Thinking Beyond Networking in “Smart Cities”

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A smart city is an urban area that uses different types of electronic Internet of things (IoT) sensors to collect data and then use these data to manage assets and resources efficiently. This includes data collected from citizens, devices, and assets that is processed and analyzed to monitor and manage traffic and transportation systems, power plants, water supply networks, waste management, crime detection, information systems, schools, libraries, hospitals, and other community services.
Understanding city life
Transit Analytics
How do riders use the Transit System

Analyzing transit behavior
Where are most popular origin-destination pairs?
Popular times?
How long are wait times in bus stops?
Population Analytics
How is the city being used?

**Brief description**
Where are the people? What is the busiest street corner
“Where is the party tonight?”
City-scale sensing

A connected bus with Mcube sensors

Real-time check for parking spots, pedestrians, cycles, etc.

Multiple buses on roadways collecting data.
Leverage our edge platform

ParaDrop

3rd party apps/services drop into your home WiFi router on-demand
ParaDrop

• A programmable substrate

• Virtualization framework
  • “Chutes”
  • Isolated and proprietary

• Multiple wireless interfaces
  • WiFi, Bluetooth, ZigBee

• Wireless interference management and a context API
Virtualization in ParaDrop

• Uses container technology
  – LXC
  – Docker

OS level containers

App level containers
How it works?
How it works?

SeeCam cloud service

ParaDrop cloud manager

EnvSense cloud service

SeeCam

EnvSense
Example: Transcoding

- Transcode video to adapt to wireless channel conditions
Example: Caching

• Cache movies in router from head of instant queue
Additional capabilities

• A wireless context API
  – What else is happening in the wireless environment
Additional capabilities

• A wireless context API
  – What else is happening in the wireless environment
  – Where are devices located?
    • Which room?
Additional capabilities

• A wireless context API
  – What else is happening in the wireless environment
  – Where are devices located?
    • Which room?
  – Which devices are co-located?
Transit analytics
Motivation
Motivation

• Transit operator needs passenger usage information to improve the system
Motivation

• How can we get passenger usage characteristics?
• Examples of passenger usage characteristics
  – Popular origin-destination station pairs
    • Just knowing origin of passenger trip is easier --- available from farecard data perhaps, but correlating that to the destination is hard
  – Occupancy of vehicles
  – Waiting time of passengers at stations
Possible Solution: Survey?

- Needs a lot of human labor work
- Inefficient
Possible Solution: Farecard?

• Only know where passenger gets on

• Cannot infer where the passenger gets off
Possible Solution: Camera?

- Costly solution in both hardware and software
- Harder in dark conditions
Sensing based solution: Trellis

- Wireless based monitoring system
- Wireless sniffing module onboard
- GPS module
Trellis Overview

Passenger

Pedestrian
What Trellis can do?

• Identify which individual is inside the bus and who is outside (on the street or in a bus stop)

• Identify where a person gets on and where the same person gets off the bus
Implementation

• System runs on our existing ParaDrop gateways that provide WiFi service

• Deployed on a few city buses in Madison, WI
Implementation

- 4G Cellular Card
- WiFi Card
- ParaDrop Gateway
- GPS
- Power Supply
Bus Route

Region 1
Region 2
Region 3
Region 4
Region 5
Region 6
Region 7
Statistics

• Record data from two metro buses

• Collect more than 20,000 miles data in total

• Identified more than 114,000 devices over experiment period
Observations & Analytics

• Passenger Activity Trends
  – Automatic Passenger Counting
  – Transit Riding Pattern
  – Transit Scheduling Analytics

• Pedestrian Activity Trends & On-Time Performance
  – Time Impacts on Pedestrian Activities
  – On-Time Performance

• Impacts of Weather
  – Impacts on Passenger & Pedestrian Activities
Automatic Passenger Counting

- Counting number passengers get on and off to get ground truth data
- Evaluating accuracy by calculating the correlation between estimated passenger number and ground truth
- Having an average correlation of 0.76
Pedestrian Activity Trends

- Morning
- Noon
- Evening
- Night
Impacts of Weather

Quantify temperature and weather impacts on human activities
Fuel efficient driving
EcoDrive Overview

→ Automate drive actions to be fuel efficient

20% ~ 30% fuel savings

More possible if sacrificing travel time
Illustrative Example

- Conservative driver: Cruise at 15 km/h (less efficient speed)
- Aggressive driver: Accelerate to 40km/h in 1 second and cruise to the end (less efficient acceleration)
- EcoDrive: Calculate the fuel consumptions of various acceleration and cruising strategies, and use the best
EcoDrive Architecture

- Sensing OBD parameters
- Modeling vehicle forces
- Controlling air/fuel injection rate
OBD Parameters and Power

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Gas Pedal Angle</td>
</tr>
<tr>
<td></td>
<td>Angle of the gas pedal, controlled by driver</td>
</tr>
<tr>
<td>2</td>
<td>Air/Fuel Flow Rate</td>
</tr>
<tr>
<td></td>
<td>Air/Fuel injection rate, controlled by gas pedal angle</td>
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<tr>
<td>3</td>
<td>Engine RPM</td>
</tr>
<tr>
<td></td>
<td>Engine rotation speed, transit power to wheel through transmission</td>
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<tr>
<td>4</td>
<td>Vehicular Speed</td>
</tr>
<tr>
<td></td>
<td>Speed of the vehicle</td>
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</table>
Model Vehicle Forces

➔ **Engine Propulsion**
  - Function of air/fuel rate and gear ratio (estimated by vehicular speed and engine RPM)

➔ **Drivetrain loss and wind resistance**
  - Function of propulsion when driving in constant speed

➔ **Grade resistance**
  - Function of altitude changes (extracted from online elevation dataset)
Build AFR Profile (A Lookup Table)

AFR(v, a) : the air/fuel rate when accelerates at a (m/s/s) under speed v(km/h)

<table>
<thead>
<tr>
<th>Air/Fuel Rate</th>
<th>0.0 m/s/s</th>
<th>0.1 m/s/s</th>
<th>0.2 m/s/s</th>
<th>... ...</th>
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<tbody>
<tr>
<td>1 km/h</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2 km/h</td>
<td></td>
<td>AFR(2, 0.1)</td>
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<tr>
<td>3 km/h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 km/h</td>
<td></td>
<td></td>
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</tbody>
</table>
Edge Controlled Gas Pedal

➡️ Gas Pedal (drive-by-wire)

- Human driver press the gas pedal
- The position sensor senses gas pedal position
- The gas pedal sends the position value to the Electronic Control Unit (ECU)
- ECU controls the volumes of air/fuel injected into the engine

➡️ EcoDrive Controller (Emulate gas pedal)

- It calculates the gas pedal position value
- It sends the value to the ECU through an Arduino board
Dynamic Programming based Driving Strategy

- D: road segment length
- V: speed limit
- \( S(v, d) \): minimum fuel cost at distance \( d \) with speed \( v \)

\[ \text{Case 1: The car cruises to state } S(v + 1, d + 1) \]
\[ S(v + 1, d + 1) = S(v + 1, d) + \text{AFR}(v + 1, 0) \times \text{time} \]

\[ \text{Case 2: The car accelerates to state } S(v + 1, d + 1) \text{ at acceleration } ax \]
\[ S(v + 1, d + 1) = S(v, d - dx) + \text{AFR}(v, ax) \times \text{time} \]
Implementation

➔ Hardware

◆ OBD Scanner with ELM327 USB interface
◆ Arduino board converts digital gas pedal position to voltage signals

➔ Software

◆ One thread writes commands to OBD interface through serial communication
◆ One thread reads OBD parameters and write gas pedal position to Arduino board
In-vehicle Setup
Evaluation

➔ Real road test [ over 100 miles ]
  ◆ Urban: Road segments with various lengths (50-1000m)
  ◆ Highway: Various highway segments (2km each)

➔ Comparison [ Kilometer per Liter (KPL) and Travel Time ]
  ◆ Theoretical value
  ◆ Human drivers
  ◆ Cruise control
OBD Data Collection

➔ Urban: Madison and Chicago, 5000+ miles
➔ Highway: Local highways and cross-state highways, 5000+ miles
# OBD Data Collection

<table>
<thead>
<tr>
<th>No.</th>
<th>Car Model</th>
<th>Urban</th>
<th>Highway</th>
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<tbody>
<tr>
<td>1</td>
<td>Chevrolet Impala 2011</td>
<td>1051</td>
<td>852</td>
</tr>
<tr>
<td>2</td>
<td>Nissan Rogue 2011</td>
<td>1198</td>
<td>1063</td>
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<td>3</td>
<td>Subaru Forester 2011</td>
<td>651</td>
<td>757</td>
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<tr>
<td>4</td>
<td>Buick LaCrosse 2006</td>
<td>599</td>
<td>649</td>
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<tr>
<td>5</td>
<td>Volkswagen Tiguan 2014</td>
<td>600</td>
<td>347</td>
</tr>
<tr>
<td>6</td>
<td>Honda Accord 2013</td>
<td>173</td>
<td>840</td>
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<tr>
<td>7</td>
<td>Toyota Camry 2011</td>
<td>35</td>
<td>338</td>
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<td>8</td>
<td>Volkswagen Touareg 2014</td>
<td>21</td>
<td>156</td>
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<tr>
<td>9</td>
<td>Nissan Altima 2014</td>
<td>193</td>
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<td>10</td>
<td>Nissan Rogue 2011</td>
<td>105</td>
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<td>11</td>
<td>Subaru Legacy 2015</td>
<td>119</td>
<td>30</td>
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<tr>
<td>12</td>
<td>Mazda CX5 2014</td>
<td>202</td>
<td>89</td>
</tr>
</tbody>
</table>
Case Study: Cruise Control

- Cruise control: accelerate aggressively on upslope or human manipulation
- EcoDrive: gradually change air/fuel injection rate, adapt to road conditions
Travel Time vs. Fuel Efficiency

- EcoDrive achieves higher KPL than human drivers in similar travel time
- EcoDrive provides a trade-off between travel time and fuel consumption
Understanding Driving Behavior
Safe Driving Apps

DriveWell
Cambridge Mobile Telematics

DriveSafe
StateFarm
Sensing Vehicle Dynamics

Smartphone Coordinate

Vehicle Coordinate
Hard Brake Detection

![Graph showing speed and acceleration over time with markers for normal brake and hard brake.](image-url)
Turn & Lane Change Detection
Evaluating driving behaviors

- IMU sensors can provide accurate analytics on **what** motions happened during a drive
  - Hard brakes, sudden lane changes, etc.

- Data from IMU sensors does not answer **why** the driver acted in that manner
  - Driver distraction, surrounding traffic, etc.
Also assist driver in difficult scenarios
Drive Analytics using Audio Visual Sensors

1. Motion Sensors
   - Detecting driving events through motion sensors, e.g. accelerometer, gyroscope, magnetic field sensor, GPS

2. Visual-Audio Sensors
   - Monitoring driver behaviors and surrounding traffic through audio-visual sensors, e.g. camera, microphone

3. Evaluate Driving behaviors
   - Augment driving behavior analysis by combining motion and visual-audio sensors
DriveAQ Architecture

Sensing

- Phone
- Event Detection
  - IMU, GPS
- Front View Monitoring
  - Camera
- Head Pose Monitoring
  - Camera
- Blind Spot Monitoring
  - Left-side Camera
  - Right-side Camera
- Turn Signal Monitoring
  - Camera
- Microphone

Analysis

- Context Analysis
  - Blind Spot Monitoring
    - Pedestrian, Biker
    - Car, Truck
- Front View Analysis
  - Traffic Lights
  - Traffic Signs
  - Car, Truck
- Turn Signal Usage
- Head Pose Estimation

Activity Evaluation

Extracted Context Information

Driving Behavior Evaluation

Cloud Server

Go, Fair, Poor
Why Processing Data at Edge?

- Large volume of data

- Many vehicles need to stay on the road for long and contiguous periods of time

- Opportunities to offload the data to remote data centers are infrequent and inconvenient.
Hardware

Nvidia Jetson TX2
USB Camera
Phone
Object Detection

- Face detection and head pose estimation
- Objects in blind spots
  - Vehicles and pedestrians
- Objects in front view
  - Traffic signs, vehicles, bikers, and pedestrians
Car, Traffic Light, Speed Limit, Cyclist, Collision Zone
Driving Activity Evaluation

• Develop deep understanding of each activity by combining information acquired from multiple sensors
  – Motion sensors, cameras, and microphone
• Use a decision tree for driving behavior evaluation
  – Turn, lane change, and hard brake
• Take different factors into consideration for different activities
  – E.g., five factors for lane change, they are front and rear vehicle distance, turn signal usage, head pose and maneuver duration
Right Turn
Steps for making a right turn

1. Check Right Wing Mirror
   - Using camera to track driver’s head poses

2. Check Right Blind Spot
   - Using camera to track driver’s head poses

3. Turn on Turn Signal
   - Using microphone to track turn signal usage

4. Make a Right Turn
   - Using gyroscope to identify right turn
Ridesharing and Electric Vehicles

Prototype UEV from Innova

Coverage area

Connectivity for UEV

UEV
Innova UEV

First mile, last mile shared mobility
100% Electric Vehicle with WiRover (4G LTE + WiFi) and app/cloud connectivity
Max Speed: 35 mph

up to 150 miles per charge

Rechargeable: from 20%-80% battery in less than 30 min

Trunk Capacity: 5 grocery bags + 2 bookbags
Net zero
On-demand

Rent, unlock and go.

Autonomous

Ride Share
Creating an end-to-end ecosystem

Reserve

Refine

Authenticate & Messaging

Charge aware
Charging of EVs

- What happens when all vehicles try to charge themselves in the evening?
- Can we use networking principles
  - Backoff
  - AIMD
Numerous challenges in city-scale sensing

A connected bus with Mcube sensors

Multiple buses on roadways collecting data.

Real-time check for parking spots, pedestrians, cycles, etc.
Some challenges

• What to sense?
  – Position, Video, Audio, LIDAR, RADAR and ranging
  – What else?

• Collect data from vehicles, roadside, pedestrians

• Can we upload and share all of the data?
  – Unlikely, and why is it important?
Data sharing

• Best to share processed data
• Need edge analytics inside the vehicle and elsewhere to create vectorized content, or summaries

• Can we trust the data from others?
Consider two vehicles

• They want to share data

• If vehicle A processes the data, does vehicle B trust it?

• If vehicle A has a fancy algorithm to process the data, why should A provide this capability to B for free?
A hare, a boar, and two vehicles
Who owns the data?

• Vehicle owner
• Auto manufacturer (has liability implications)
• Mandatory to share with the government?

• Sharing data has specific issues
  – Privacy
  – Security (can a vehicle share data with a vehicle it does not know or trust)
Incentives: Who to share with?

• Share more with vehicles of same manufacturer
  – Vehicles of the same type can do better platooning
  – Competitive advantage

• May prefer to share with its own infrastructure, so that some secure architecture can decide who to share with next

• Maybe share with other vehicles to increase own safety, e.g., braking vehicle informs of obstacle to vehicle behind

• Could be credits of some type for playing well (sharing)

• Cooperative driving requires some sharing and should it be mandated by regulators?
Summary

• Lots of opportunities in this space

• Networking folks can help