D3: Abnormal Driving Behavior Detection and Identification Using Smartphone Sensors

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Traffic Accidents
Human Factors

Fatigued

Distracted

Drunk
Abnormal Driving Detection

- Alcohol sensor
- Infrared sensor
- Camera

Cost
Smartphones

80% of the world’s population now has a mobile phone

5 Billion

Mobile Phones in World

Number of Smartphones in U.S

91.4 Million

Out of which only 1.08 Billion are smart phones
Abnormal Driving Behaviors

weaving  swerving  sideslipping  fast u-turn  turning with a wide radius  sudden braking

Fine-grained Abnormal Driving Behaviors Monitoring
System Architecture

Modeling Driving Behaviors (offline)
- Collected Data
- Feature Extracting:
  - Max (acc_x)
  - Min (acc_y)
  - Std (ori_x)
- Training
- Model

Monitoring Driving Behaviors (online)
- Data Sensing:
  - Acceleration
  - Orientation
- Coordinate Reorientation
- Cutting Driving Behaviors' Patterns
- Identifying:
  - weaving
  - fast u-turn
  - swerving
  - sudden braking
  - sideslipping
  - turning with a wide radius
- Alerting
System Architecture

Modeling Driving Behaviors (offline)

Collected Data

Feature Extracting

Max (acc_x)
Min (acc_y)
Std (ori_x)

Training

Model

Identification

Data Sensing

Acceleration
Orientation

Coordinate
Reorientation

Cutting Driving Behaviors' Patterns

weaving
fast u-turn
swerving
sudden braking
sideslipping
turning with a wide radius

Alerting
Data Collection

• Training Set
  – 6 months: Jan. 11 to July 12, 2014
  – 20 smartphones of 5 types:
    • Huawei Honor3C    ZTE U809    HTC sprint
    • SAMSUNG Nexus3    SAMSUNG Nexus4
  – 20 drivers/vehicles:
    • commute to work, shopping, touring
    • 60 – 80 km/day
  – Car DVR: record driving behaviors
  – Totally 4029 abnormal driving behaviors
Pattern Analysis

(a) Weaving
(b) Swerving
(c) Sideslipping
(d) Fast U-turn
(e) Turning with a wide radius
(f) Sudden braking
Pattern Analysis

(a) Weaving

(b) Swerving

(c) Sideslipping

(d) Fast U-turn

(e) Turning with a wide radius

(f) Sudden braking
Weaving

range[accX] – Big
μ[accX] ≈ 0
σ[accX] – Big
T – Long
Pattern Analysis

(a) Weaving

(b) Swerving

(c) Sideslapping

(d) Fast U-turn

(e) Turning with a wide radius

(f) Sudden braking
Swerving

range[accX] – Big
range[oriX] – Big
σ[accX] – Big
σ[oriX] – Big
μ[accX] ≠ 0
T – Short
Pattern Analysis

(a) Weaving
(b) Swerving
(c) Sideslipping
(d) Fast U-turn
(e) Turning with a wide radius
(f) Sudden braking
\[
\min[\text{accY}] < 0 \\
\mu[\text{accY}] < 0 \\
\text{range}[\text{accY}] \rightarrow \text{Big} \\
\mu[\text{accX}] \neq 0 \\
T \rightarrow \text{Short}
\]
Pattern Analysis

(a) Weaving

(b) Swerving

(c) Sideslipping

(d) Fast U-turn

(e) Turning with a wide radius

(f) Sudden braking
σ[accX] – Big at beginning/end
μ[accX] ≠ 0
range[accX] – Big
oriX across 0 point
T – Long

Fast U-turn
Pattern Analysis

(a) Weaving
(b) Swerving
(c) Sideslipping
(d) Fast U-turn
(e) Turning with a wide radius
(f) Sudden braking
Turning with a wide radius

\[ \sigma[\text{accX}] - \text{Big} \]

\[ \mu[\text{accX}] \neq 0 \]

\[ \sigma[\text{oriX}] - \text{Big} \]

\[ \sigma[\text{oriY}] \approx 0 \]

\[ \mu[\text{oriX}] \neq 0 \]

T – Long
Pattern Analysis

(a) Weaving  (b) Swerving  (c) Sideslipping

(d) Fast U-turn  (e) Turning with a wide radius  (f) Sudden braking
Sudden braking

σ[accX] – Small
σ[accY] – Big
range[accY] – Big
oriX across 0 point
T – Short
Feature Extraction

- Normal vs. Abnormal
- Weaving vs. Swerving
- Weaving vs. Sideslipping
- Weaving vs. Fast T-turn
- Weaving vs. Turning with a wide radius
- Weaving vs. Sudden braking
Feature Extraction

Normal vs. Abnormal
(range[acc,x], range[acc,y])

Weaving vs. Swerving
(σ[acc,x], σ[ori,y])

Weaving vs. Sideslapping
(μ[acc,x], range[acc,y])

Weaving vs. Fast T-turn
(μ[acc,x], max[ori,y])

Weaving vs. Turning with a wide radius
(μ[acc,x], σ[ori,y])

Weaving vs. Sudden braking
(range[acc,x], min[acc,y])
## Machine Learning

<table>
<thead>
<tr>
<th>Feature</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>( \text{range}_{\text{acc},x} )</td>
<td>subtraction of maximum minus minimum value of ( \text{acc}_x )</td>
</tr>
<tr>
<td>( \text{range}_{\text{acc},y} )</td>
<td>subtraction of maximum minus minimum value of ( \text{acc}_y )</td>
</tr>
<tr>
<td>( \sigma_{\text{acc},x} )</td>
<td>standard deviation of ( \text{acc}_x )</td>
</tr>
<tr>
<td>( \sigma_{\text{acc},y} )</td>
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<td>( \mu_{\text{ori},y} )</td>
<td>mean value of ( \text{ori}_y )</td>
</tr>
<tr>
<td>( \mu_{\text{acc},x,1} )</td>
<td>mean value of 1(^{st}) half of ( \text{acc}_x )</td>
</tr>
<tr>
<td>( \mu_{\text{acc},x,2} )</td>
<td>mean value of 2(^{nd}) half of ( \text{acc}_x )</td>
</tr>
<tr>
<td>( \text{max}_{\text{ori},x} )</td>
<td>maximum value of ( \text{ori}_x )</td>
</tr>
<tr>
<td>( \text{max}_{\text{ori},y} )</td>
<td>maximum value of ( \text{ori}_y )</td>
</tr>
<tr>
<td>( \text{min}_{\text{acc},y} )</td>
<td>minimum value of ( \text{acc}_y )</td>
</tr>
<tr>
<td>( t )</td>
<td>time duration between the beginning and the ending of a driving behavior</td>
</tr>
</tbody>
</table>

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**SVM**

**Classifier Model**
System Architecture

Modeling Driving Behaviors (offline)

Collected Data → Feature Extracting
- Max (acc_x)
- Min (acc_y)
- ...
- Std (ori_x)

→ Training → Model

Monitoring Driving Behaviors (online)

Data Sensing
- Acceleration
- Orientation

Coordinate Reorientation → Cutting Driving Behaviors’ Patterns

Identifying
- weaving
- fast u-turn
- swerving
- sudden braking
- sideslipping
- turning with a wide radius

Alerting
System Architecture

Modeling Driving Behaviors (offline)

- Collected Data
- Feature Extracting
  - \( \text{Max ( acc}_x \) \)
  - \( \text{Min ( acc}_y \) \)
  - \( \text{Std ( ori}_x \) \)
- Training
- Model

Monitoring Driving Behaviors (online)

- Data Sensing
  - Acceleration
  - Orientation
- Coordinate Reorientation
- Cutting Driving Behaviors' Patterns
- Identifying
  - weaving
  - fast u-turn
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  - sudden braking
  - sideslipping
  - turning with a wide radius
- Alerting
Evaluation

• **Metrics:**

  **Accuracy:** The probability that the identification of a behavior is the same as the ground truth.

  **Precision:** The probability that the identifications for behavior A is exactly A in ground truth.

  **Recall:** The probability that all behavior A in ground truth are identified as A.

  **FPR:** The probability that a behavior of type Not A is identified as A.
Test Set

– 4 months: July 21 to Nov. 30, 2014
– 20 smartphones of 5 types:
  • Huawei Honor3C, ZTE U809, SAMSUNG Nexus3
  • HTC sprint, SAMSUNG Nexus4
– 20 drivers/vehicles:
  • commute to work, shopping, touring
  • 60 – 80 km/day
– Car DVR: record driving behaviors
– Totally 3141 abnormal driving behaviors
Prototype

<table>
<thead>
<tr>
<th>Abnormal Driving Behavior Analysis</th>
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</tr>
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<tr>
<td>D3: abnormal driving behavior detection and identification system</td>
<td></td>
</tr>
<tr>
<td>Weaving</td>
<td>→ 11</td>
</tr>
<tr>
<td>Swerving</td>
<td>→ 3</td>
</tr>
<tr>
<td>Sideslipping</td>
<td>→ 4</td>
</tr>
<tr>
<td>Fast U-turn</td>
<td>→ 20</td>
</tr>
<tr>
<td>Turning with a wide radius</td>
<td>→ 17</td>
</tr>
<tr>
<td>Sudden braking</td>
<td>→ 36</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>→ 91</td>
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Abnormal Driving Behavior Analysis

<table>
<thead>
<tr>
<th>Start</th>
<th>Stop</th>
</tr>
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</table>

Car DVR

Testbeds

D3: abnormal driving behavior detection and identification system

- Weaving: 11
- Swerving: 3
- Sideslipping: 4
- Fast U-turn: 20
- Turning with a wide radius: 17
- Sudden braking: 36
- Total: 91
Accuracy Evaluation (1)

<table>
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<tr>
<th>Behavior</th>
<th>Accuracy(%)</th>
<th>Precision(%)</th>
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<tbody>
<tr>
<td>Normal</td>
<td>99.84</td>
<td>98.80</td>
<td>100.00</td>
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<tr>
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<td>94.81</td>
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<tr>
<td>Weaving</td>
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<td>87.87</td>
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<tr>
<td>Swerving</td>
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<tr>
<td>Turning with a wide radius</td>
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<td>Sudden braking</td>
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Total Accuracy 95.36%
Accuracy Evaluation (1)

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Total Accuracy **95.36%**
Accuracy Evaluation (2)

FPRs of identifying different types of driving behaviors.
Thanks!