Tracking driver actions and guiding phone usage for safer driving

Hongyu Li
Jan 25, 2018
Smart devices — risks and opportunities

- **Risks**: Smart Devices Distraction while driving
- **Opportunities**: More Smart Devices are accessible.
Outline

• Proposed a model **distinguish a driver’s phone from passenger’s** based on the inertial sensors of smartphones and wrist-mounted devices.

• Designed a method to **detect whether a driver’s hand is on or off steering wheel**.

• Proposed an architecture to **channel a driver’s phone usage into relative safer periods**, and implemented the system in the context of waiting for traffic lights.
Related works

- **Driver or passenger:** Recognize when their user is driving and distinguish that from being a passenger.

  - NFC based
  - Vehicle dynamics based
  - Audio infrastructure based

- Infrastructure may not be available.
- Phone Position Dependable
System Design

- **Feature Extraction**
  - Rotational change
  - Arm’s acceleration
  - Car’s acceleration
  - X axis value of phone’s gyroscope
  - Duration of first hand movement
  - Gyroscope’s magnitude of hand

- **Driver Detection**
  - Classification
    - Driver
    - Passenger

**Turn Detection**
- Vehicle Turn
- Entire Turn
- First Hand Movement

**Sensor Inputs**
- Accelerometer
- Gyroscope
- Magnetometer
Turn detection

- **Vehicle turn**
  - Vehicle is actually turning in this period.
  - Use smartphone gyroscope magnitude to detect.

- **First hand movement**
  - First hand steering motion (from t1 to t2).
  - This period often begins prior to the vehicle turn.
  - Use wearable gyroscope x-axis value to detect.

- **Entire turn**
  - Entire turn is the union of the vehicle turn period and the first hand movement period.

![Graphs and images illustrating turn detection process]
Experiment setup

• We conduct our experiments with 3 Invensense MPU-9150 9-axis motion sensor.

• The sample rate is set as 100Hz in the experiments.
• Sensor data is collected from several hours’ drives, total 280 turns (560 cases).
• In the whole data set, passenger might be stationary, using phone or eating.
Classification and evaluation

- Turn detection
  - For our limited dataset, we did not find any false positives.
- Driver detection

<table>
<thead>
<tr>
<th></th>
<th>All data</th>
<th>Stationary</th>
<th>Using phone</th>
<th>Eating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy (%)</td>
<td>98.9%</td>
<td>100%</td>
<td>100%</td>
<td>96.7%</td>
</tr>
</tbody>
</table>
Outline

• Proposed a model **distinguish a driver’s phone from passenger’s** based on the inertial sensors of smartphones and wrist-mounted devices.

• Designed a method to **detect whether a driver’s hand is on or off steering wheel**.

• Proposed an architecture to **channel a driver’s phone usage into relative safer periods**, and implemented the system in the context of waiting for traffic lights.
Motivation

• Mobile and Wearable devices are often viewed as distraction
  Can they compensate for the distraction by enabling safety applications?

A driver using both hands to text while driving.
Related Work

Behavior Detection

- Lane change assistance[12,13,19]
- Safe following distance
- Drowsy driving[20 & 19]

Activity Tracking with wearables

- Smoking detection and other activities
- Not specific to driving

(Raif et al)
System Design

- **Input**
  - Coordinate Alignment
  - Driver/Passenger Classification

- **Hand On/Off Steering Wheel Detection**
  - Hard Movement Detection
  - Linear Direction Estimation
  - Rotation Based Movement Matching

- **Steering Wheel Angle Estimation**
  - Data Calibration and Integration
  - Profile Construction
  - Angle Estimation

- **Output**
  - User is a passenger
  - Periods when driver’s hand is off steering wheel
  - Steering wheel rotation angle when driver’s hand is on steering wheel

- **Application**
  - Curve Speed Warning
  - Understeer/Oversteer Estimation
  - Driver Behavior Guidance
  - Car Maintenance Detection

- **Speed up**
  - $V_{beginning} = 0$
  - $V_{max}$
  - $V_{ending} = 0$
  - $\text{acceleration}_{first half} > 0$
  - $\text{acceleration}_{second half} < 0$

- **Slow down**
  - $V_{beginning} = 0$
  - $V_{max}$
  - $V_{ending} = 0$
  - $\text{acceleration}_{first half} < 0$
  - $\text{acceleration}_{second half} > 0$

- **Move to Leg**
  - Slow down
  - Move back

- **Hand on Leg**
  - Speed up
  - Slow down
Up&Down Movement

- Data Observation according to Intuition
- (The data below is the experiment with hand operating side window. Although the movement is mostly horizontal, the data also has the same property.) *(z axis acceleration of watch in earth coordinate system)*
Hand on/off Steering Wheel Detection

So many peaks → Peak clustering → Still have noise → Cluster filter
Hand on/off Steering Wheel Detection

![Graphs showing hand on/off steering wheel detection with manually labeled groundtruth and estimate result.](image-url)
Experiment Setup

- Invensense MPU-9150 9-axis motion sensors @50hz
  - On wrist
  - On steering wheel: $\theta_{\text{real}}$, ground truth
- Smartphone
- GoPro camera
- Honda Civic, Toyota Camry

Steering wheel angle evaluation
(20 trips)
- Highway: smooth curves, small angles
- Local Road: sharp turns, large angles

Hand on/off evaluation
- Extra route: frequent hand movements intentionally

Fig. 8: Position of sensors and smartphone.
Performance Evaluation

- In terms of duration: the system achieves **99.9%** true positive rate and **89.2%** true negative rate.
- In terms of hands on/off events:

![Graph showing performance evaluation]

- Hand on/off performance for different movement types:

  - Leg: $>91.5$
  - Arm Rest: $>91.5$
  - Sun Visor: $>81.5$
  - Total: $=89.2$
  - Positives: Hands on the wheel
  - Negatives: Hands off the wheel
Outline

• Proposed a model **distinguish a driver’s phone from passenger’s** based on the inertial sensors of smartphones and wrist-mounted devices.

• Designed a method to **detect whether a driver’s hand is on or off steering wheel**.

• Proposed an architecture to **channel a driver’s phone usage into relative safer periods**, and implemented the system in the context of waiting for traffic lights.
Vision

Complete Prohibition

Channel driver’s device and information system use into safer periods
Related Work

- User Attention Management
  - [8, 16].
- Intelligent Notification
  - [11, 12, 19].
- Reducing Interactions while Driving
  - GPS based: [2, 3, 4]
  - Bluetooth based: [1]
  - Additional Hardware based: [5, 23]
  - Context Awareness: [17].

Only consider general notification context

Completely ignore incoming calls and texts
• **Is it possible to channel driver’s attention?**
  
  • Analysis based on data sets

• **How could we channel driver’s attention?**
  
  • System design

• **How well could we channel driver’s attention?**
  
  • System evaluation
Is it Possible to channel driver’s attention?

<table>
<thead>
<tr>
<th>Category</th>
<th>Average Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Text</td>
<td>9.56</td>
</tr>
<tr>
<td>Finance Apps</td>
<td>37.01</td>
</tr>
<tr>
<td>Travel Apps</td>
<td>44.72</td>
</tr>
<tr>
<td>Communication Apps</td>
<td>46.92</td>
</tr>
</tbody>
</table>

- A stop longer than 9.56s occurs every 3.96 minutes for a 10min trip, we could expect about 2.5 such opportunities.
- 92% of cases the first car’s waiting duration is more than 10s, 32% of cases it exceeds 60s.

1. How common are safe opportunities to interact with information systems during driving?
2. How much time is needed for short interactions?
3. How much would interactions be delayed?
• Is it possible to channel driver’s attention?
  • Analysis based on data sets

• **How could we channel driver’s attention?**
  • System design

• How well could we channel driver’s attention?
  • System evaluation
System Design

detect and classify stop periods
extract period feature vector
filter and channel safer notifications
Case Study

\[ T_{\text{Waiting}} = T_{\text{StoptoGreen}} + T_{\text{GreentoLeave}} \]
Case Study

\[ T_{\text{Waiting}} = T_{\text{Stop to Green}} + T_{\text{Green to Leave}} \]

- \( t_{\text{cycleStart}_i} \) is the time when a cycle starts (i.e., when the traffic light changes to green),
- \( d_{t_i} \) is the offset with respect to current cycle length (x) and \( t_{\text{cycleStart}_i} \)
- \( d_t \) is the average offset calculated by all \( t_{\text{cycleStart}_i} \) samples.
✓ fast converge based on few samples
✓ increase prediction performance with promotional to more samples
• Is it possible to channel driver’s attention?
  • Analysis based on data sets

• How could we channel driver’s attention?
  • System design

• **How well could we channel driver’s attention?**
  • System evaluation
Evaluation on Practical Data

- First day: 25 stops, 3:30pm to 4:15pm
- Second day: 18 stops, 5:15pm to 6:00pm
- Two different cars: Honda Civic and Toyota Camry
- Two different phones: Nexus 5 and Nexus 6
- Same APP: automatically logging data

mean error = 2.37s
mean error = 2.50s
61.43s average stop duration
Evaluation on Simulation Data

![Graph showing mean error per cycle and cycle length for different traffic systems.]

Figure 6: Prediction error of different traffic systems.

✓ The prediction accuracy of our system converges quickly.
The prediction accuracy is performance proportional with the number of cycles and the number of data samples within one cycle.
Conclusion

• Explore the possibility of improving the safety of drivers’ interactions with mobile devices by limiting the interaction periods to relatively safe one, in particular when the vehicle is stopped.

  • Propose an architecture design and further implement parts of it under the case of waiting for traffic lights

  • The system performs an accurate waiting duration prediction based on both practical and simulation data sets.

  • Our fast converge and performance proportional calibration mechanism enable the system to correct itself through increased amount of the crowd-sourced data

• Our results provide confidence to channel safer notifications while driving.
Papers


• Cagdas Karatas, Luyang Liu, Hongyu Li, Jian Liu, Yan Wang, Sheng Tan, Jie Yang, Yingying Chen, Marco Gruteser, Richard Martin. Leveraging Wearables for Steering and Driver Tracking. *IEEE International Conference on Computer Communications (INFOCOM) 2016*
