6.808: Mobile and Sensor Computing aka IoT Systems

http://6808.github.io

Lecture 9: The Pothole Patrol

The Two Lecture Series

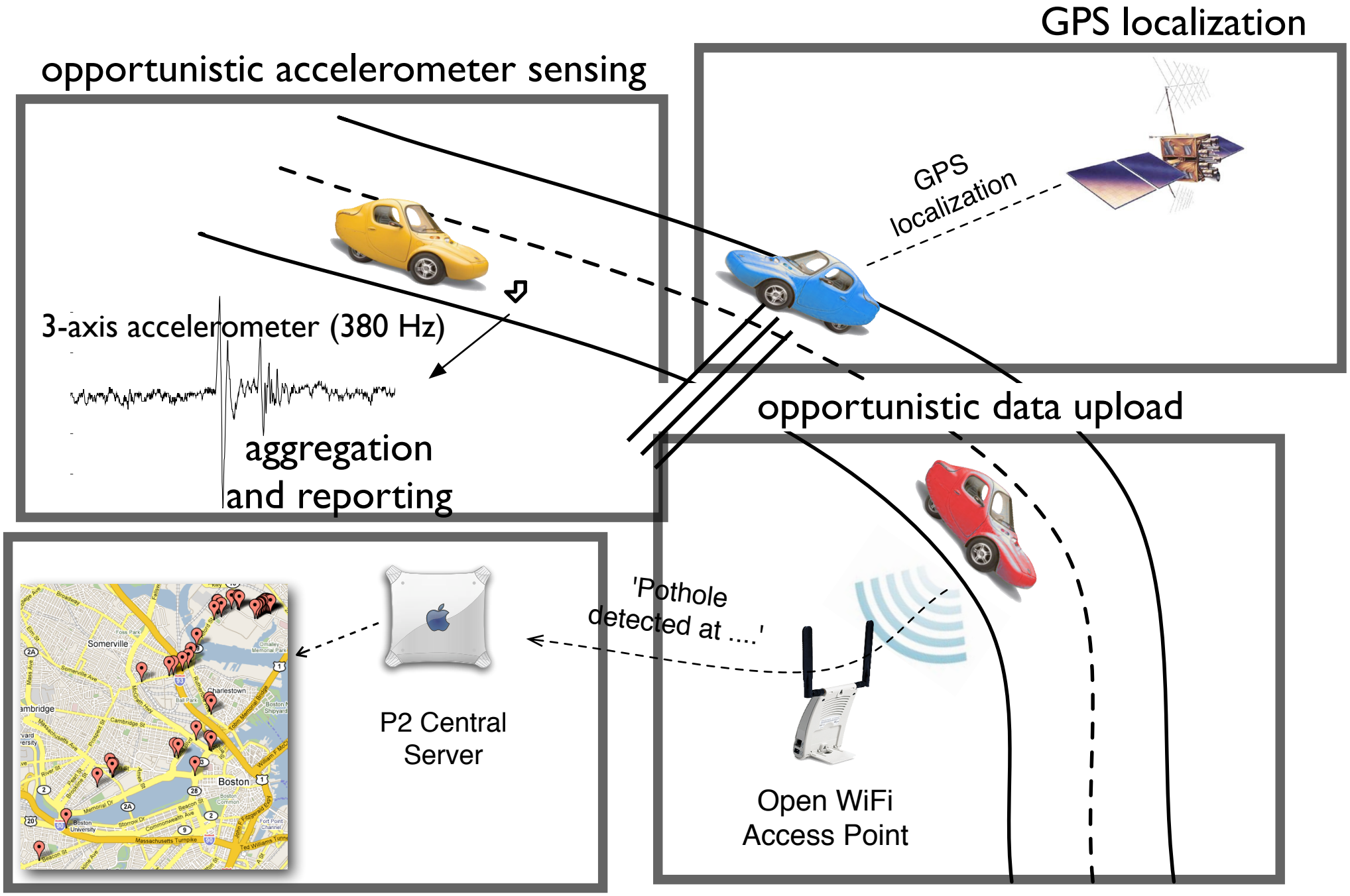
Fundamentals & Applications of Inertial Sensing

1. What are the fundamentals of inertial sensing? ✓
2. How does dead-reckoning work? And how do strap-down navigation systems operate? ✓
3. Case-study based application of inertial sensing: Pothole patrol
4. Practical approaches to combating sensory noise in real-world settings

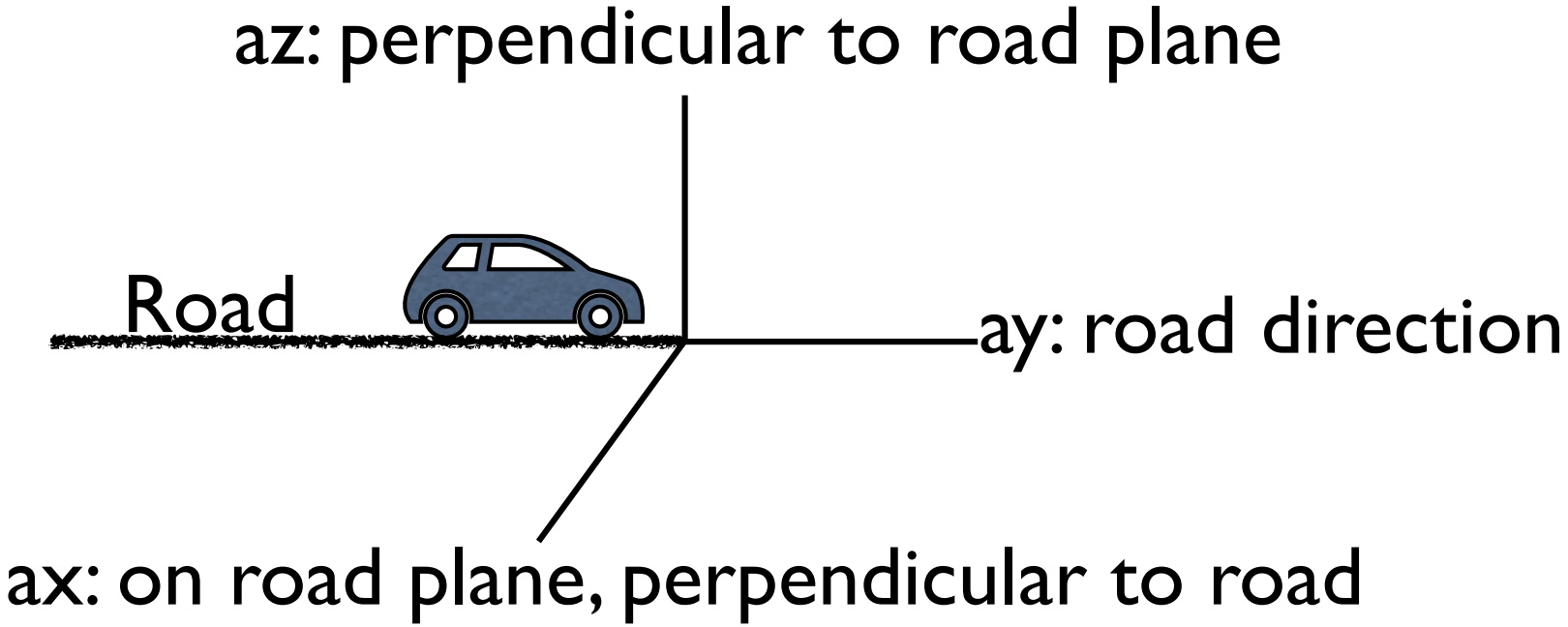
this lecture

- road decay unavoidable, hard to predict
- current monitoring methods costly/ineffective

the Pothole Patrol



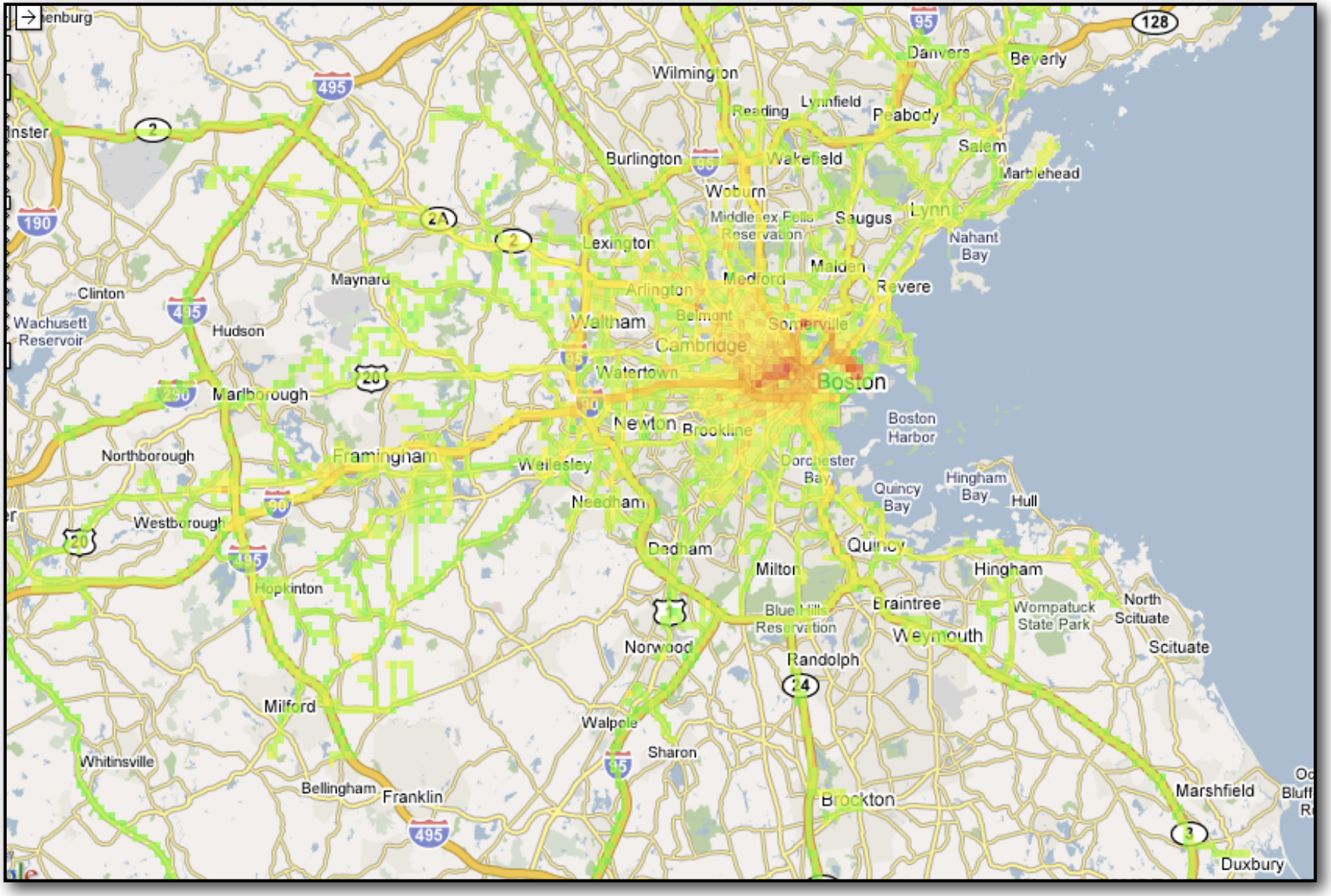
Acceleration vector

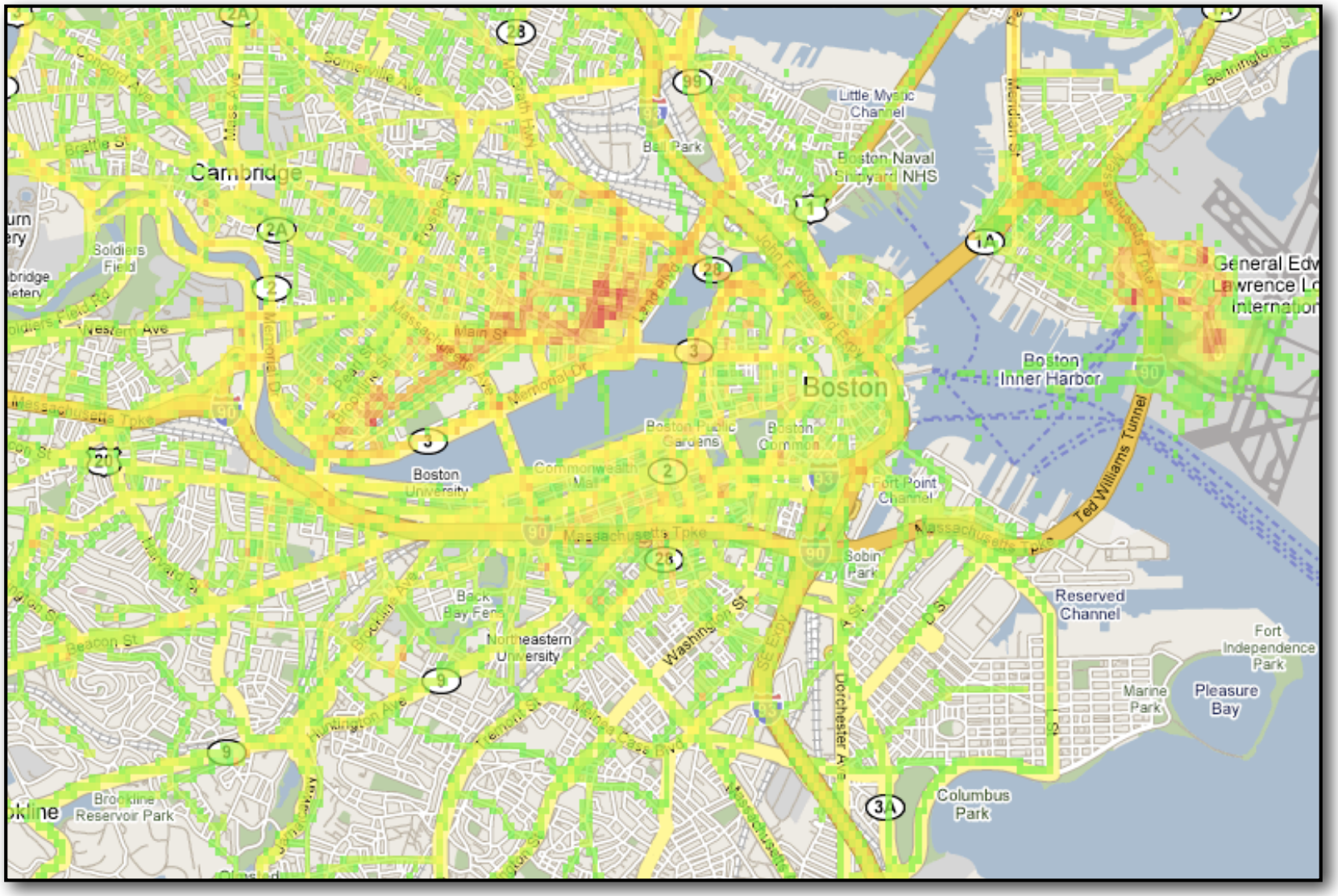


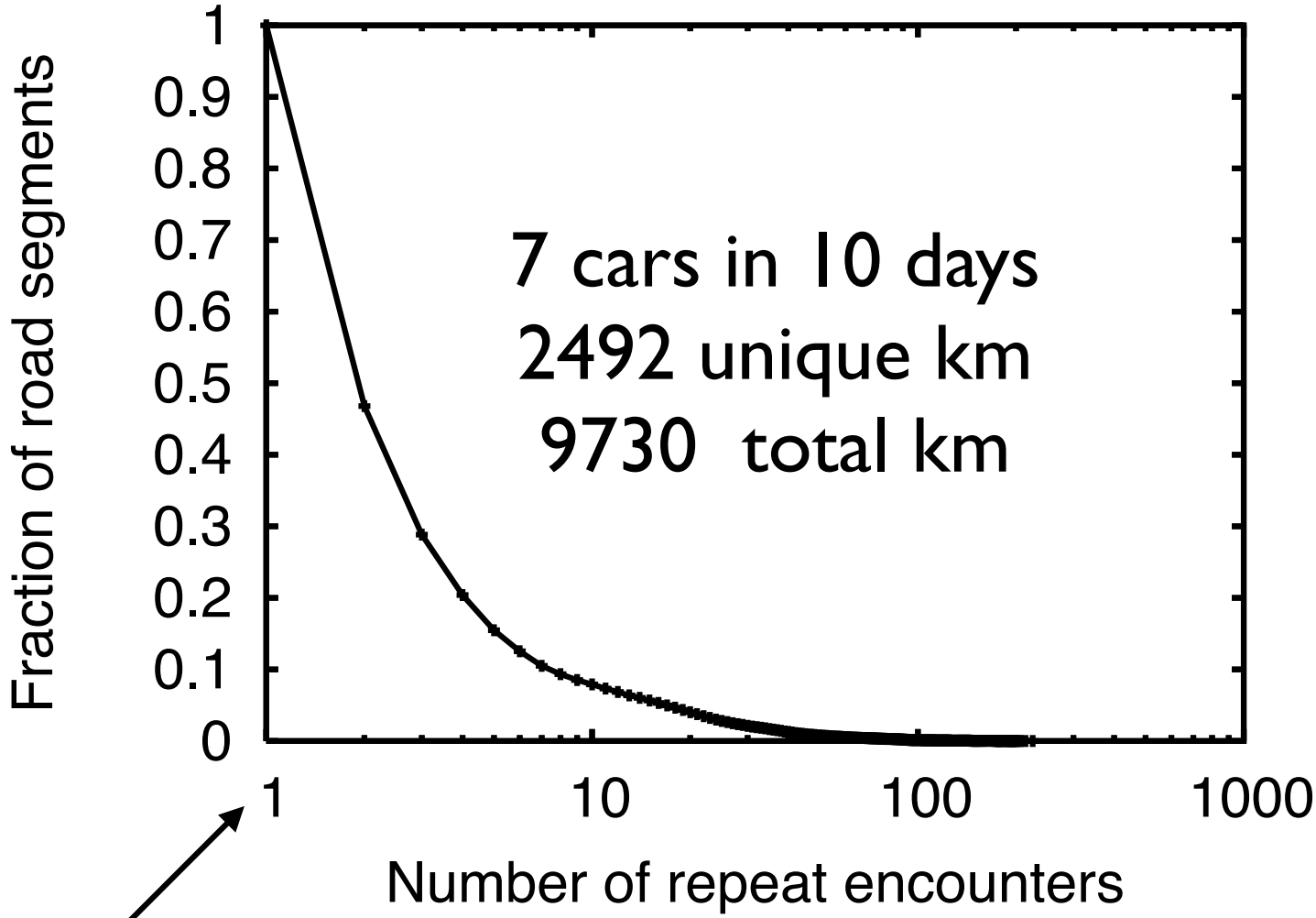
experimental platform

- 7 Boston/Cambridge taxis
- small computer in glove box
- 380 Hz 3-axis accelerometer
- 802.11a/b/g wireless interface
- GPS receiver on roof
- <time,location,heading,speed,ax,ay,az>

wide-area sensing

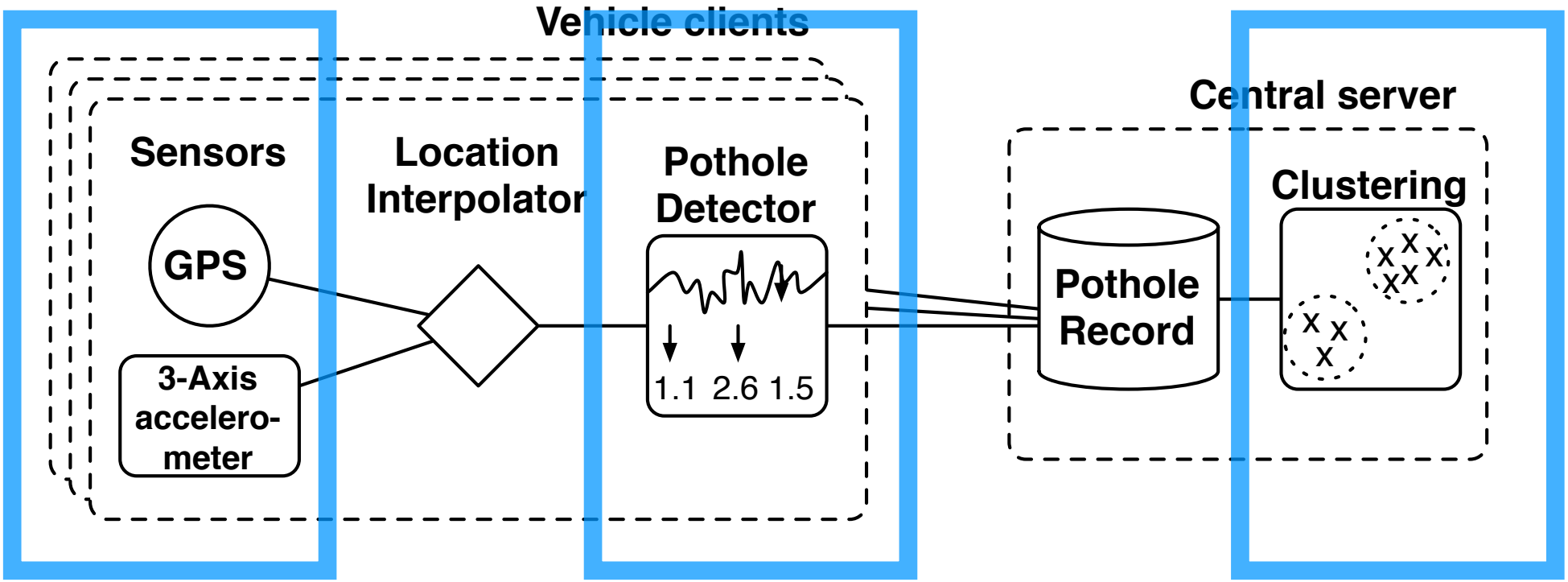



Cambridge
Boston
Boston Inner Harbor
Boston Naval Shipyard NHS
Little Mystic Channel
Soldiers Field
Boston University
Boston Public Gardens
Boston Common
Commonwealth Mall
Fort Point Channel
Reserved Channel
Sobin Park
Back Bay Fens
Northeastern University
Brookline Reservoir Park
Marine Park
Pleasure Bay
Fort Independence Park
Columbus Park
Ted Williams Tunnel
Massachusetts Turnpike
Memorial Dr
Main St
Western Ave
Washington St
Dorchester Ave
McGrath Hwy



appear at least once

P² architecture



sensor placement

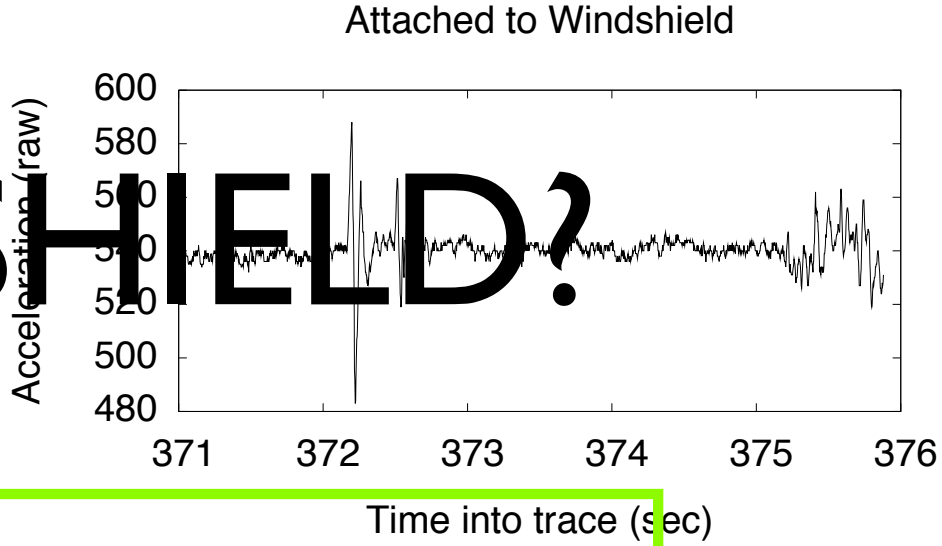
Pros? Cons?

- highly accurate
- difficult mounting
- extreme exposure

try to stay inside vehicle

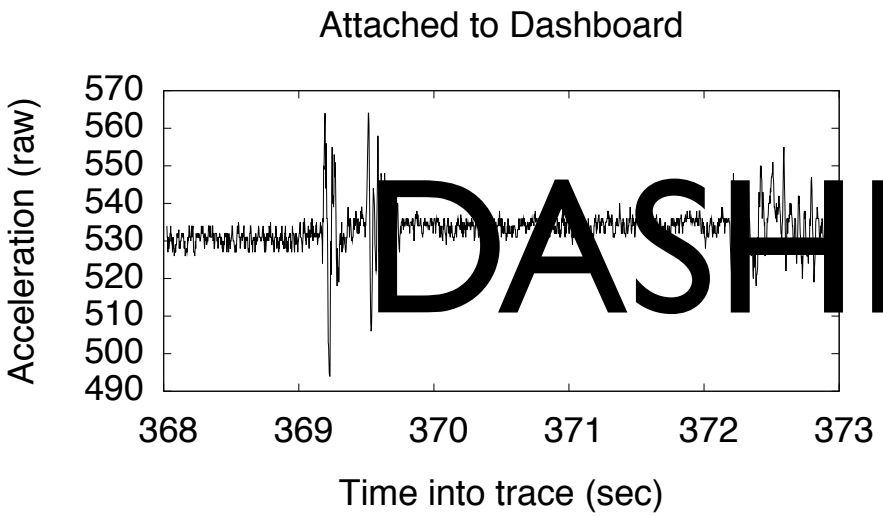
- very clean signal
- 'gold standard'
- "in the way" (if large device)

WINDSHIELD?



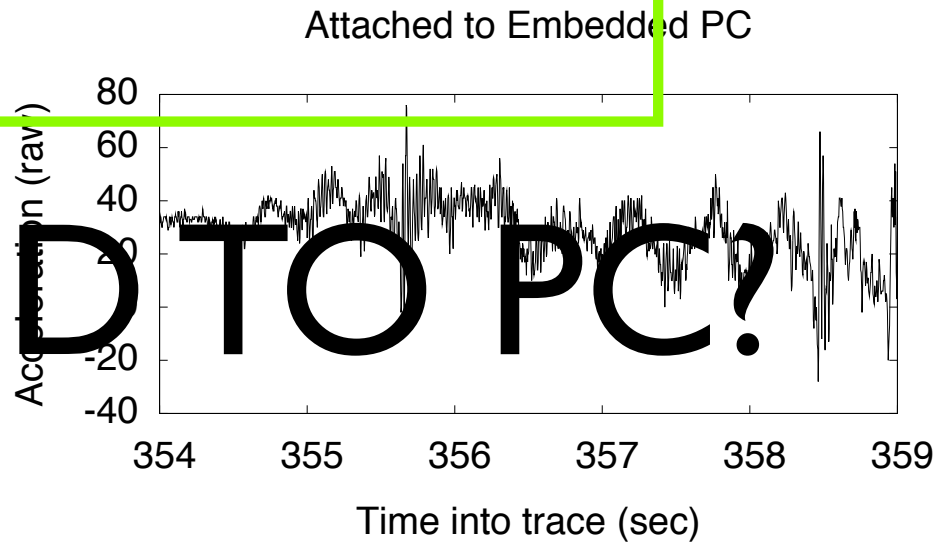
DASHBOARD?

- good signal
- easy to mount?
- "out of the way"



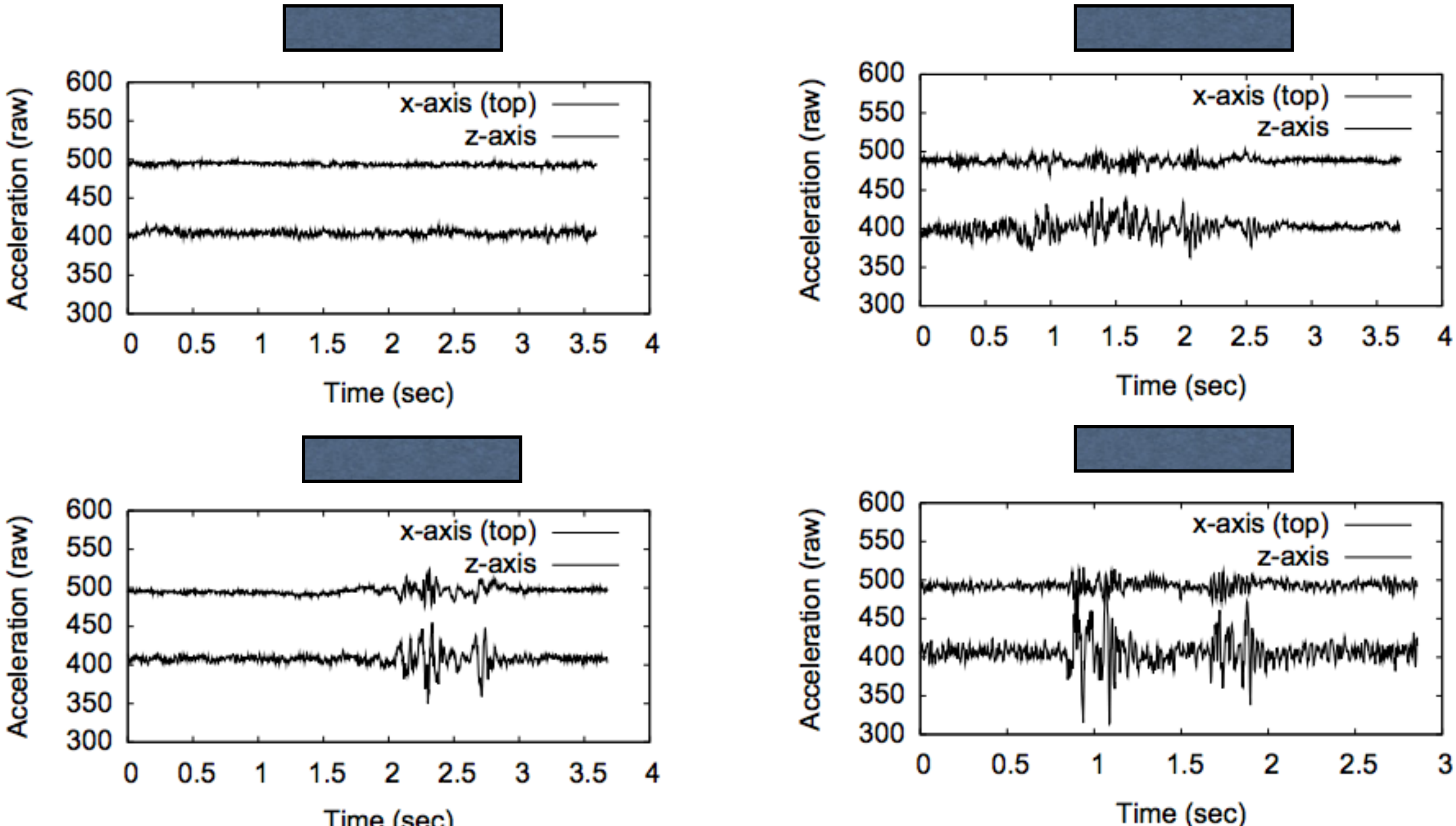
ATTACHED TO PC?

- ~~poor signal~~
- ~~no mounting necessary~~



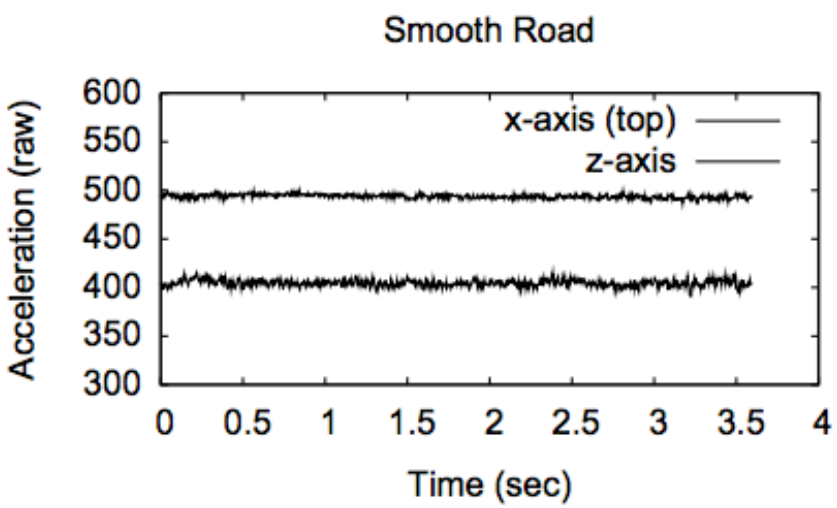
pothole v. not pothole

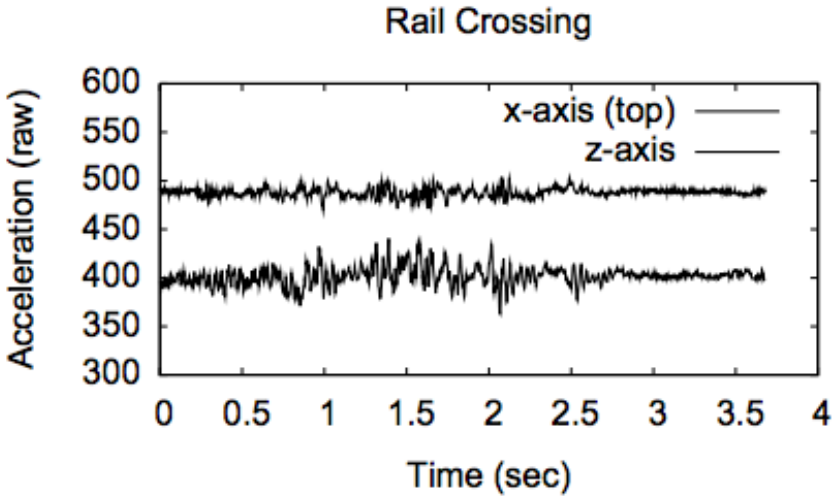
challenge: “pothole” v. “not pothole”

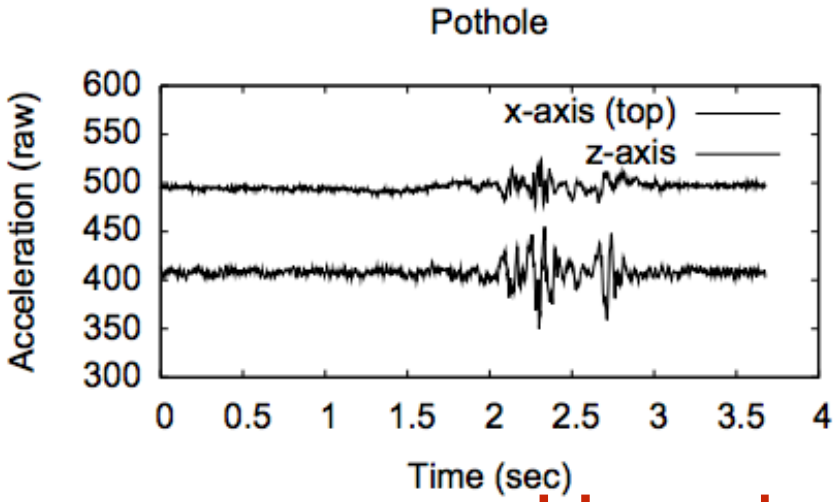


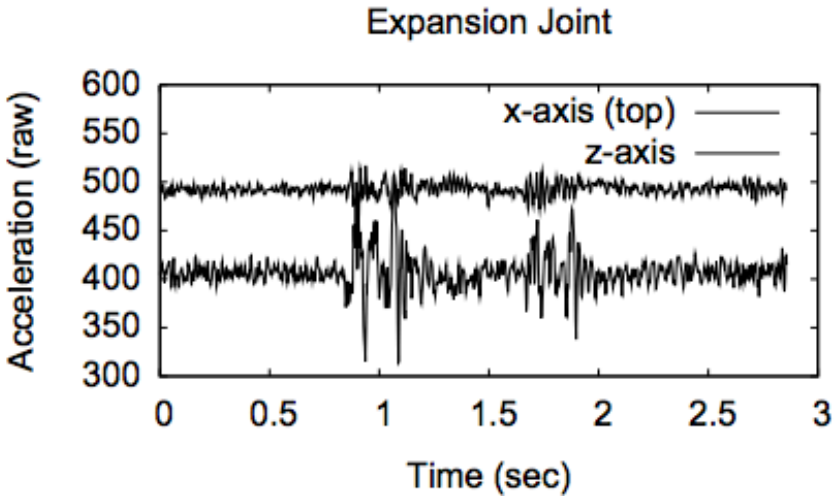
How do we identify pothole vs others?

challenge: “pothole” v. “not pothole”

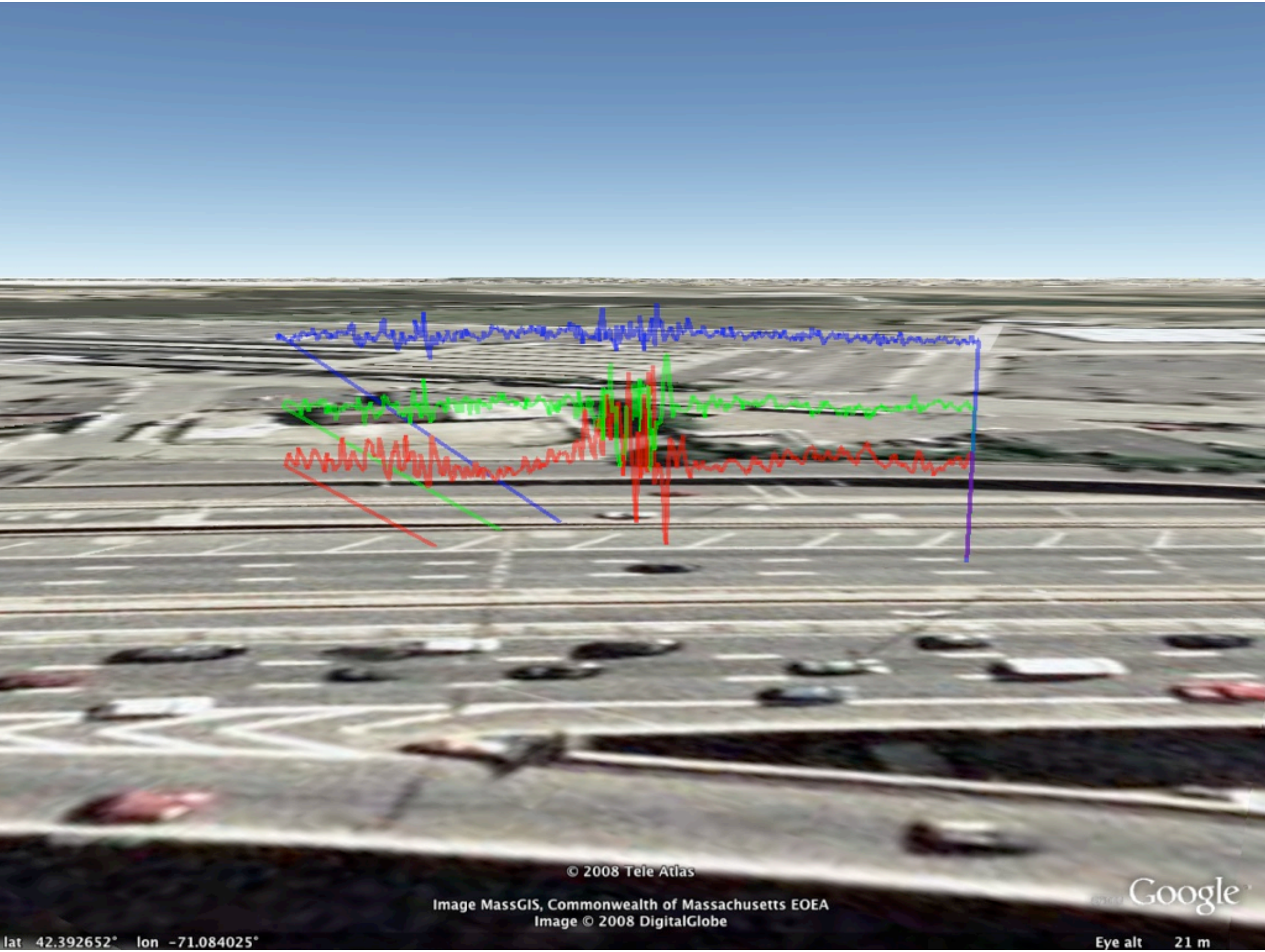








How do we identify pothole vs others?

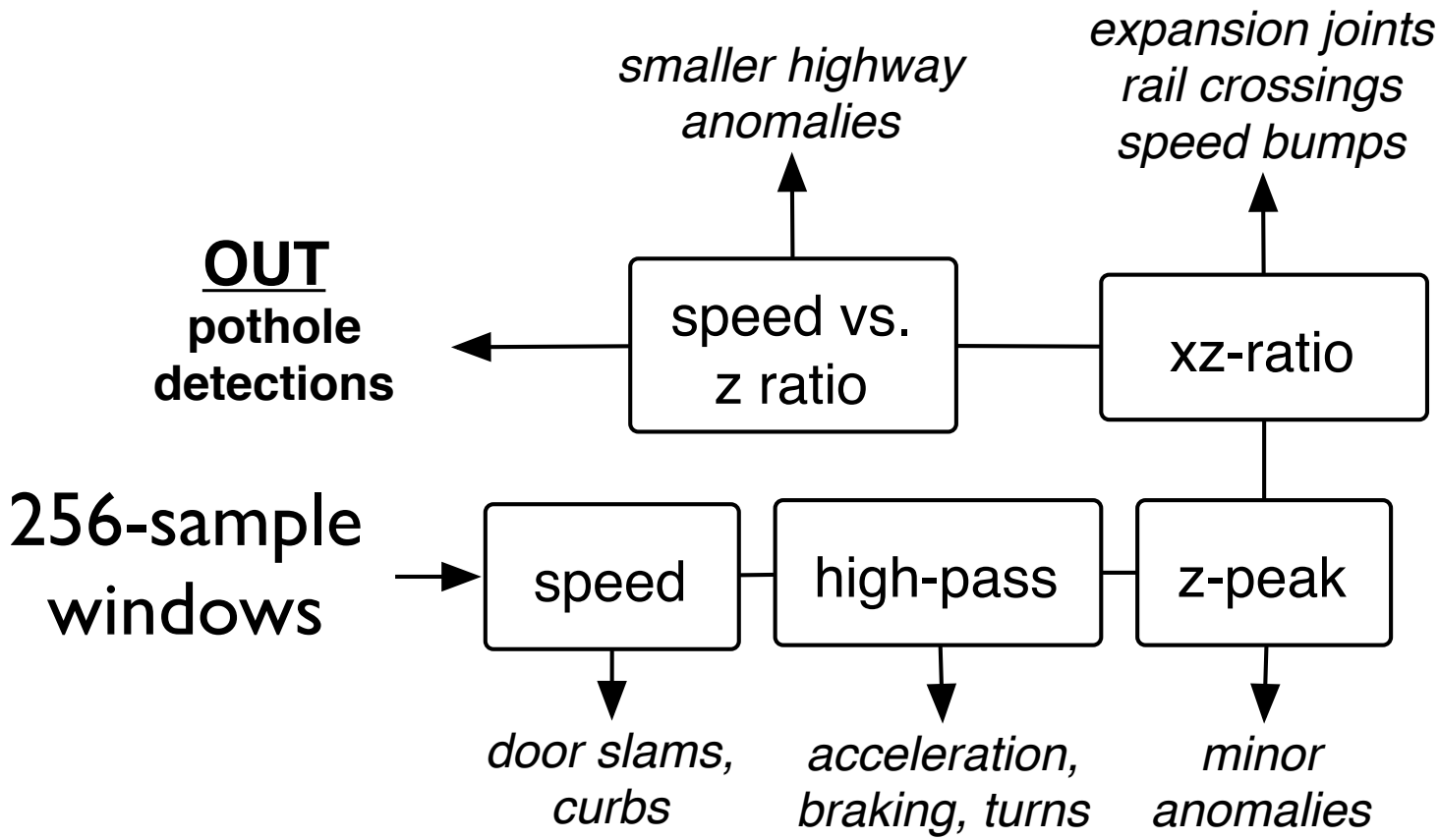

© 2008 Tele Atlas
Image MassGIS, Commonwealth of Massachusetts EOEA
Image © 2008 DigitalGlobe
Google
lat 42.392652° lon -71.084025°
Eye alt 21 m

P^2 detector

256-sample
windows

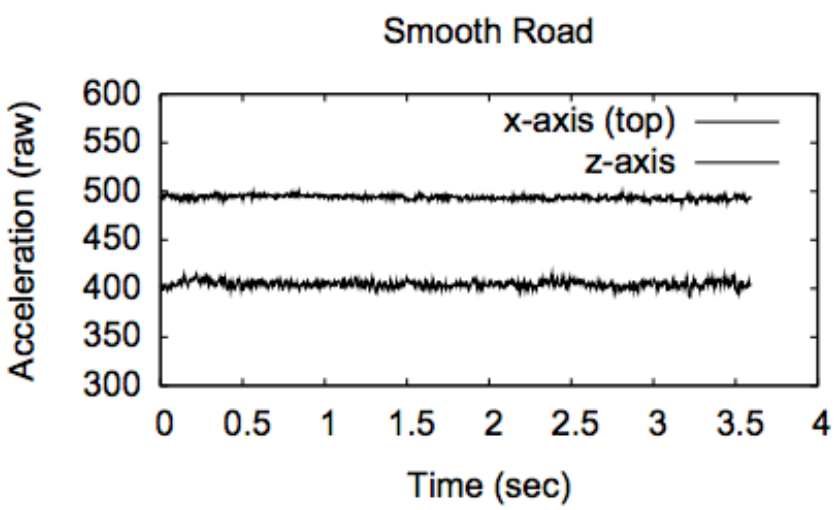
Events usually of much shorter duration than 256 samples

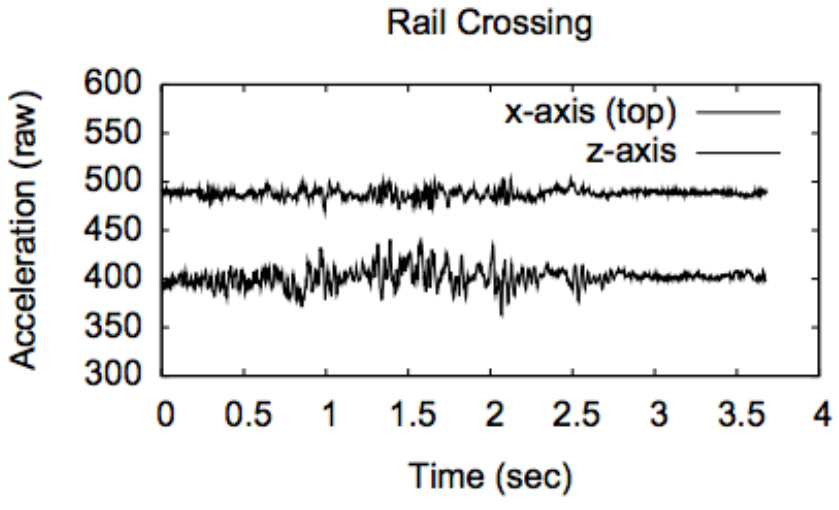
P² detector

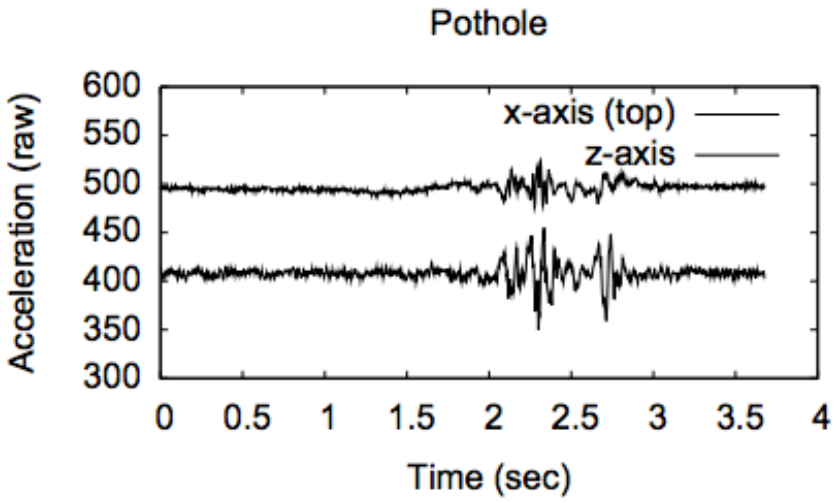


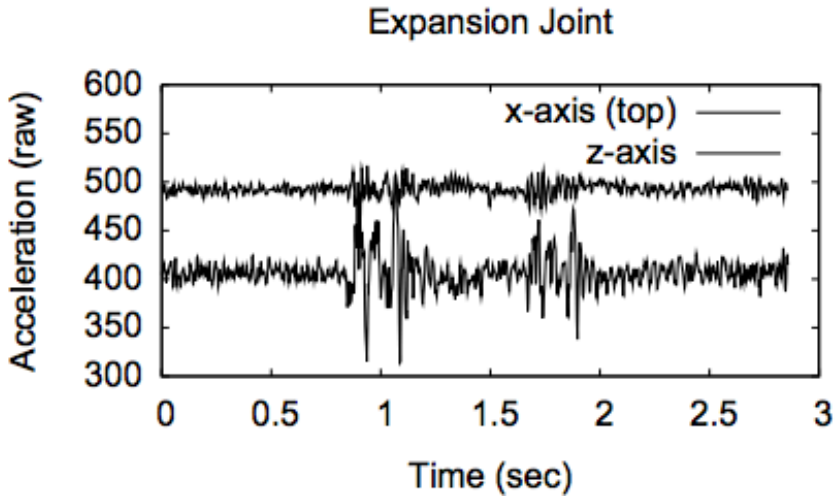
Events usually of much shorter duration than 256 samples

Need to learn threshold parameters (will come back to it later)

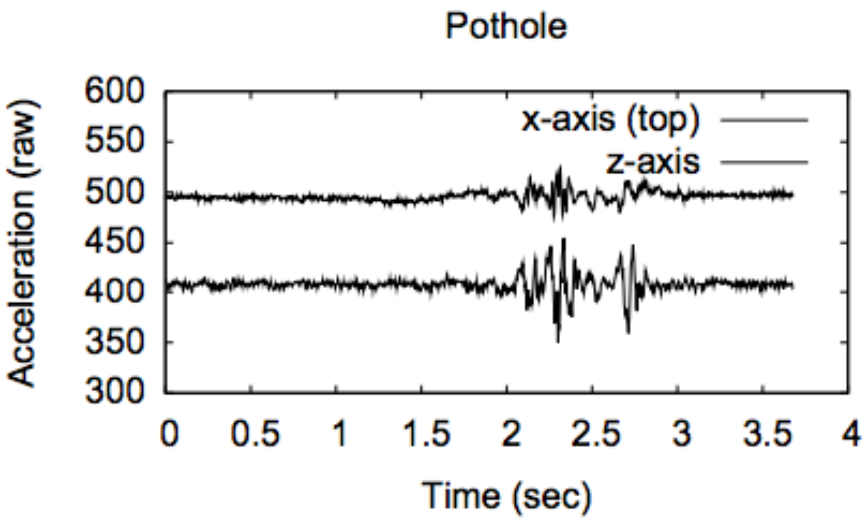

Smooth Road
Acceleration (raw)
600
550
500
450
400
350
300
x-axis (top)
z-axis
0
0.5
1
1.5
2
2.5
3
3.5
4
Time (sec)

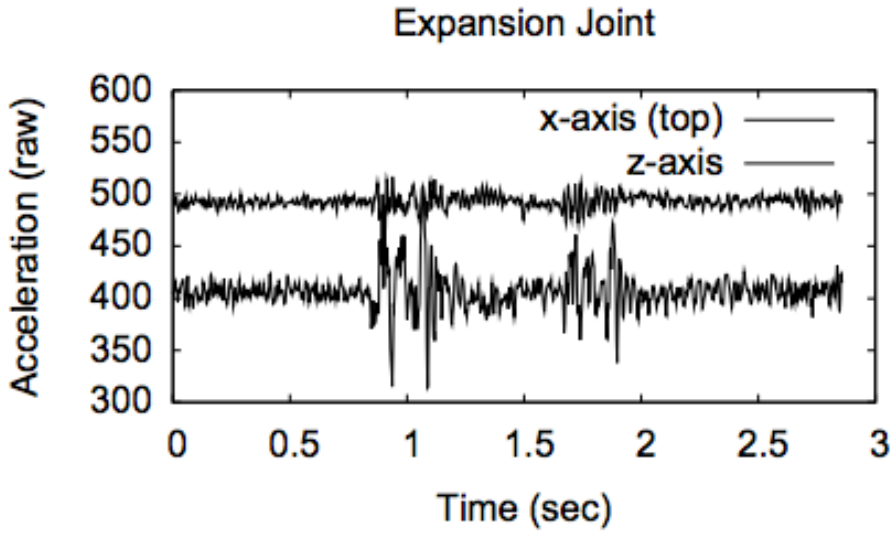

Rail Crossing
Acceleration (raw)
600
550
500
450
400
350
300
x-axis (top)
z-axis
0
0.5
1
1.5
2
2.5
3
3.5
4
Time (sec)


Pothole
Acceleration (raw)
600
550
500
450
400
350
300
x-axis (top)
z-axis
0
0.5
1
1.5
2
2.5
3
3.5
4
Time (sec)


Expansion Joint
Acceleration (raw)
600
550
500
450
400
350
300
x-axis (top)
z-axis
0
0.5
1
1.5
2
2.5
3
Time (sec)

x-z ratio “high enough”





hand-labeled training data

- **Smooth road (SM)**: Segments of road surface that are considered smooth.
- **Crosswalks and Expansion Joints (CWEJ)**: Crosswalks using extra-thick paint, brick, strips of pavers, or raised dots. Metal expansion joints in bridges and overpasses.
- **Railroad Crossing (RC)**: Train tracks. Such crossings can be jarring, and are sometimes confused for a disturbed road surface.
- **Potholes (PH)**: Missing chunks of pavement, severely sunk in or protruding manhole covers, other significant road surface anomalies.
- **Manholes (MH)**: Manhole covers and other equipment in the road that are nearly flush with the road surface. Moderate cracking, sinking or bulging.
- **Hard Stop (ST)**: A rapid deceleration, sometimes with the familiar jerk at the end.
- **Turn (TU)**: Turning a corner. This sometimes exhibits a rather violent acceleration profile.

training the detector

- manually label training samples

Type	Count	Percentage
Smooth road (SM)	64	23%
Potholes (PH)	63	23%
Manholes (MH)	59	21%
Railroad Crossing (RC)	18	6%
Crosswalk/Exp. Joint (CWEJ)	76	27%

loosely-labeled training

- needed to avoid over-training with unrepresentative manually curated data

- under-samples “smooth” roads
  - **Storrow Dr.** Heavily used four-lane parkway on the Boston side of the Charles River with several bridges, some potholes.
  - **Memorial Dr.** Heavily used four-lane parkway on the Cambridge side of the Charles River, good condition.
  - **Binney St.** A two-lane street with many sunk-in manholes and sealed cracks, one pothole.
  - **Hwy I-93** An 8 lane interstate highway that cuts through the center of Boston in good condition.
  - **Beacham St** A heavily trafficked back road in very poor condition.

training the detector

- pick an objective function

$$s(\mathbf{t}) = corr - incorr^2$$

$$s(\mathbf{t}) = corr - incorr_{labeled}^2 - \max(0, incorr_{loose} - count_r).$$

- optimize over 3 threshold parameters
  - z-peak
  - xy-ratio
  - speed vs. z-ratio

detector performance

Among the segmented reported as potholes by the algorithm

After training on loosely labeled data

Class	before	after
Pothole	88.9%	92.4%
Manhole	0.3%	0.0%
Exp. Joint	2.7%	0.3%
Railroad Crossing	8.1%	7.3%

E.g., 7.3% of detected "potholes" are railroad

Note: Actual false positive rate is not 7.6%

Why?

estimating false +ve rate

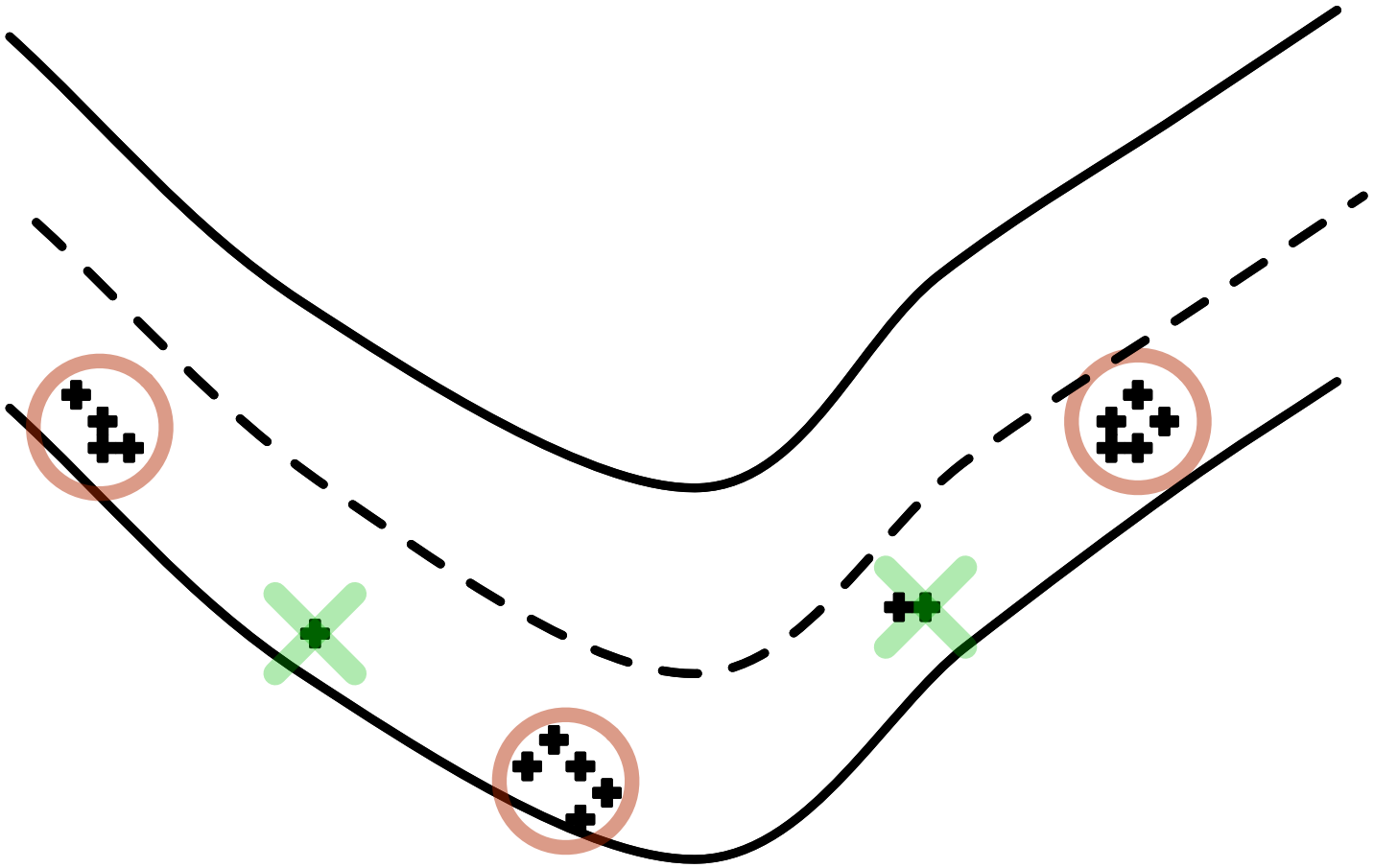
Road	# potholes	#win	#det.	rate
Storrow Dr.	few	1865	3	0.16%
Memorial Dr.	few	1781	2	0.12%
Hwy I-93	few	2877	5	0.17%

# of sample windows

# of detections/ # windows

upper bound on FPs

clustering

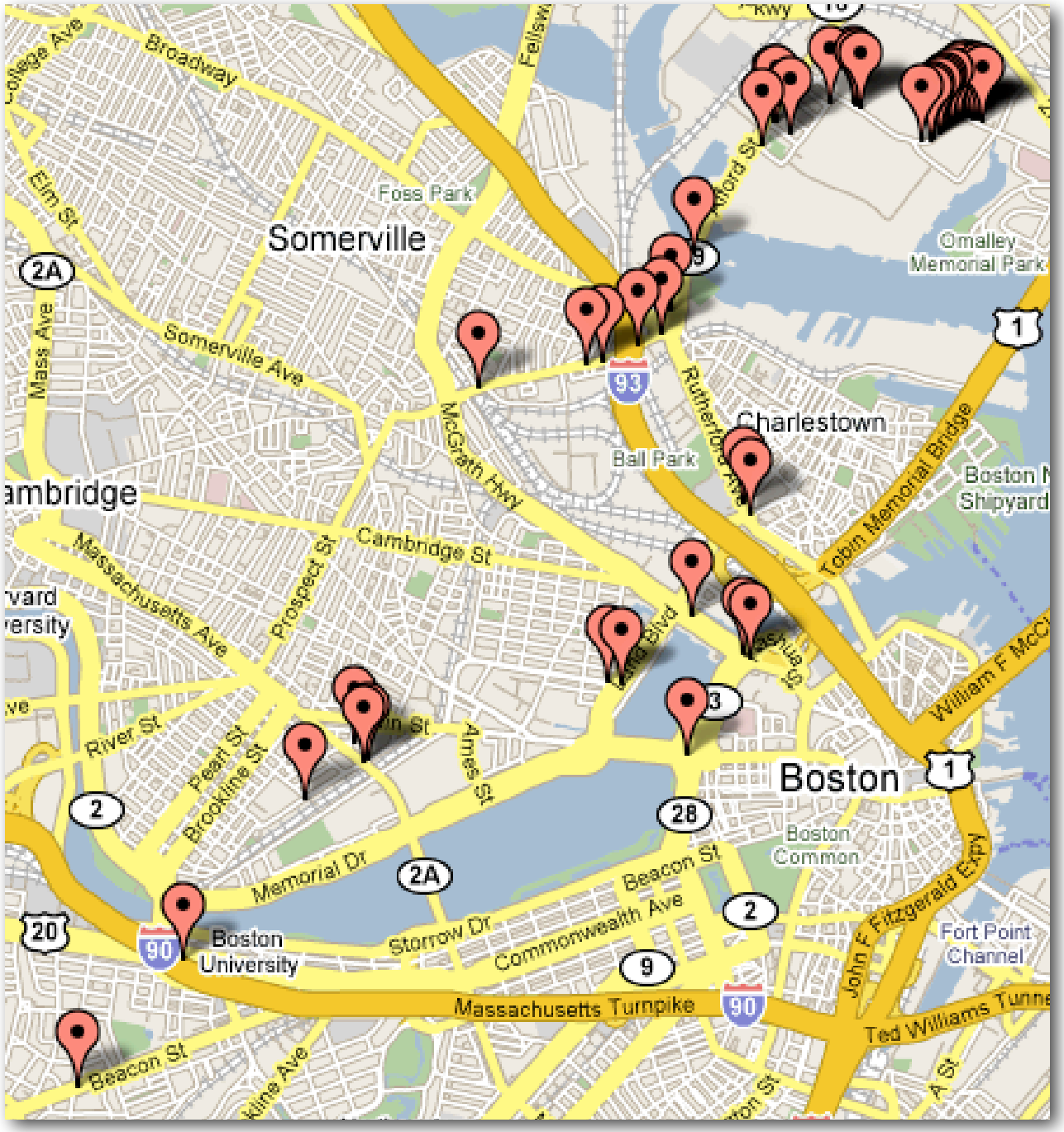


experiments

- 7 taxis over 10 days
- 9730 total km of road covered
- 2492 unique km of road covered
- 1.4 million sample windows
- 4131 severe detections
- **2709** unique locations (after clustering)

48 spot-checks

potholes	39
sunk-in manholes	3
railways and exp. joints	4
undetermined	2


Somerville
Foss Park
Broadway
Elm St
Mass Ave
Somerville Ave
McGrath Hwy
Cambridge St
Prospect St
Massachusetts Ave
River St
Pearl St
Brookline St
Ames St
Memorial Dr
Storrow Dr
Boston University
Beacon St
Commonwealth Ave
Massachusetts Turnpike
Charlestown
Ball Park
Rutherford Ave
Tobin Memorial Bridge
O'malley Memorial Park
Boston
Boston Common
Beacon St
John F Fitzgerald Expy
Fort Point Channel
Ted Williams Tunnel
William F McC
2A
93
1
2
28
20
90
9
3

P²: the Pothole Patrol

- automatic wide-area road-quality monitoring
- use of opportunistic mobility
  - mobile sensing w/ delay-tolerant communication
  - machine learning classifier with labeled and loosely-labeled data
  - Data collection and curation is hard!
- low-cost approach to help solve a costly problem

The Two Lecture Series

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1. What are the fundamentals of inertial sensing? ✓
2. How does dead-reckoning work? And how do strap-down navigation systems operate? ✓
3. Case-study based application of inertial sensing: Pothole patrol ✓
4. Practical approaches to combating sensory noise in real-world settings. ✓

Projects

Students have most fun & learn most from the projects

- All projects involve system implementation
- Ideal group size: 3
- We'll suggest project ideas; you should also feel free to choose your own projects

Timeline (check 6.808 web site):

- Proposal (1-2 pages): March 16 (Wednesday)
  - Meet on March 30 and April 4 (during class) to give feedback
  - Last 3 weeks of classes: dedicated to project meetings
- Demos and presentations: May 9