Transportation system monitoring method by using probe vehicles that observe other vehicles

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Introduction
Transportation system
A system where travelers are traveling
- Automotive road network
- Pedestrian space
- City

Monitoring
Acquiring information on a transportation system’s dynamics
- State
  - Flow
  - Speed
- Behavior
  - Macroscopic behavior of travelers
    - System model
  - Microscopic behavior of a traveler
    - Destination/route choice (strategic)
    - Interaction between travelers (tactical, operational)
Methods for monitoring

**Eulerian observation**
Observe a system’s dynamics from fixed points in the system
- Traffic detectors
- Cameras
- Ticket transaction data

**Lagrangian observation (probe)**
Observe a system’s dynamics from floating points that move along with travelers
- GPS
Probe vehicles that observe other vehicles

Eulerian observation

- Rich information at the sensor’s installed points can be acquired
- Wide-ranging observation is difficult due to the cost of the observation

Diagram showing time, observation point, space, traffic detector, and fixed camera.
Lagrangian observation (probe)

- Information over **wide-ranging** space can be acquired
- Passive observation can acquire information **cost-efficiently**
- **Volume-related information** can not be estimated from these sampled trajectories

Probe vehicles that observe other vehicles

GPS-equipped probe vehicle

BCALs (Hato 2010)

smartphone
Summary of current monitoring methods

**Eulerian observation**
- Can acquire
  - Volume-related info. (flow, density)
  - Quality-related info. (speed, reliability)
- Can not acquire
  - Wide-ranging info. (for time and space)

**Lagrangian observation (probe)**
- Can acquire
  - Quality-related info.
  - Wide-ranging info.
- Can not acquire
  - Volume-related info.

**Problem:** How we can acquire volume-related info over a wide range?
A solution

New Lagrangian observation: Probe travelers that observe other travelers

- **Volume-related information** can be estimated, since local density is available
- Information over **wide-ranging** space can be acquired
- Can be **efficient** in traffic flow monitoring in the near future
Spacing measurement technologies

- Technologies of recognizing surrounding environment of a vehicle from an on-vehicle equipment were developed
  - Radar, Laser scanner, Monoeye/stereo camera
  - Other vehicles, road alignment

Movie source: Stein et al. (2005)
Advanced driver assistance systems (ADAS)

- record driving
- warn the driver
- semi-automation (ACC)
- full-automation (autonomous car)

- **Vehicle-to-vehicle distance** (≃ spacing) must be measured in order to achieve traffic safety

- ADAS-equipped probe vehicle data can be utilized for estimation of the volume-related variables, since spacing is inverse of local density
Supposed future traffic system

- Traffic control center (public/private organizations)
- Traffic system
- Traffic state (Flow, Density, Speed)
- Data base
- Public policies (traffic control, transp. planning)
- Commercial services (info. provision)
- Formulation
- Validate with a proof-of-concept field experiment

- ADAS
- Spacing measurement technologies
- Equip

Some **drivers** will gain benefit from ADAS by equipping the SMT

**Entire social** will gain benefit from policies and services based on the collected probe vehicle data
Motivations and Objective

Motivations

- Transportation managements will be significantly improved if it is monitored by using Lagrangian observation only
  - arterial roads, developing courtiers

- Current probe vehicles can not acquire volume-related information

- Spacing measurement technologies were practically implemented; and have potential to spread to the world in order to enable ADAS

Objective

- To develop and validate a methodology of estimating traffic state using probe vehicles with spacing measurement equipment
Traffic State Estimation method
Supposed situations

**Target road**
- One-way
- The schematics are known

**Probe vehicles**
- randomly distributed in the traffic at a certain penetration rate
- measure its position and spacing
- no measurement errors
- their characteristics and driving behavior are the same as the rest of traffic

**Target of estimation**
- Traffic state (flow, density, speed) with a certain time space resolution
Estimation method

- Traffic flow represented as a time-space diagram
  - vertical axis: space
  - horizontal axis: time
  - curves: vehicle trajectories

- The probe vehicle acquire its own trajectory and its leading vehicle’s one

- Traffic state in any closed region $A$ can be estimated from the probe vehicles’
  - distance traveled
  - time traveled
  - area of region between the probe and its leading vehicle

Based on Edie’s generalized definition (1963)
Characteristics of the method

- The method can estimate traffic state including the volume-related variables from Lagrangian observation data only.

- The method can estimate traffic state with an arbitrary time space resolution:
  - 1 min-100 m traffic state
  - hourly traffic volume of a link
  - macroscopic fundamental diagram

- The method relies on few exogenous assumptions: Data oriented approach:
  - It can be utilized for estimating behaviors in system (BinN?)
Validation with a Field Experiment
Field experiment at Tokyo

- Date/time: Sep. 24, 2013 (Fri.), 15:00 – 16:00
- Location: Cruising lane, Inner Circular Route (counterclockwise), Tokyo, Japan
- Number of probe vehicles: 20 (=3.5% penetration rate)
- Measurement devices: GPS logger and Mono-eye camera
Inner Circular Route

- Total section length: 14.2km
  - The survey area is cruising lane of 11km length section excluding tunnels

- Most of the section has two lanes and 50km/h speed limit

- It has complex traffic flow characteristic
  - curves, elevations, merging/diverging sections

- A lot of detectors are installed. Reliable ground truth data is available
  - time reso.: 1 min
  - space reso.: roughly 250m and per lane
Actual traffic state

Density as a time-space diagram
- plot color: density
- vertical axis: space
- horizontal axis: time

Probe vehicles that observe other vehicles

Toru Seo (Tokyo Tech)
Probe vehicles

- 20 standard sized passenger vehicles driven by non-professional drivers were employed as probe vehicles
  - 44 laps were performed during 1 hour
  - It corresponds to 3.5% probe vehicle penetration rate

- They measured their position and spacing with 15 s interval

- The position was measured by the GPS logger

- The spacing was measured by analyzing images taken by the camera
  - width of the leading vehicle in the images
  - actual width of the leading vehicle
  - field of view of the camera
Estimation results

- Density as time-space diagrams
- penetration rate 3.5%, time resolution 5min, space resolution with 500m
- Dynamical features of the traffic flow were reproduced – free, congestion, queue extension
Estimation results

- Error indices of various estimation scenarios
  - root mean square percentage error (RMSPE)

<table>
<thead>
<tr>
<th>penetration rate (probe per hour)</th>
<th>estimation target</th>
<th>error (RMSPE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5% (42veh)</td>
<td>5min flow</td>
<td>14%</td>
</tr>
<tr>
<td>0.2% (2veh)</td>
<td>1hour flow</td>
<td>16%</td>
</tr>
</tbody>
</table>

- High resolution information can be acquired where enough number of probe vehicles exist
  - highway traffic managements

- Lower resolution information can be precisely acquired even if the penetration rate is low
  - transportation planning
Conclusion
Achievements

- We developed a traffic state estimation method that utilize using probe vehicles with spacing measurement equipment.

- We validated the method under an actual traffic condition.

- As result, the characteristics and performance of the method were clarified.
Future plan

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References


Some images were taken form external sources