RoadAware: Learning Personalized Road Information on Daily Routes with Smartphones*

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Outline

• Introduction
• System Design
• Performance Evaluation
• Conclusion
Introduction

• Automobile is common in modern society
  • Boosting social and economical development
  • Meanwhile raising problems: traffic delay & safety
    • Americans spend over 100 hours a year on commuting cars

• Road and traffic monitoring is necessary
  • Provide traffic information for better management
  • Dedicated sensor networks can serve this purpose but are expensive
Introduction

• Vehicles are natural data source for road and traffic condition
  • Large amount of distributed “sensing nodes”
  • Offer first hand data at a low cost

• Vehicles are not yet ready for this purpose
  • Cars are relatively “closed” nowadays
    • Lacking interfaces to report collected data
    • Limited amount of sensors
Introduction

• Smart phones can be a suitable sensing tool on vehicles
  • Wide availability
    • Around 2 billion smart phone users now

• Rich sensing & computing capability on smart phones
  • GHz level CPUs
  • Various sensors: GPS/Microphone/Accelerometer

• Open environment for application development
Introduction

• Rich investigation in this direction
  • Traffic light sensing (Infocom’12)
  • Traffic signal scheduling advisory (MobiSys’11)
  • Traffic delay estimation (SenSys’09)
  • Road & traffic condition monitoring (SenSys’08)
  • Etc.

• Most of current works are for overall road status
  • Few are for individual drivers to collect information on commute roads
Introduction

• Propose RoadAware for individual road information collection
  • Exploit smartphones carried by drivers
  • Collect and deduce some data on commuting roads
    • Travel distance and time between traffic lights
    • Average duration of red/green lights
    • Traffic volume on the roads between traffic lights
• Exclude road information during events such as football games and holidays because
  • 1) RoadAware aims to provide benchmark data during normal daily commute
  • 2) people are more sensitive to working day traffic status
Outline

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System Design: Route Model

• Route $R$
  • A set of traffic lights ($L$) and road segments ($S$) in sequence

  ![Diagram of Route $R$]

  • $A_0$ is the start point and $E_{m+1}$ is the ending point
  • There are total $m$ traffic lights, whose GPS positions are already known
  • Only consider two traffic light statuses: **red (yellow)/stop** and **green/pass**
System Design : Measurement

- Measurement unit
  - Each segment and the traffic light at its end, e.g., $S_1$ and $L_1$

- Collect data daily to deduce information of each unit
  - Average travel length and time
  - Average traffic volume
  - Average length of the red/green signal
System Design : Measurement

• Trip Length & Time
  • Rely on periodically reading GPS data
  \[ D(P_j, P_{j+1}) = (t_{j+1} - t_j)(v_{j+1} + v_j)/2 \]
  • \((t_{j+1} - t_j)\) means the amount of time between two GPS readings
  • \((v_{j+1} + v_j)/2\) means the average speed during this period of time
  • More accurate than calculating the distance directly with two GPS positions
System Design: Deduce Information

- Traffic signal information
  - A car cannot get such information directly (does not always stay before the traffic light)
  - Observation:
    - A car’s waiting time in front of a traffic light is related to the traffic rate and the length of the red light
  - Solution:
    - Modeling the waiting queue before a traffic light
    - Combining daily collected waiting time and queue length information and use the model to deduce traffic signal information
System Design: Deduce Information

- Waiting queue modeling
  - $\lambda_{ia}$ and $\lambda_{id}$ denote the rate that cars enter and leave the queue, respectively.
  - The traffic light turns to red at $t_{irs}$.
  - A car stops at $t_{ia}$ and starts to move at $t_{id}$.
  - When it stops, the red light has elapsed for $T_{irp} = t_{ia} - t_{irs}$.
  - The waiting time in the queue is $T_{iw} = t_{id} - t_{ia}$.
  - $Y_{ir}$: the length of the red light.

$$T_{iw} = Y_{ir} - T_{irp} + T_{irp} \cdot \frac{\lambda_{ia}}{\lambda_{id}}$$
$$= Y_{ir} + T_{irp} \cdot \left(\frac{\lambda_{ia}}{\lambda_{id}} - 1\right)$$
System Design: Deduce Information

- Waiting queue modeling
  - First, we have
    \[ T_{iw} = Y_{ir} - T_{irp} + T_{irp} \times \frac{\lambda_{ia}}{\lambda_{id}} \]
    \[ = Y_{ir} + T_{irp} \times \left( \frac{\lambda_{ia}}{\lambda_{id}} - 1 \right) \]
  - \( Y_{ir} \): the length of the red light
  - \( Y_{ir} - T_{irp} \): the remaining amount of time of the red light
  - \( T_{irp} \times \frac{\lambda_{ia}}{\lambda_{id}} \): the time used by cars before the sensing car to leave the queue
System Design: Deduce Information

- Waiting queue modeling
  - On the other hand:
    \[ T_{irp} = \frac{d_{is}}{\bar{r}}/\lambda_{ia} \]
  - \( d_{is} \): the length of the queue in front of the red light
  - \( \bar{r} \): average length of a car
  - \( d_{is}/\bar{r} \): the number of cars in front of the sensing car in the waiting queue
  - \( (d_{is}/\bar{r})/\lambda_{ia} \): the amount of time used by those cars to enter the waiting queue
System Design : Deduce Information

- Waiting queue modeling
  - Combine the above two equations, we have

\[ T_{iw} = Y_{ir} + d_{is} \times \kappa_i \]

where

\[ \kappa_i = \frac{\lambda_{ia} - \lambda_{id}}{\lambda_{ia} \lambda_{id} \bar{r}} \]

- \( \kappa_i \) usually is negative as cars leave the queue quicker than entering it
System Design: Deduce Information

• Deduce traffic light information
  • Collect multiple pairs of waiting time ($T_{iw}$) and the distance to the traffic light when stopped ($d_{is}$) over multiple days
  • Apply to the equation
  • Obtain red light length ($Y_{ir}$) and traffic volume ($\lambda_{ia}$)
  • Use linear regression to enhance accuracy

\[
T_{iw} = Y_{ir} + d_{is} \times \kappa_i
\]

where

\[
\kappa_i = \frac{\lambda_{ia} - \lambda_{id}}{\lambda_{ia} \lambda_{id}}
\]
System Design : Deduce Information

• Deduce traffic light information
  • Use the probability to meet green light and red light to deduce the length of green light

\[ Y_{ig} = Y_{ir} \times \frac{N_g}{N_r} \]

where \( N_g \) is number of green lights the car has met and \( N_r \) is the number of red lights

• Require accumulating data over a longer period of time to get good accuracy
Evaluation

- Toy implementation on Windows phones
Evaluation

- Toy implementation on Windows phones
- Tested over three routes
  - Home2Campus(H2C), Campus2Home(C2H), and LongRoute(LRt)

<table>
<thead>
<tr>
<th>Route</th>
<th># of traffic light</th>
<th>Length (m)</th>
<th>Test period</th>
</tr>
</thead>
<tbody>
<tr>
<td>H2C</td>
<td>5</td>
<td>1900</td>
<td>7:30AM - 8:10AM</td>
</tr>
<tr>
<td>C2H</td>
<td>5</td>
<td>1900</td>
<td>4:30PM - 5:10PM</td>
</tr>
<tr>
<td>LRt</td>
<td>6</td>
<td>4900</td>
<td>5:20PM - 6:00PM</td>
</tr>
</tbody>
</table>
Evaluation: Travel Length & Time

The travel distance match with the ground truth well (the ground truth is from Google map)

<table>
<thead>
<tr>
<th>Traffic light</th>
<th>H2C</th>
<th>C2H</th>
<th>LRt</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_1$</td>
<td>181.6</td>
<td>106.7</td>
<td>767.8</td>
</tr>
<tr>
<td>$L_2$</td>
<td>226.6</td>
<td>245.4</td>
<td>600.6</td>
</tr>
<tr>
<td>$L_3$</td>
<td>523.6</td>
<td>270.3</td>
<td>1299.7</td>
</tr>
<tr>
<td>$L_4$</td>
<td>325</td>
<td>311.2</td>
<td>726.3</td>
</tr>
<tr>
<td>$L_5$</td>
<td>271.5</td>
<td>521.2</td>
<td>897.3</td>
</tr>
<tr>
<td>$L_6$</td>
<td>350.4</td>
<td>416.6</td>
<td>436.3</td>
</tr>
<tr>
<td>$L_7$</td>
<td>-</td>
<td>-</td>
<td>195.7</td>
</tr>
<tr>
<td>Total</td>
<td>1878.7</td>
<td>1871.4</td>
<td>4923.7</td>
</tr>
<tr>
<td>Actual Total</td>
<td>1900</td>
<td>1900</td>
<td>4900</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic light</th>
<th>H2C</th>
<th>C2H</th>
<th>LRt</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_1$</td>
<td>29.1</td>
<td>66.5</td>
<td>110.1</td>
</tr>
<tr>
<td>$L_2$</td>
<td>49.9</td>
<td>72.7</td>
<td>66.2</td>
</tr>
<tr>
<td>$L_3$</td>
<td>39.8</td>
<td>37.1</td>
<td>89.9</td>
</tr>
<tr>
<td>$L_4$</td>
<td>39.3</td>
<td>24.3</td>
<td>50.7</td>
</tr>
<tr>
<td>$L_5$</td>
<td>91.1</td>
<td>67.9</td>
<td>67.9</td>
</tr>
<tr>
<td>$L_6$</td>
<td>28.7</td>
<td>35.8</td>
<td>42.5</td>
</tr>
<tr>
<td>$L_7$</td>
<td>-</td>
<td>-</td>
<td>23.5</td>
</tr>
<tr>
<td>Total</td>
<td>277.9</td>
<td>304.3</td>
<td>450.8</td>
</tr>
</tbody>
</table>
Evaluation: Red Light Length

Fig. 8: The duration of red lights on the three routes.

(a) Home2Campus.
(b) Campus2Home.
(c) LongRoute.

The deduced value is close to actual value measured manually.
Evaluation : Traffic Volume

The deduced traffic volume is also close to manually counted data

### TABLE VI: Traffic volume at each $L_i$ in Home2Campus.

<table>
<thead>
<tr>
<th></th>
<th>$L_1$</th>
<th>$L_2$</th>
<th>$L_3$</th>
<th>$L_4$</th>
<th>$L_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RoadAware</td>
<td>0.090</td>
<td>0.067</td>
<td>0.131</td>
<td>0.234</td>
<td>0.130</td>
</tr>
<tr>
<td>Actual Value</td>
<td>0.102</td>
<td>0.072</td>
<td>0.140</td>
<td>0.232</td>
<td>0.119</td>
</tr>
</tbody>
</table>

### TABLE VII: Traffic volume at each $L_i$ in Campus2Home.

<table>
<thead>
<tr>
<th></th>
<th>$L_1$</th>
<th>$L_2$</th>
<th>$L_3$</th>
<th>$L_4$</th>
<th>$L_5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RoadAware</td>
<td>0.068</td>
<td>0.218</td>
<td>0.243</td>
<td>0.244</td>
<td>0.116</td>
</tr>
<tr>
<td>Actual Value</td>
<td>0.059</td>
<td>0.245</td>
<td>0.233</td>
<td>0.252</td>
<td>0.103</td>
</tr>
</tbody>
</table>

### TABLE VIII: Traffic volume at each $L_i$ in LongRoute.

<table>
<thead>
<tr>
<th></th>
<th>$L_1$</th>
<th>$L_2$</th>
<th>$L_3$</th>
<th>$L_4$</th>
<th>$L_5$</th>
<th>$L_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RoadAware</td>
<td>0.22</td>
<td>0.22</td>
<td>-</td>
<td>0.12</td>
<td>0.14</td>
<td>0.12</td>
</tr>
<tr>
<td>Actual Value</td>
<td>0.25</td>
<td>0.23</td>
<td>0.13</td>
<td>0.13</td>
<td>0.13</td>
<td>0.15</td>
</tr>
</tbody>
</table>
Conclusion

• Exploit smartphones to record and deduce the traffic and trip information on commuting routes for a driver

• Solution:
  • Model a car’s waiting time in front of a traffic light with the traffic rate and the length of red light
  • Use GPS to collect data and deduce more information

• Future work:
  • Large scale experiment and evaluation
  • Integrate data from multiple drivers for more useful applications
Thank you!

Questions & Comments?