,000 shapes lower than threshold:
  \[ p(\text{shape}) = \frac{500}{10,000} = \frac{1}{20} \]

Ref: Yoram Yekutieli, “Challenges in image analysis of shoeprints”, Tomorrow 9:45
Assuming independence of the parameters, for one accidental we have:

\[
p(\text{accidental}) = p(\text{location}) \times p(\text{orientation}) \times p(\text{shape}) = \frac{1}{40} \times \frac{1}{18} \times \frac{1}{6752} = 2.06 \times 10^{-7}
\]
Probability of a combination of accidentals

We assume the orientations are independent.

We assume that their shapes are independent.

We assume the locations are independent.

\[
p(\text{combination}) = p(3 \text{ locations}) \times p(3 \text{ orientations}) \times p(3 \text{ shapes})
\]

And this is the same as \(( p(\text{single accidental})^3 ) \times 3!\)

Ref: Yoram Yekutieli, “Challenges in image analysis of shoeprints”, Tomorrow 9:45
The SESA system

Configuration of 13 defects

Probability of finding configurations similar to this one =

\[ < \frac{1}{6,111,491,029,665,863,000,000,000,000,000,000,000} \]

= \text{< 1.6363e-046}

Total probability

Probability of finding defects similar to this one =

\[ P(\text{total}) = P(\text{orientation}) \times P(\text{location}) \times P(\text{shape}) = \]

\[ (1/9.4162) \times (1/40) \times (1/70.2177) = 1/26,447 = 3.7811e-005 \]

Shape

Probability of finding shapes similar to this one =

\[ P(\text{shape}) = (1/70.2177) = 0.014241 \]

Location: \((-99.6, 38.3) + (-1.67, 1.67)\) [%]

Probability of finding defect around this location =

\[ P(\text{location}) = (1/40) = 0.025 \]

Orientatation: \(47 + -9.5\) [deg]

Probability of finding orientation in range \([37.5 \text{ to } 56.5]\) =

\[ P(\text{orientation}) = (1/9.4162) = 0.1062 \]
Location - Checking the assumptions

Is it justified to assume one accidental per cell?
Orientation

Checking the assumptions

How accurate is determining the orientation error based on the degree of elongation?
Shape - Checking the assumptions

• Probability of rare accidentals limited by No. of accidentals in database.

• Texture of shoe may interfere with correctly determining the shape contour.
Total probability
Checking the assumptions

• Is there any dependence between location, orientation and shape of an accidental?
• Some accidentals are pattern element dependent!
• Is there any dependence between different accidentals?
How does the working procedure affect the reliability of the database?
Test impression scanning method

Former scanning method

Present scanning method
Size of accidentals found with the new scanning and comparison method
From theory to reality

SCIENCE:
Theory vs. Reality

Eureka! My creativity paid off!

We're cutting half our R&D budget. Also you probably have cancer from all those chemicals.

Toothpaste For Dinner.com
Real life shoeprints

Print from crime scene

Test impression
Real life accidentals

• Partial shoeprint
Real life accidentals

• Twisted prints
Real life accidentals

• Partial accidental
Real life accidentals

• Noise
Real life accidentals

• Vague resemblance
Presenting the conclusion at court

How do we translate the derived probabilities to an understandable and reliable conclusion?
# ENFSI Marks conclusion scale

<table>
<thead>
<tr>
<th>Level</th>
<th>Likelihood ratio</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Extremely strong support for proposition A</td>
<td>1,000,000 and above</td>
</tr>
<tr>
<td></td>
<td>1,000,000 and above</td>
<td>Identification</td>
</tr>
<tr>
<td>2</td>
<td>Very strong support for proposition A</td>
<td>10,000 – 1,000,000</td>
</tr>
<tr>
<td></td>
<td>Strong support for proposition A</td>
<td>1000 – 10,000</td>
</tr>
<tr>
<td></td>
<td>Very probably</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Moderately strong support for proposition A</td>
<td>100 – 1000</td>
</tr>
<tr>
<td></td>
<td>Moderate support for proposition A</td>
<td>10 – 100</td>
</tr>
<tr>
<td></td>
<td>Weak support for proposition A</td>
<td>2 - 10</td>
</tr>
<tr>
<td></td>
<td>Probably</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Inconclusive</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Inconclusive</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Weak support for proposition ◦ (◦ =not A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate support for proposition ◦</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderately strong support for proposition ◦</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Strong support for proposition ◦</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Very strong support for proposition ◦</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Very likely not</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Elimination</td>
<td></td>
</tr>
</tbody>
</table>
Probability based on SESA system

Configuration of 13 defects

Probability of finding configurations similar to this one =

<
1/6,111,491,029,665,863,000,000
,000,000,000,000,000,000,000,000
0 = < 1.6363e-046
Distribution of probabilities per levels of certainty

Box plot of the log program's probability

-30 -30
-60 -60
-90 -90

Identification  Very probably  Probably
Level of Certainty

SAMSI
September 1st, 2015
High Quality shoeprint
Low quality shoeprint
Distribution of probabilities

High quality prints

![Boxplot showing the distribution of probabilities for different levels of certainty: Identification, Very probably, and Probably.](image-url)
probability cut-off between levels of certainty – high quality

• Identification: probability < 10E-33
• Highly probable: 10E-33 < probability < 10E-17
• probable: 10E-17 < probability
Distribution of probabilities
Mid quality prints
probability cut-off between levels of certainty – mid quality

- Level 1: probability < 10E-43
- Level 2: 10E-43 < probability < 10E-27
- Level 3: 10E-27 < probability
probability cut-off between levels of certainty

<table>
<thead>
<tr>
<th>Level</th>
<th>High Quality</th>
<th>Mid quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>$p &lt; 10E^{-33}$</td>
<td>$p &lt; 10E^{-43}$</td>
</tr>
<tr>
<td>Level 2</td>
<td>$10E^{-33} &lt; p &lt; 10E^{-17}$</td>
<td>$10E^{-43} &lt; p &lt; 10E^{-27}$</td>
</tr>
<tr>
<td>Level 3</td>
<td>$10E^{-17} &lt; p$</td>
<td>$10E^{-27} &lt; p$</td>
</tr>
</tbody>
</table>
Distribution of probabilities
Low quality prints
“Need to do” list

• All assumptions must be further tested!
• How do we create a universal database for all working procedures?
• Crime-scene shoeprints much more complex than test impressions!
• What should be the meaning in court of the results?
• How do we calibrate the probabilities based on the present conclusions?
The demand for science

“In most forensic science disciplines, no studies have been conducted of large populations to establish the uniqueness of marks or features”.

(NAS: Strengthening Forensic Science in the United States: A Path Forward, 2009.)

The court suggested that the expert’s practice has no sound basis. “There is not a sufficiently reliable “scientific” basis for the evidence to be admitted”.

(Regina vs. T, 2010, Court of Appeal, England)
Evaluation of forensic science findings in court uses probability as a measure of uncertainty. This is based upon the findings, associated data and expert knowledge, case specific propositions and conditioning information. Evaluation ... is based on the assignment of a likelihood ratio.

(ENFSI guideline for evaluative reporting in forensic science, 2015)
To be termed scientific, a method of inquiry is commonly based on empirical or measurable evidence subject to specific principles of reasoning.

(Rules for the study of natural philosophy", Newton transl. 1999)

Science: ✓ Empirical evidence
✓ Testing hypothesis
Suggested model for sound testimony in court

• Collection of as much data as possible.
• Create statistical model based on data.
• Present in court probability for specific case.
• Don’t base probability on subjective knowledge and guesses.
• Transfer subjective knowledge to court verbally for it’s consideration.