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

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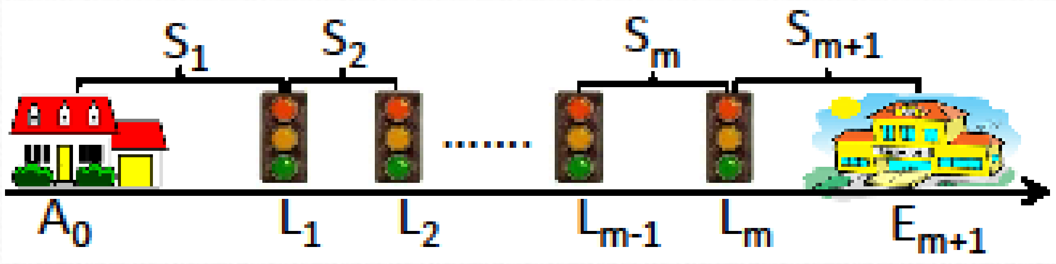
System Design : Route Model

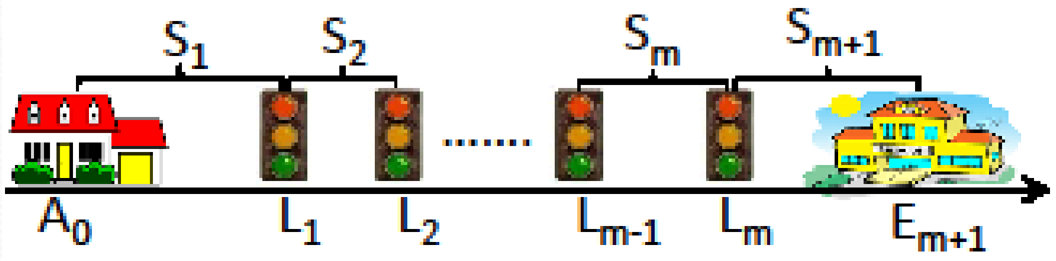
- Route *R*
  - A set of traffic lights (*L*) and road segments (*S*) in sequence



  - 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

$$D(P_j, P_{j+1}) = (t_{j+1} - t_j)(v_{j+1} + v_j)/2$$

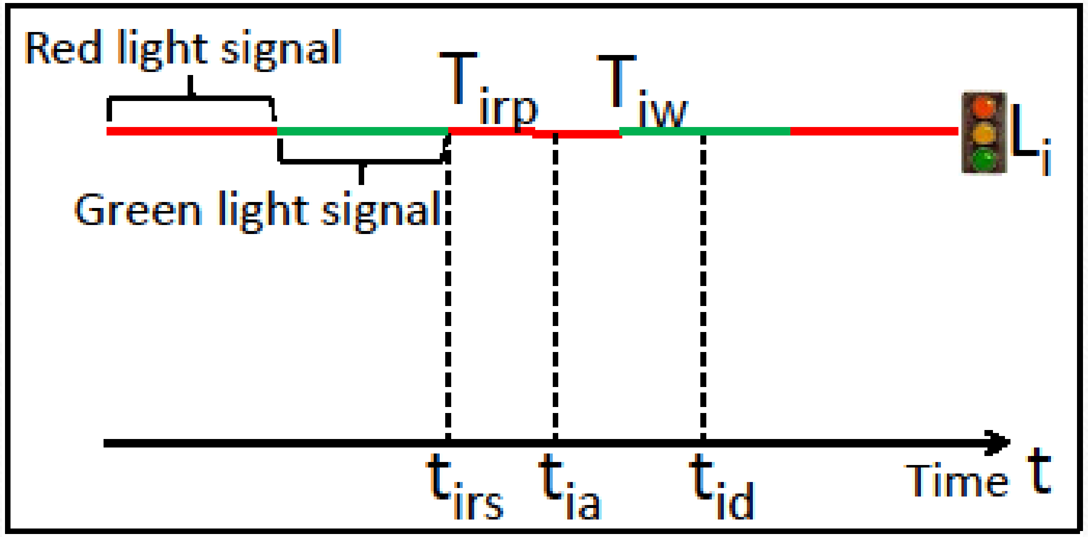
  - $(t_{j+1} - t_j)$ means the amount of time between two GPS readings
  - $(v_{j+1} + v_j)/2$ means the average speed during this period of time
  - More accurate than calculating the distance directly with two GPS positions

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 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
  - λ_{ia} and λ_{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



Waiting queue modeling

$$T_{iw} = Y_{ir} - T_{irp} + T_{irp} * \lambda_{ia}/\lambda_{id}$$
$$= Y_{ir} + T_{irp} * (\frac{\lambda_{ia}}{\lambda_{id}} - 1)$$

System Design : Deduce Information

- Waiting queue modeling
  - First, we have

$$T_{iw} = Y_{ir} - T_{irp} + T_{irp} * \lambda_{ia}/\lambda_{id}$$
$$= Y_{ir} + T_{irp} * (\frac{\lambda_{ia}}{\lambda_{id}} - 1)$$

  - Y_{ir}: the length of the red light
  - $Y_{ir} - T_{irp}$: the remaining amount of time of the red light
  - $T_{irp} * \lambda_{ia}/\lambda_{id}$: the time used by cars before the sensing car to leave the queue

System Design : Deduce Information

- Waiting queue modeling
  - On the other hand:

$$T_{irp} = (d_{is}/\bar{r})/\lambda_{ia}$$

  - 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

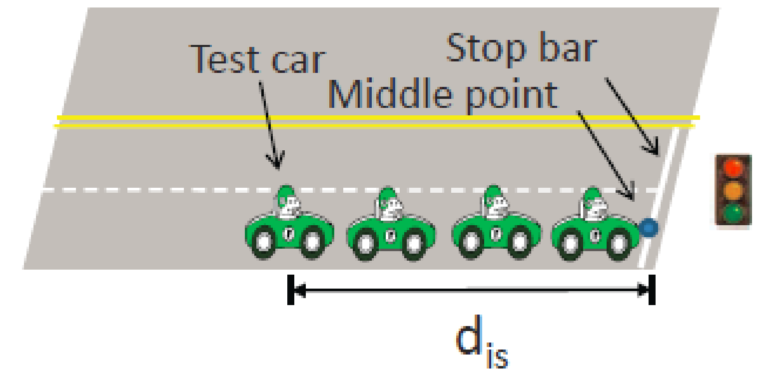


Fig. 2: Measuring waiting queue length.

System Design : Deduce Information

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

$$T_{iw} = Y_{ir} + d_{is} * \kappa_i$$

where

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

  - κ_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

$$T_{iw} = Y_{ir} + d_{is} * \kappa_i$$

where

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

  - Obtain red light length (Y_{ir}) and traffic volume (λ_{ia})
  - Use linear regression to enhance accuracy

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

$$Y_{ig} = Y_{ir} * N_g / N_r$$

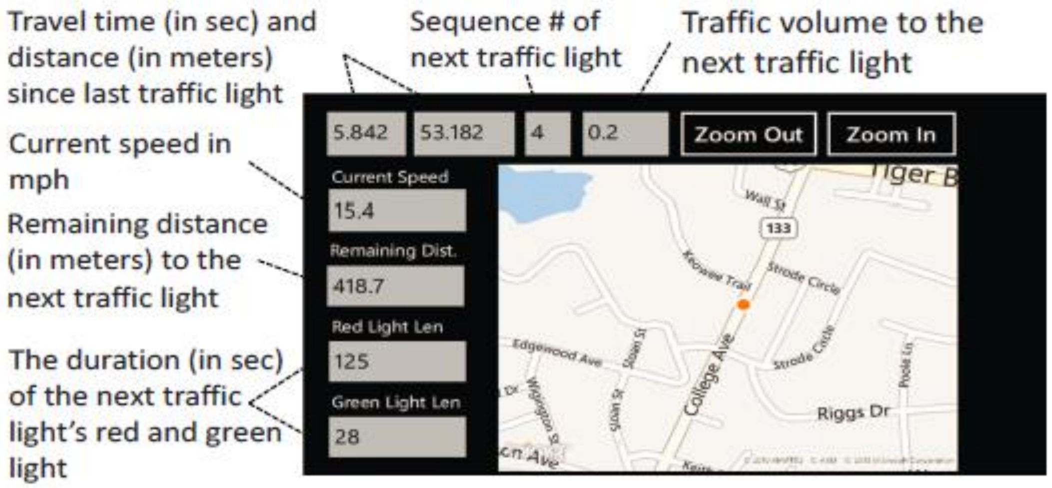
where N_g is number of green lights the car has met and N_r is the number of red lights

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

Evaluation

- Toy implementation on Windows phones

(a) Main interface.



(b) Information panel when the vehicle is on road.

Evaluation

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

TABLE II: Experiment settings.

Route	# of traffic light	Length (m)	Test period
H2C	5	1900	7:30AM - 8:10AM
C2H	5	1900	4:30PM - 5:10PM
LRt	6	4900	5:20PM - 6:00PM

Evaluation : Travel Length & Time

TABLE IV: Travel distance of each route segment (m).

Traffic light	H2C	C2H	LRt
L_1	181.6	106.7	767.8
L_2	226.6	245.4	600.6
L_3	523.6	270.3	1299.7
L_4	325	311.2	726.3
L_5	271.5	521.2	897.3
L_6	350.4	416.6	436.3
L_7	-	-	195.7
Total	1878.7	1871.4	4923.7
Actual Total	1900	1900	4900

TABLE V: Travel time of each route segment (s).

Traffic light	H2C	C2H	LRt
L_1	29.1	66.5	110.1
L_2	49.9	72.7	66.2
L_3	39.8	37.1	89.9
L_4	39.3	24.3	50.7
L_5	91.1	67.9	67.9
L_6	28.7	35.8	42.5
L_7	-	-	23.5
Total	277.9	304.3	450.8

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

Evaluation : Red Light Length

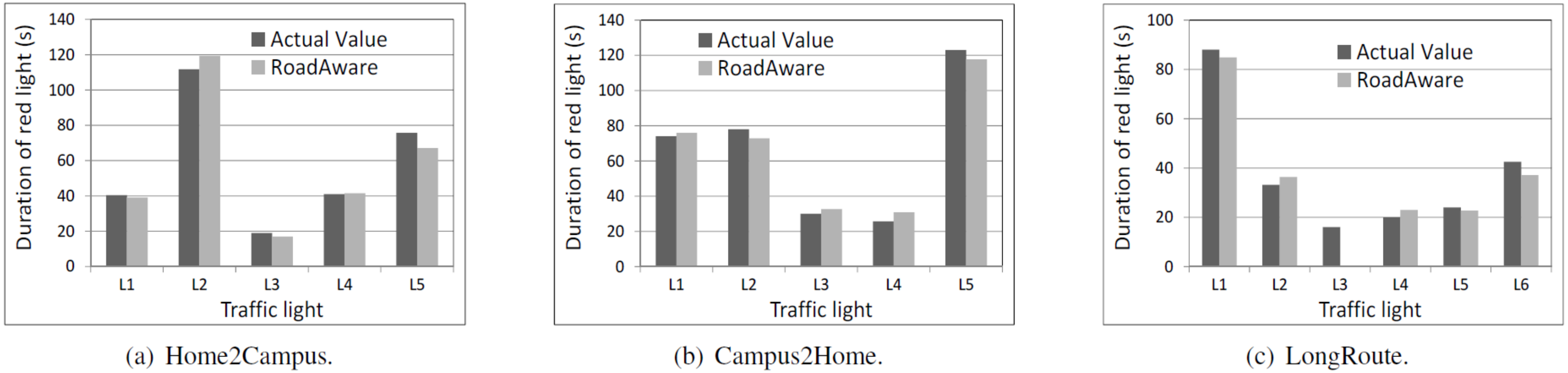


Fig. 8: The duration of red lights on the three routes.

The deduced value is close to actual value measured manually

Evaluation : Traffic Volume

TABLE VI: Traffic volume at each L_i in *Home2Campus*.

	L_1	L_2	L_3	L_4	L_5
RoadAware	0.090	0.067	0.131	0.234	0.130
Actual Value	0.102	0.072	0.140	0.232	0.119

TABLE VII: Traffic volume at each L_i in *Campus2Home*.

	L_1	L_2	L_3	L_4	L_5
RoadAware	0.068	0.218	0.243	0.244	0.116
Actual Value	0.059	0.245	0.233	0.252	0.103

TABLE VIII: Traffic volume at each L_i in *LongRoute*.

	L_1	L_2	L_3	L_4	L_5	L_6
RoadAware	0.22	0.22	-	0.12	0.14	0.12
Actual Value	0.25	0.23	0.13	0.13	0.13	0.15

The deduced traffic volume is also close to manually counted data

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?