



6.1820/MAS.453: Mobile and Sensor Computing aka IoT Systems

<https://6mobile.github.io/>

Lecture 9: The Pothole Patroll

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Announcements

1. Shared project ideas and inventory list. Start forming teams!
2. Lab 3 due next Tuesday, March 17

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

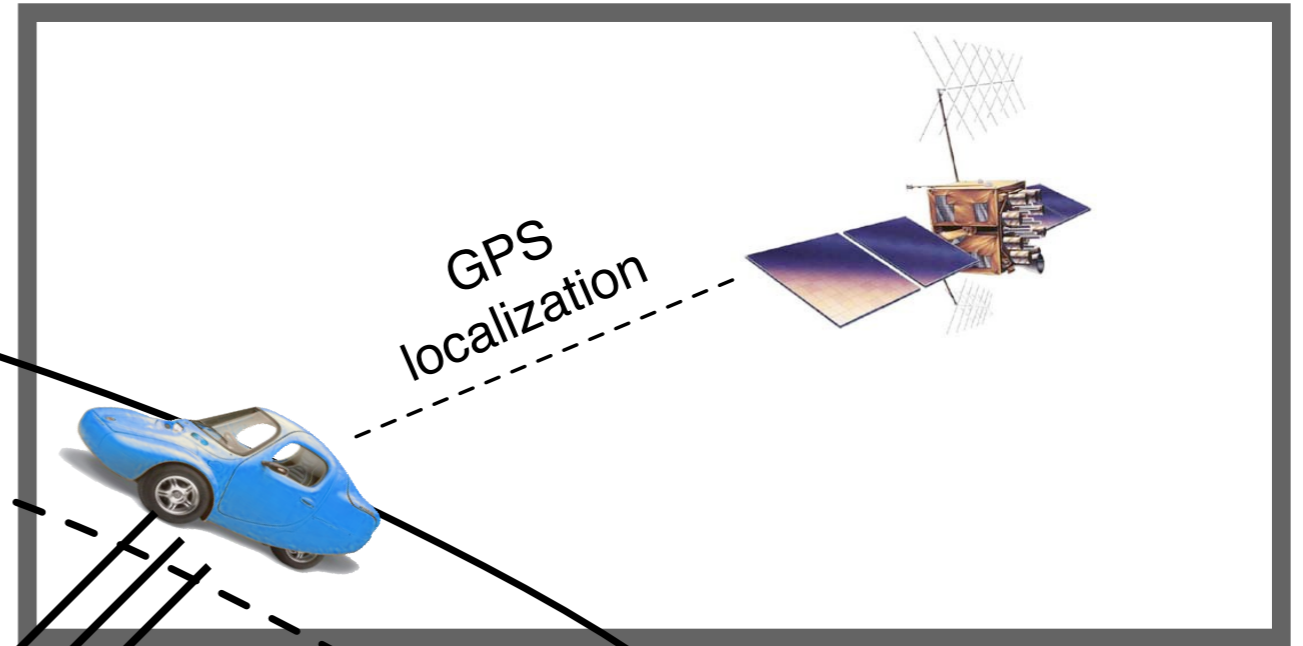
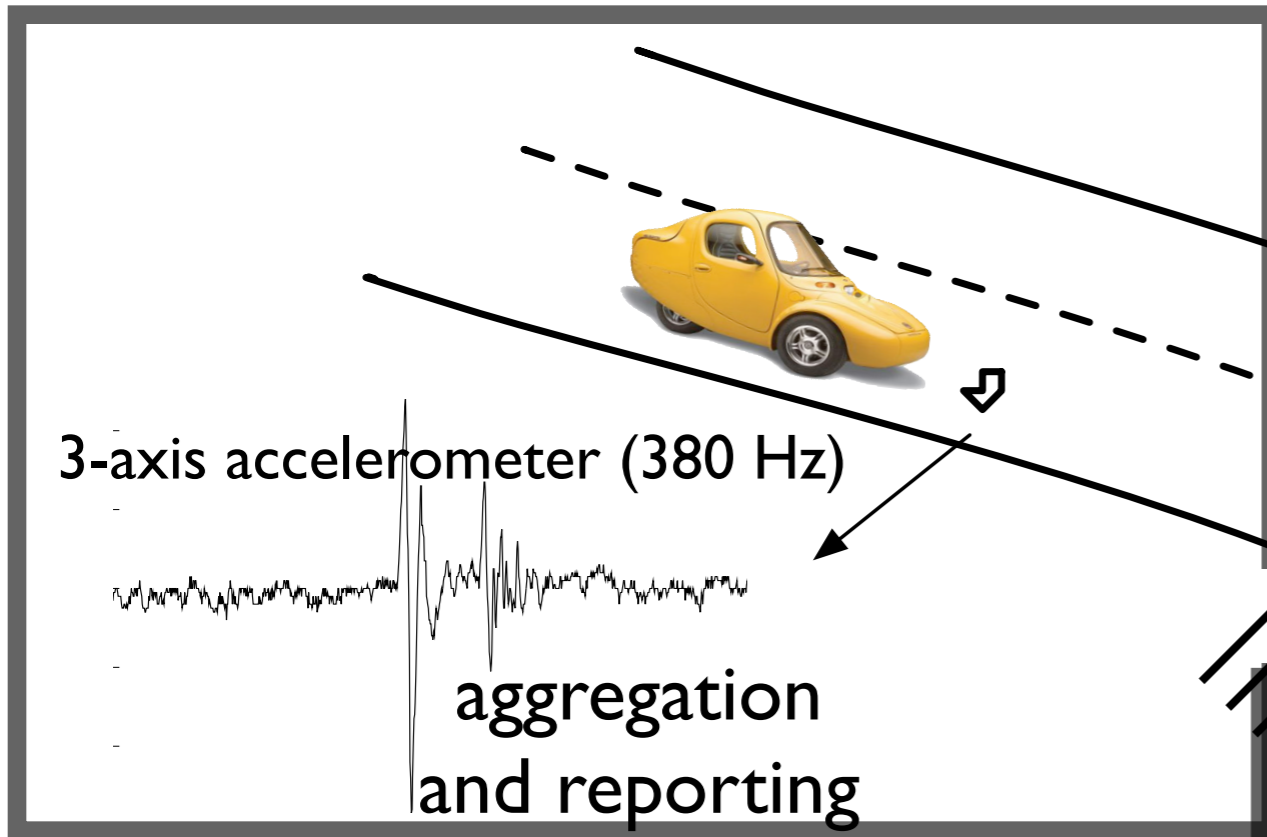


- road decay unavoidable, hard to predict
- current monitoring methods costly/ineffective

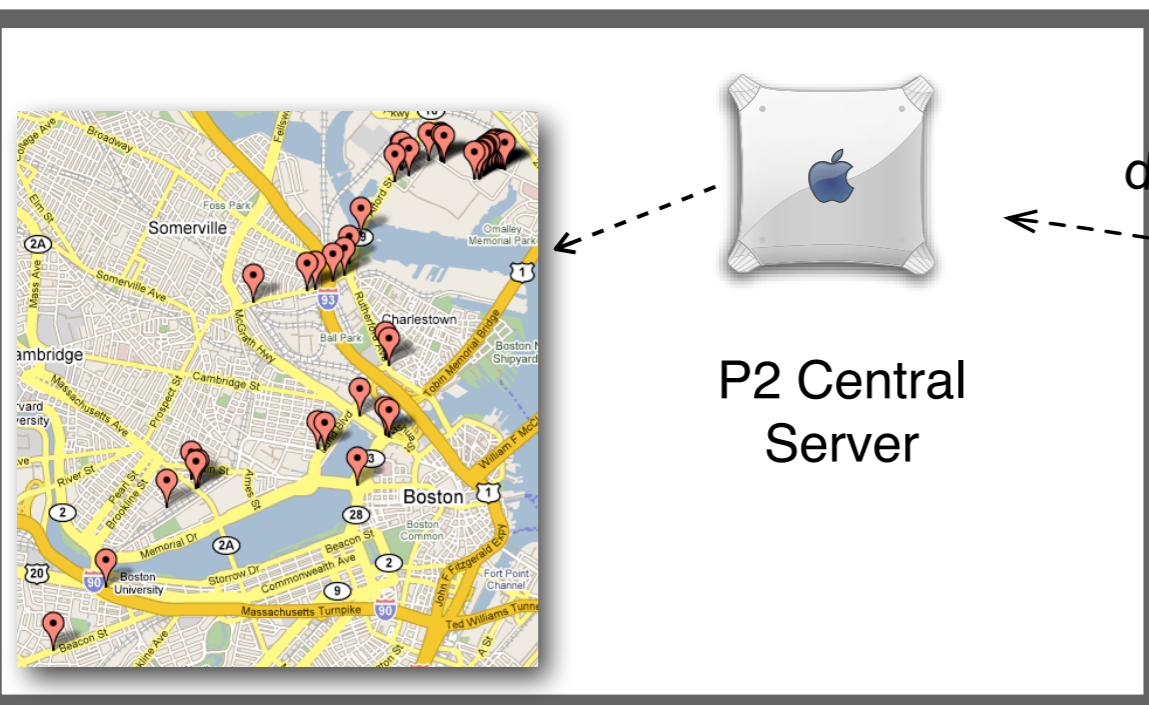
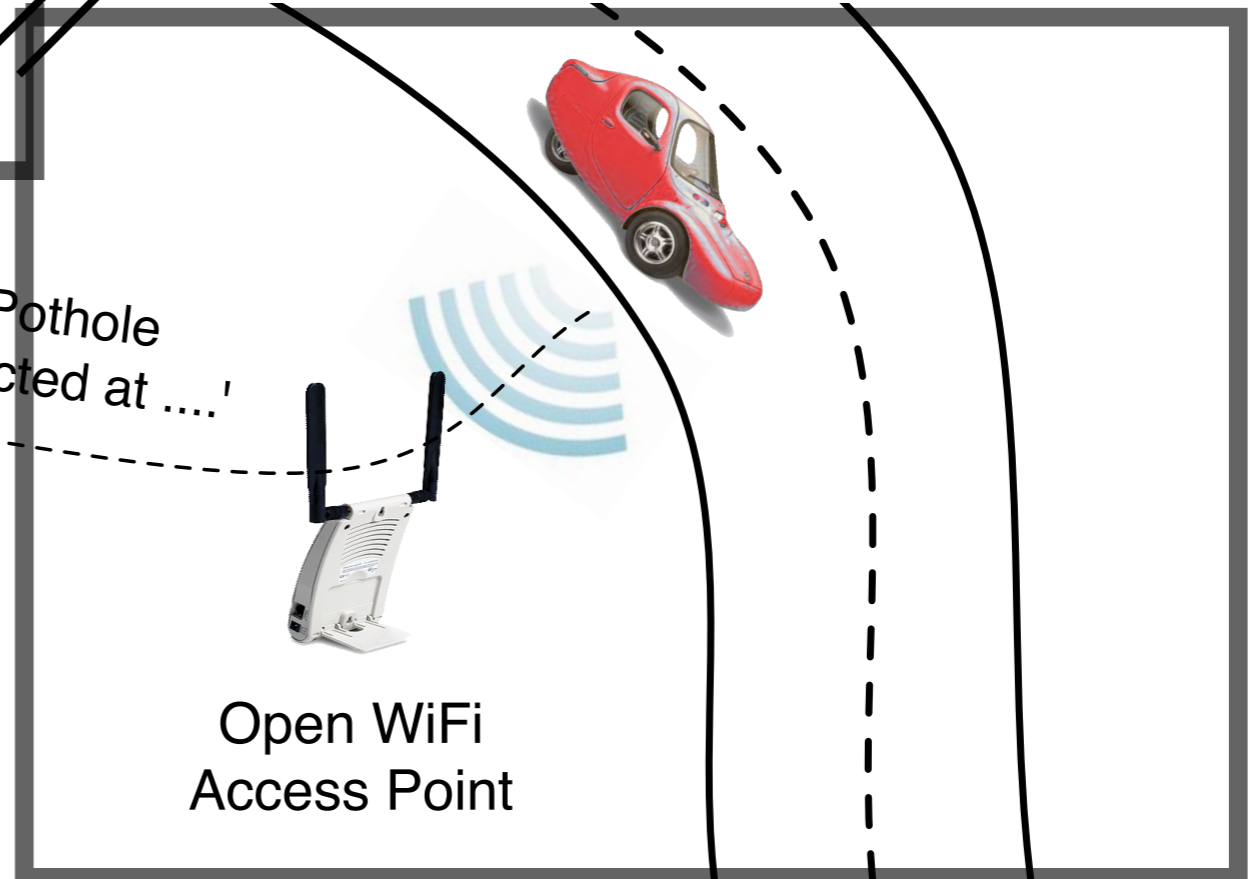
the Pothole Patrol

GPS localization

opportunistic accelerometer sensing

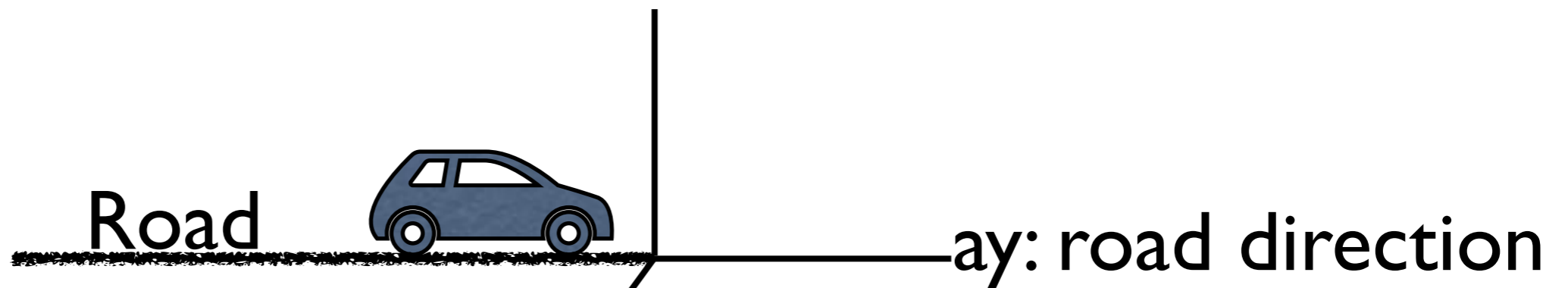


opportunistic data upload



Acceleration vector

a_z : perpendicular to road plane



a_x : on road plane, perpendicular to road

experimental platform

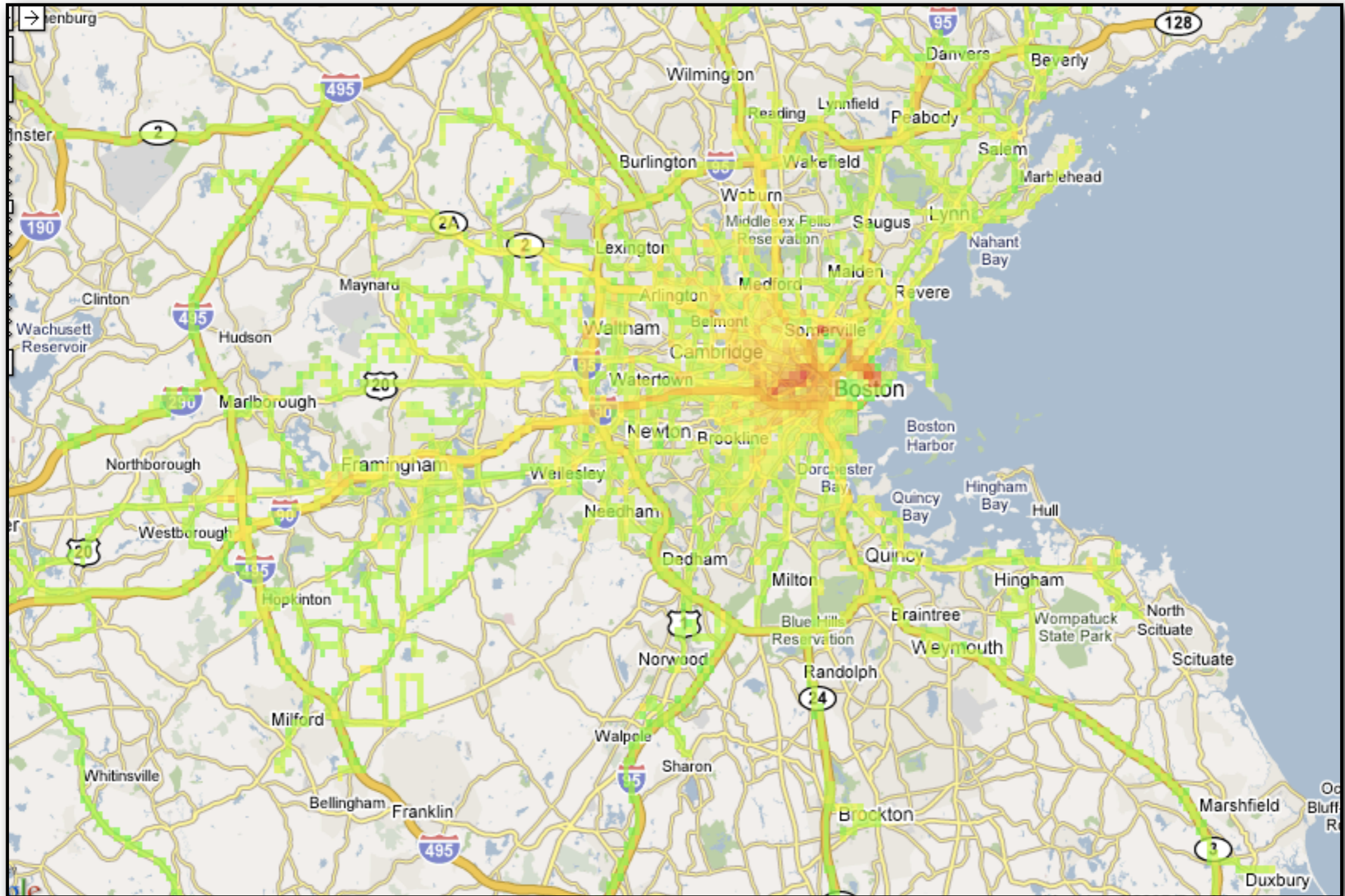
- 7 Boston/Cambridge taxis
- small computer in glove box
- 380 Hz 3-axis accelerometer
- 802.11a/b/g wireless interface
- GPS receiver on roof
- $\langle \text{time, location, heading, speed, } a_x, a_y, a_z \rangle$

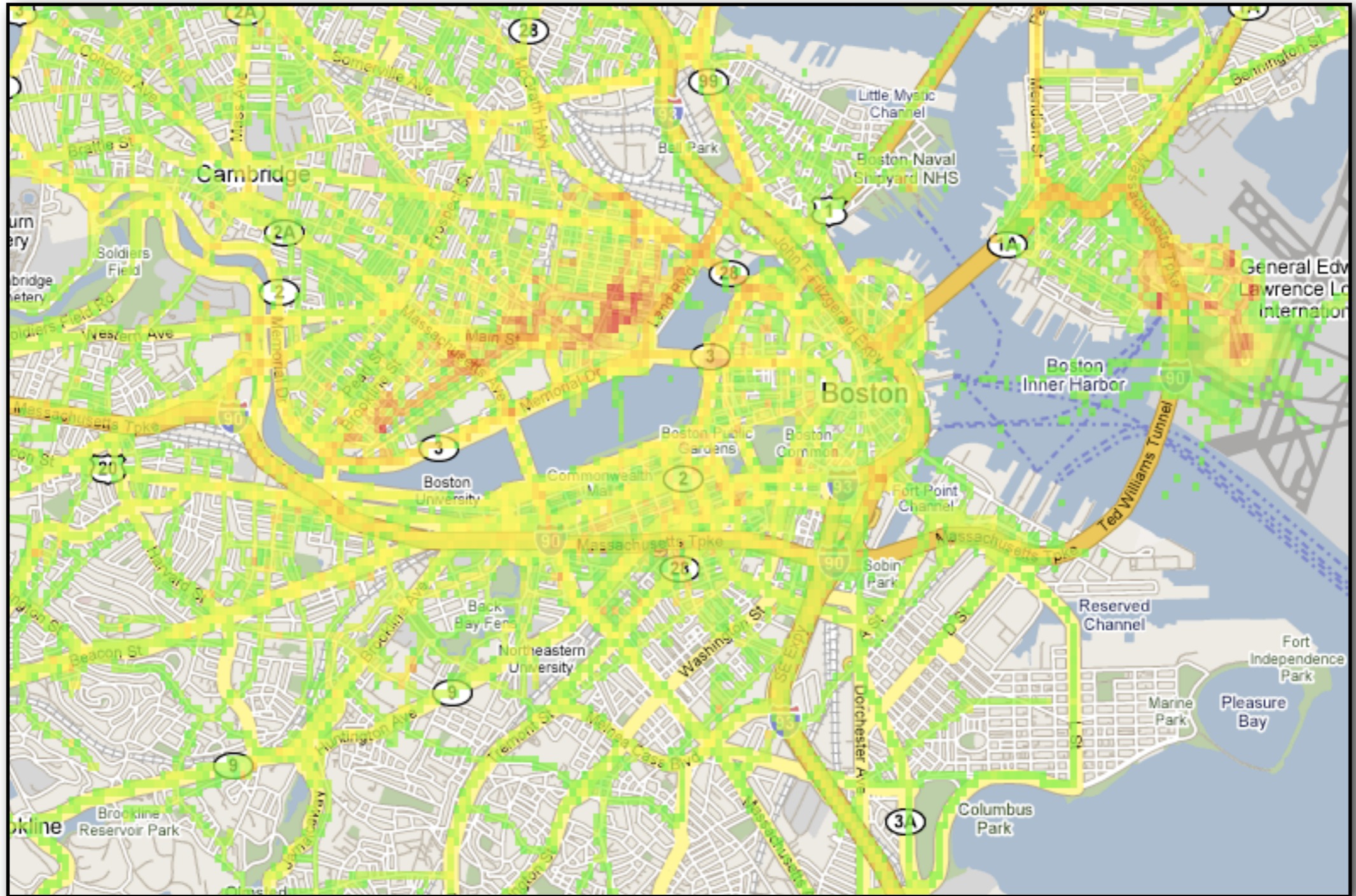


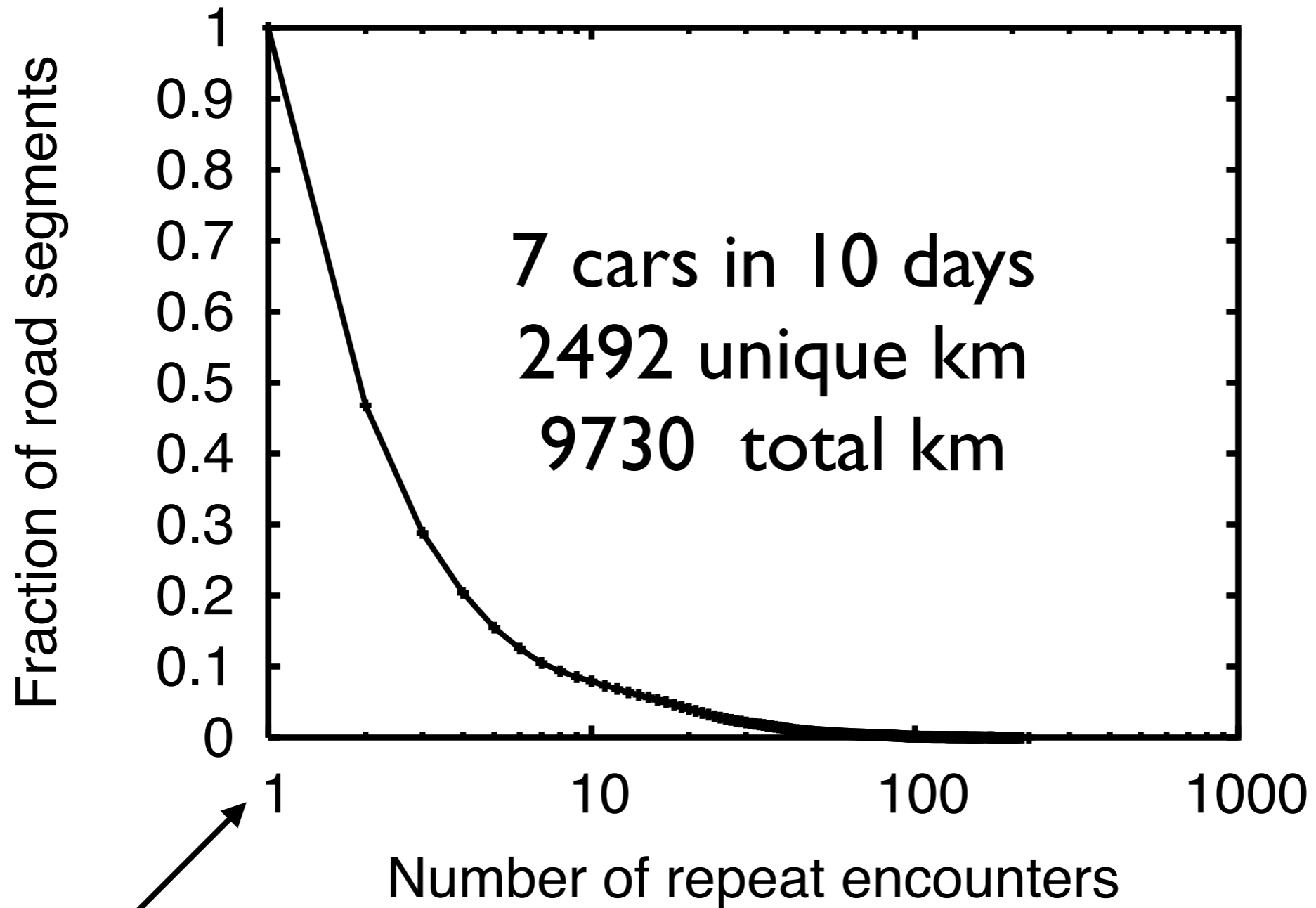
When was iPhone released?

June 2007 (this paper was published 2008)

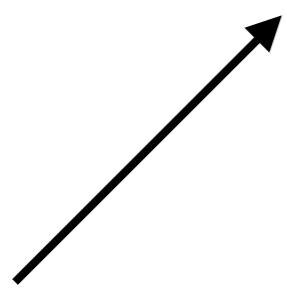
wide-area sensing







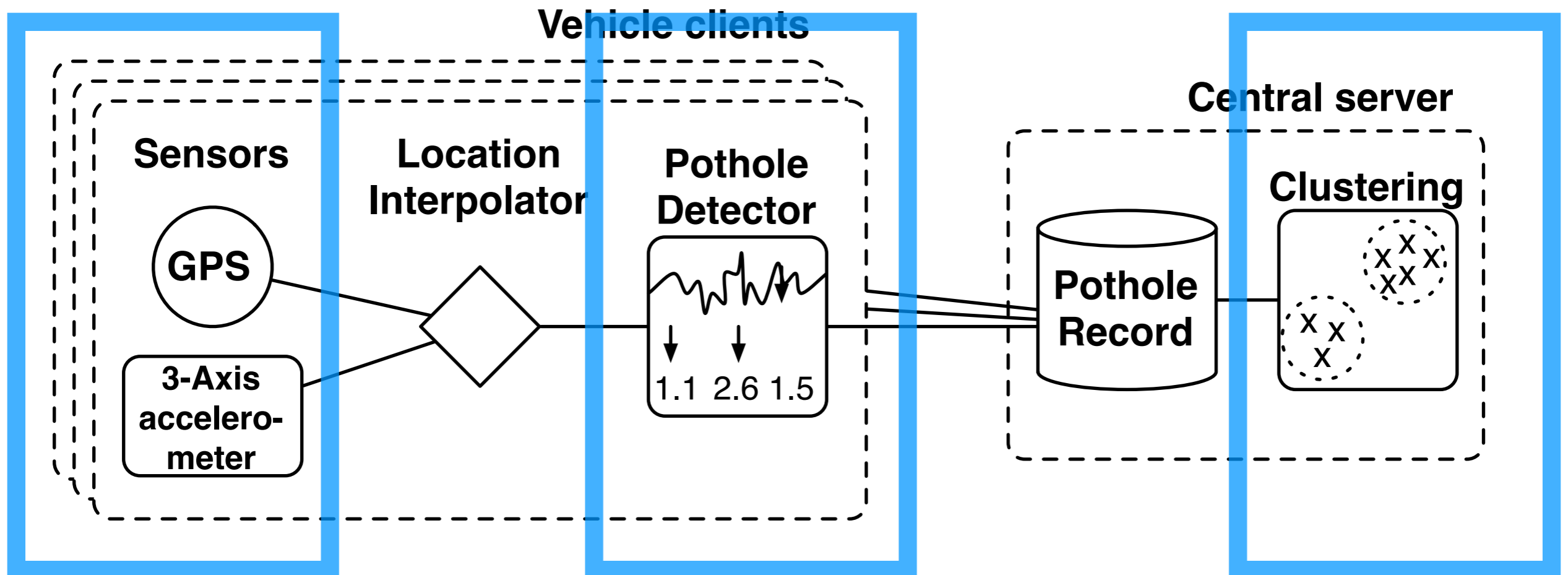
appear at least once



open WiFi connectivity



P² architecture



why interpolate?

sensor placement



Pros? Cons?

sensor placement



Pros? Cons?

- highly accurate
- difficult mounting
- extreme exposure

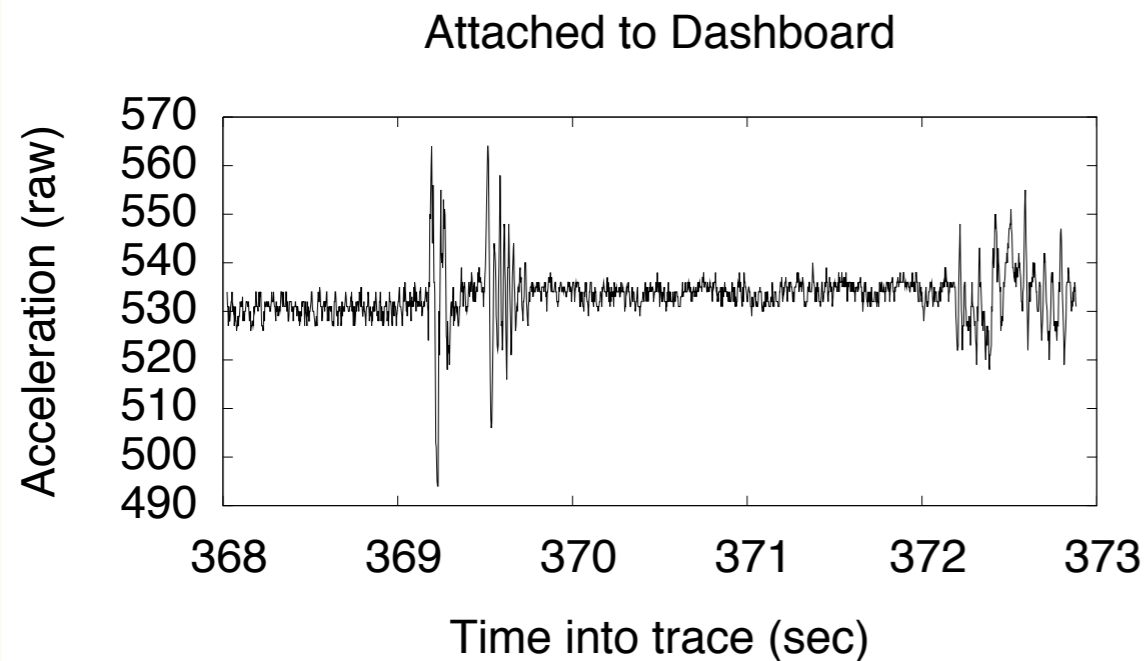
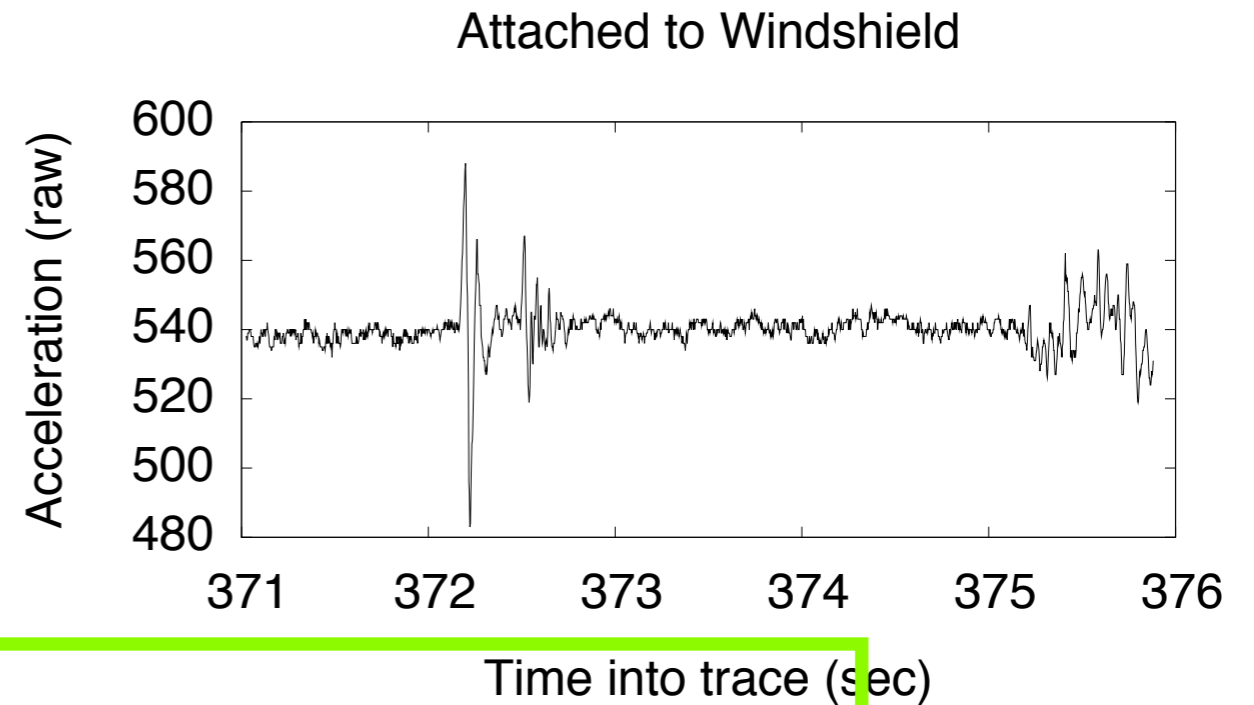
*try to stay
inside vehicle*

WINDSHIELD?

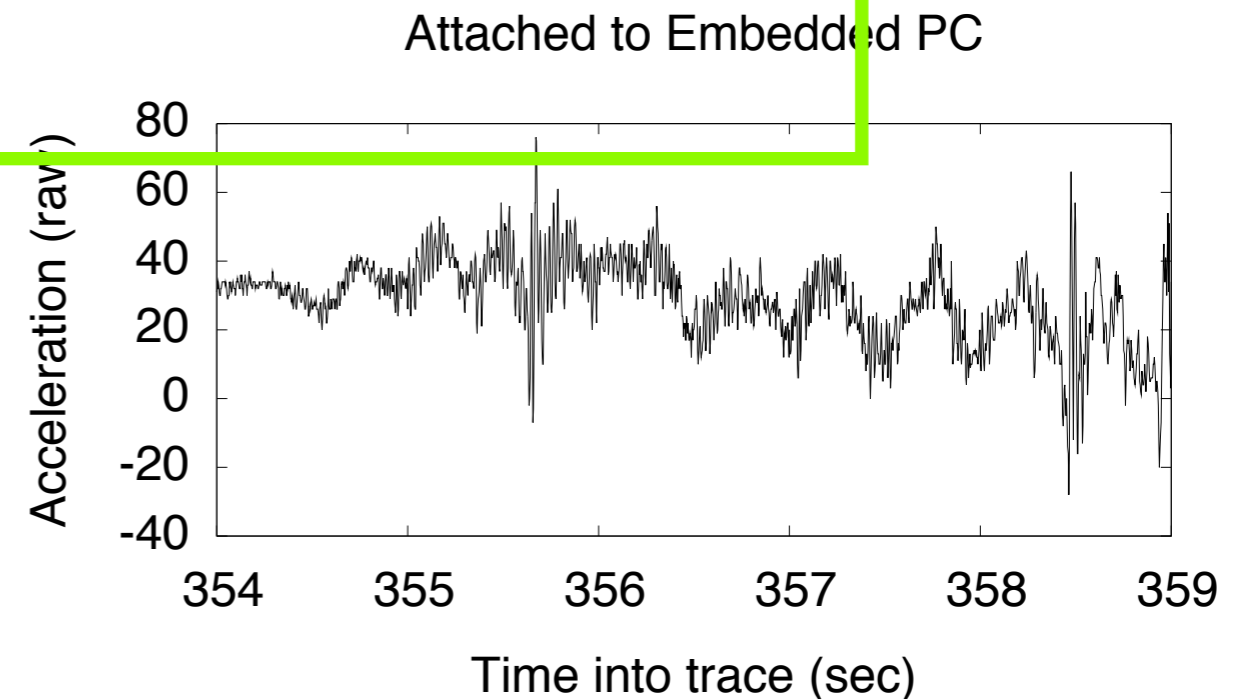
DASHBOARD?

ATTACHED TO PC?

- very clean signal
- ‘gold standard’
- “in the way”
(if large device)



- good signal
- easy to mount
- ‘out of the way’

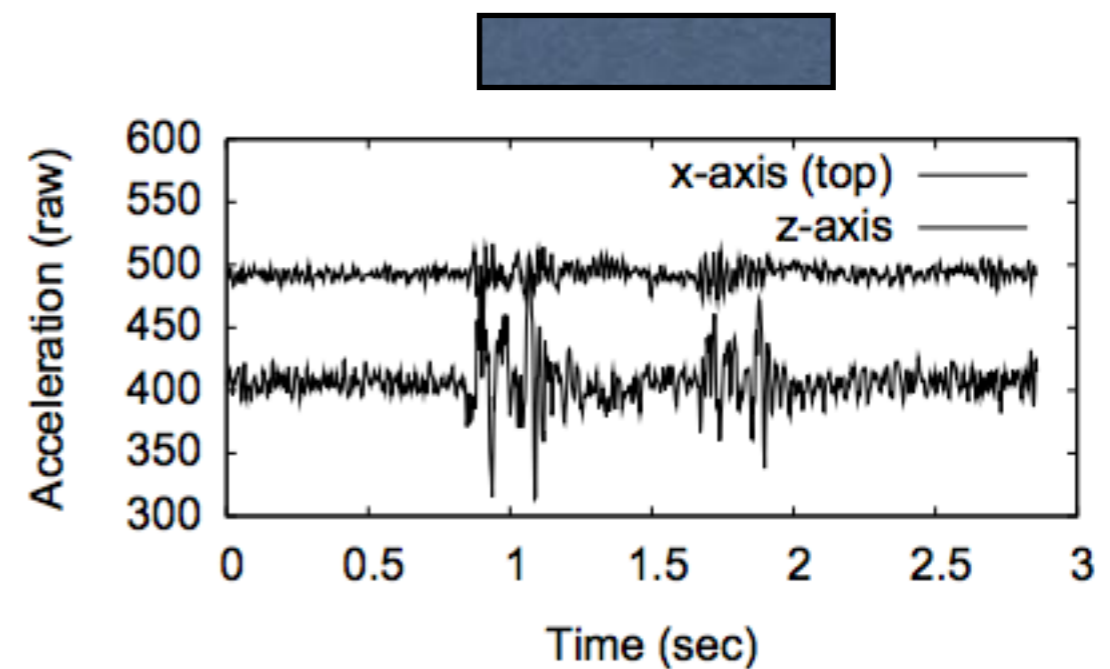
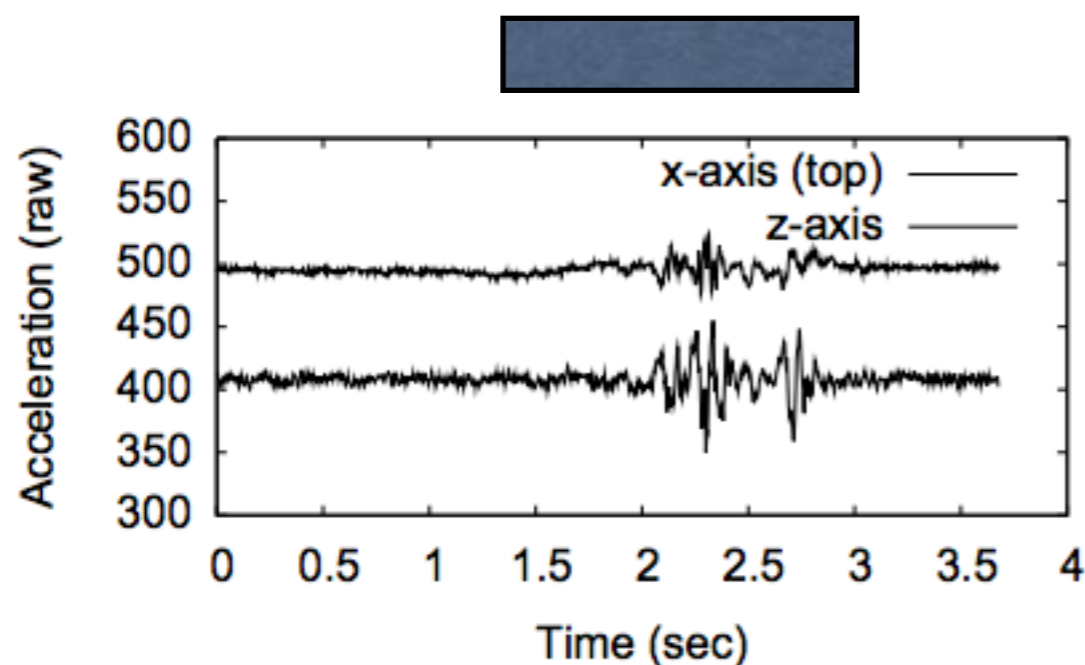
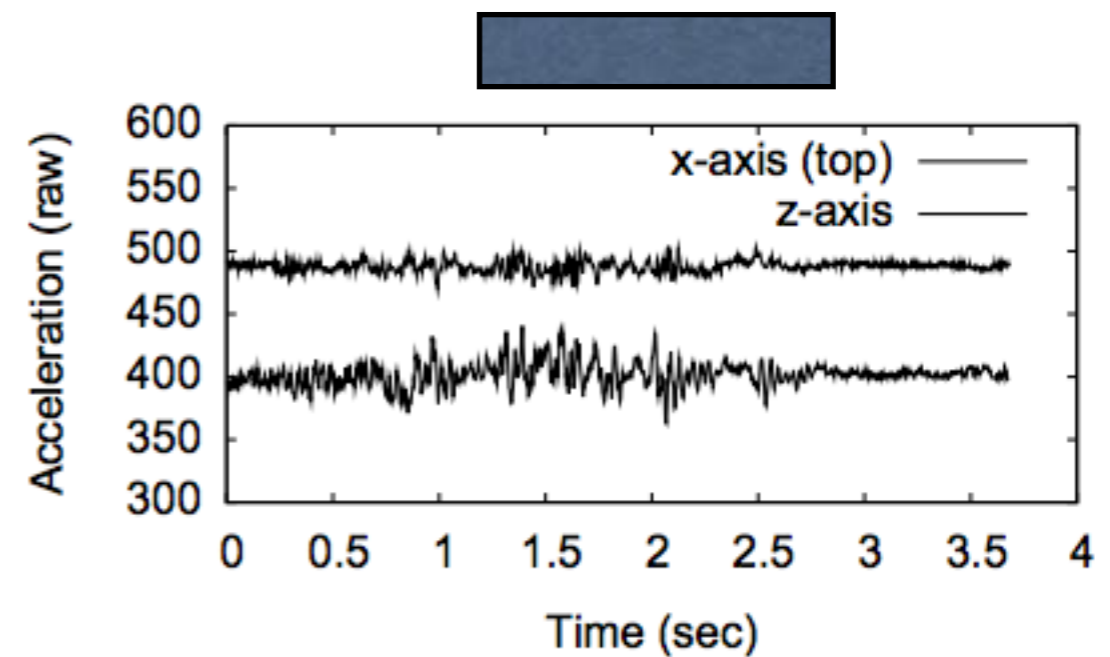
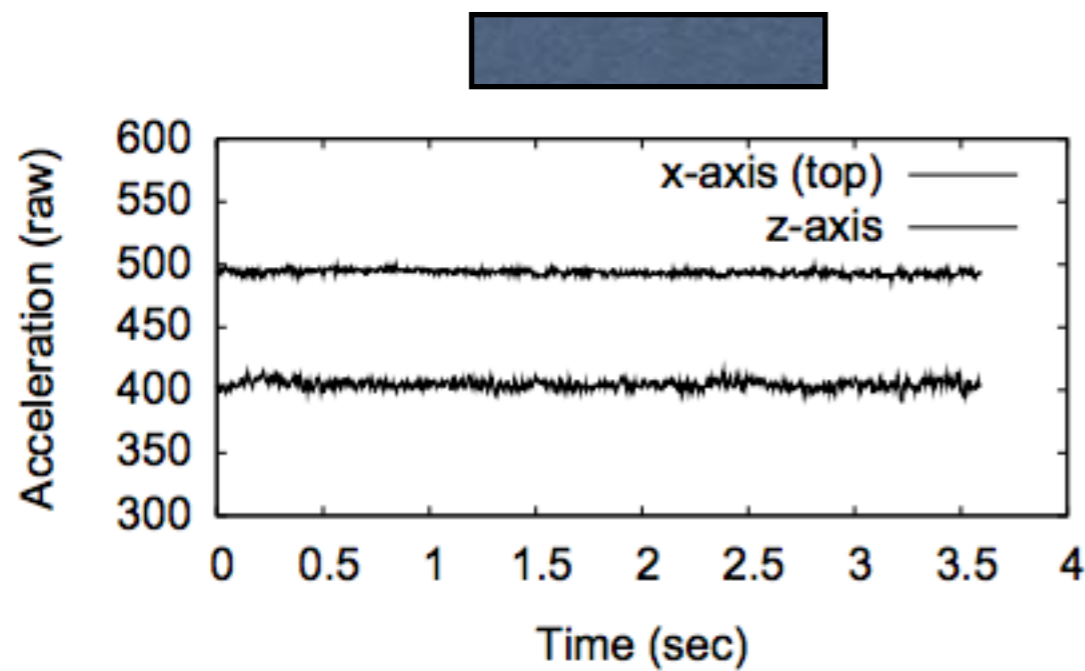


- poor signal
- no mounting necessary

pothole v. not pothole

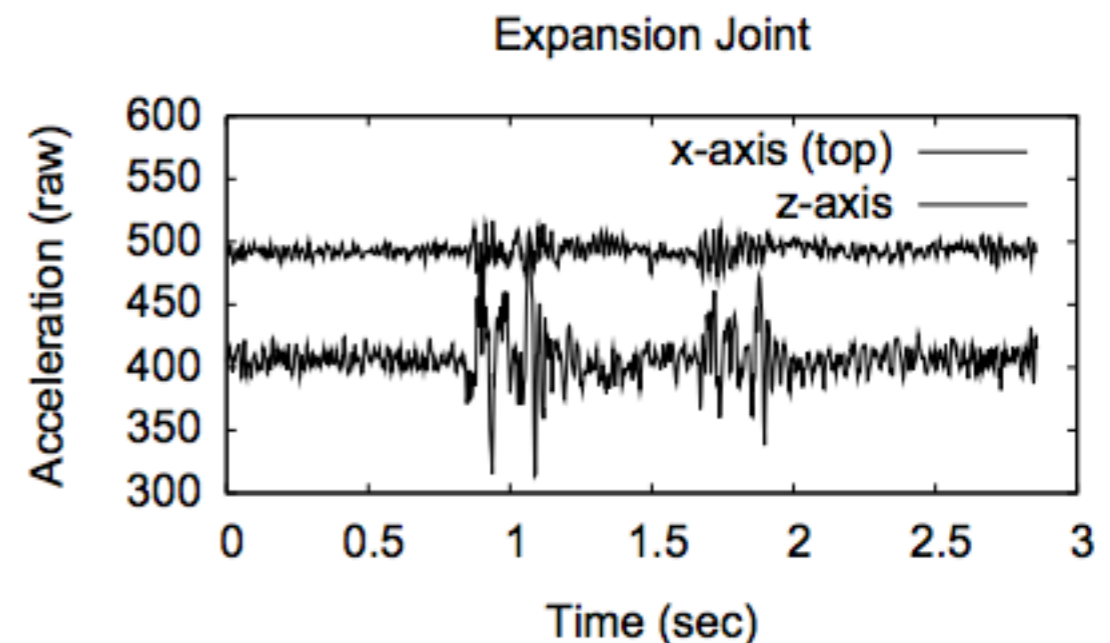
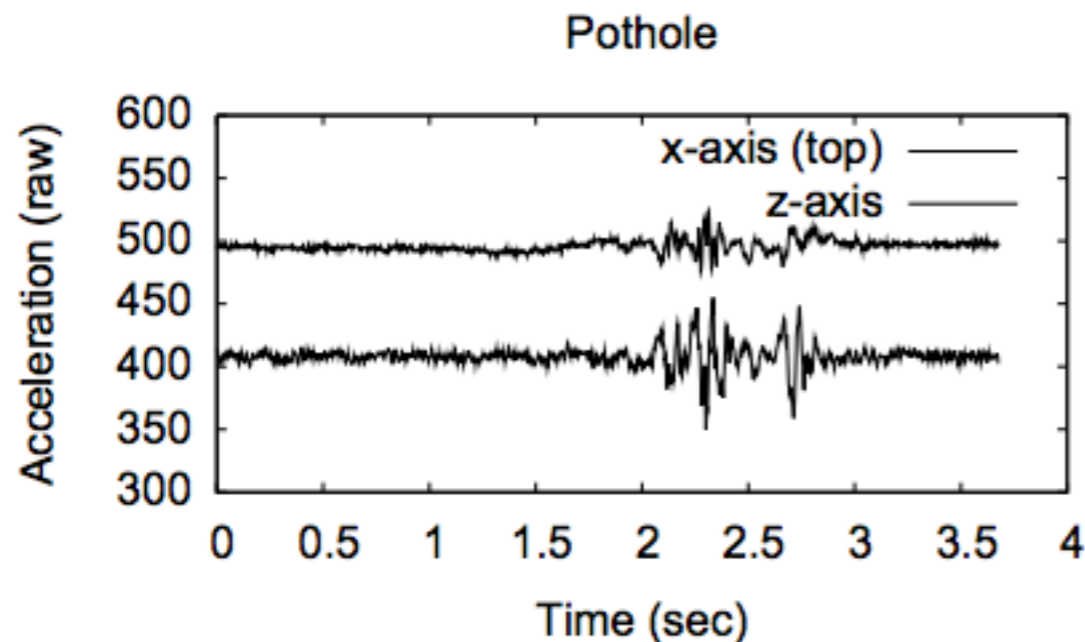
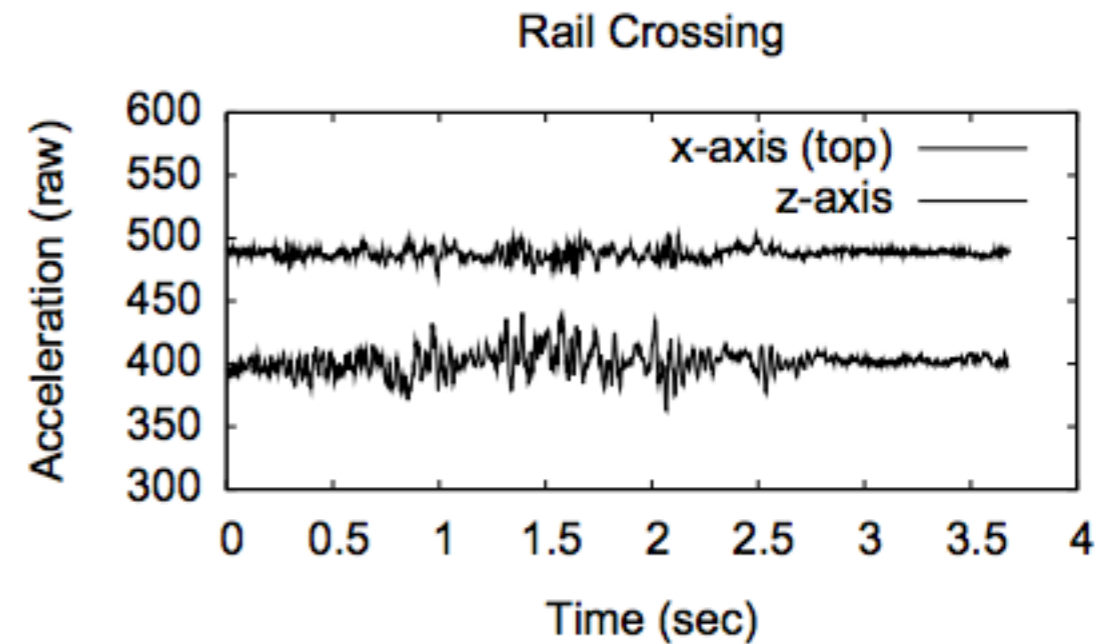
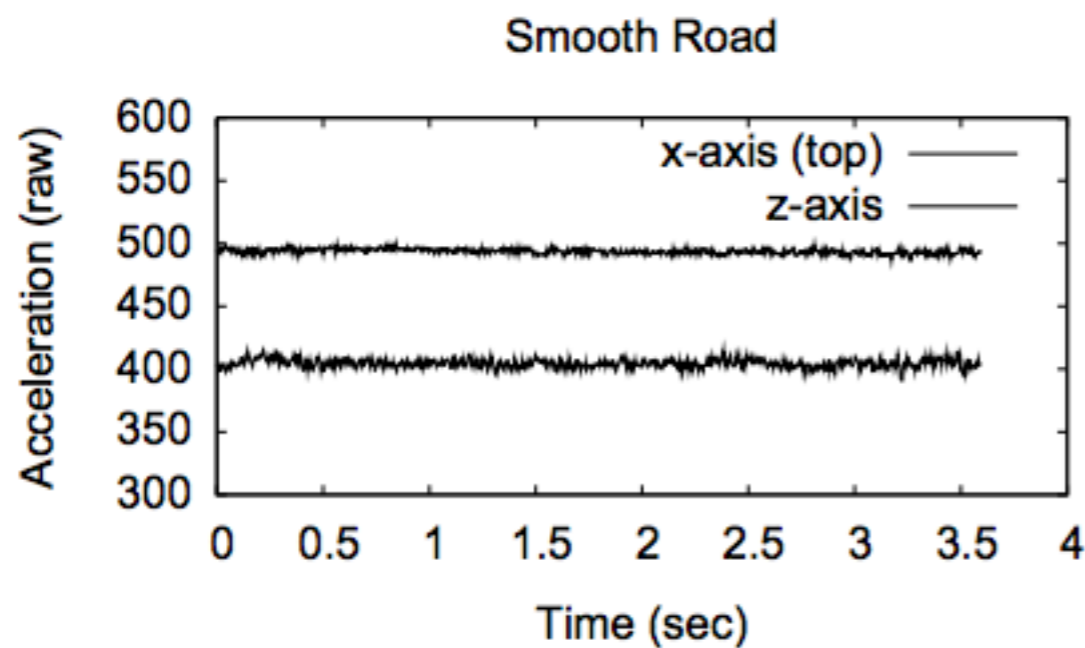


challenge: “pothole” v. “not pothole”

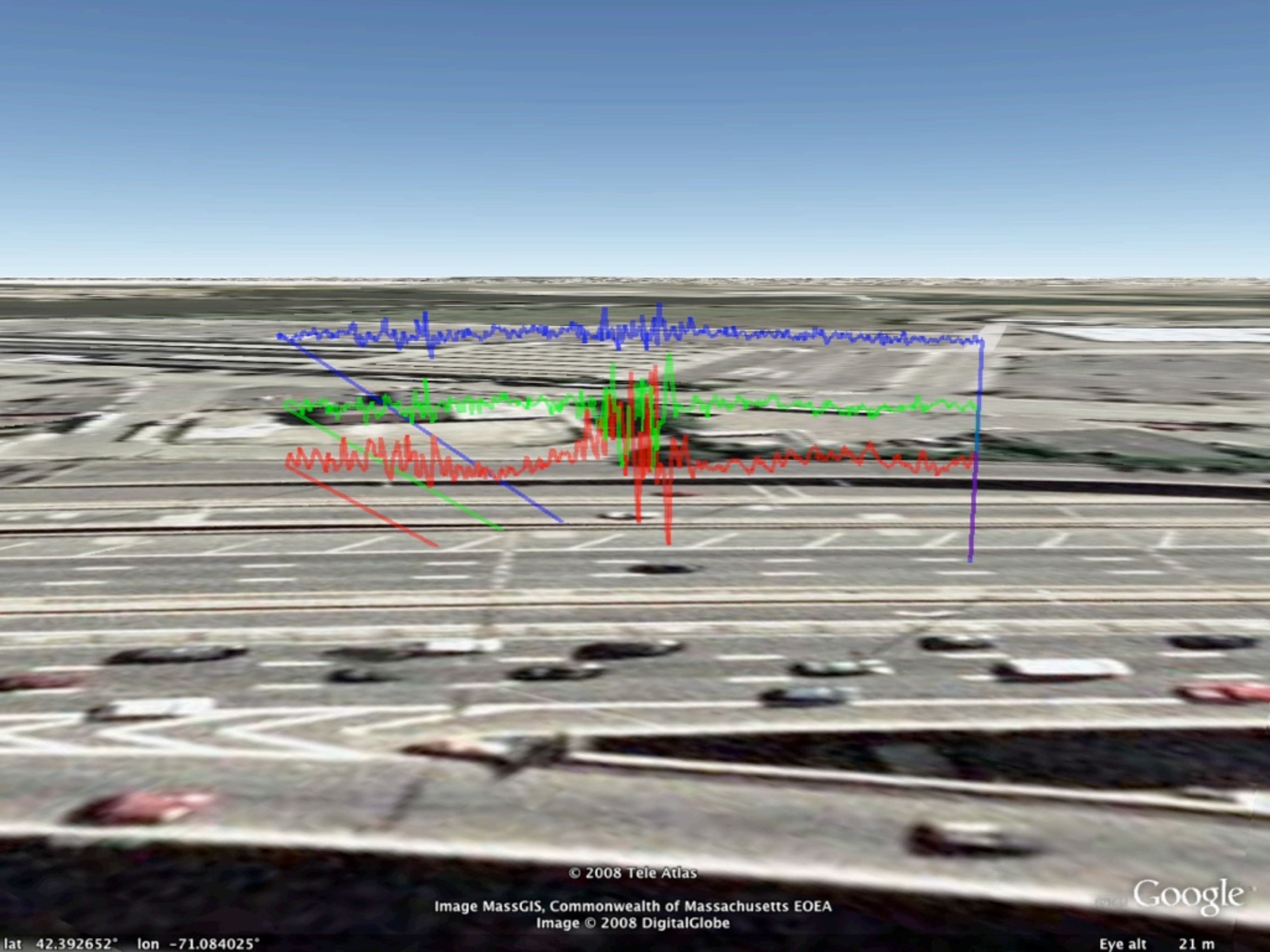


How do we identify pothole vs others?

challenge: “pothole” v. “not pothole”



How do we identify pothole vs others?



© 2008 Tele Atlas

Image MassGIS, Commonwealth of Massachusetts EOE
Image © 2008 DigitalGlobe

©2008 Google

lat 42.392652° lon -71.084025°

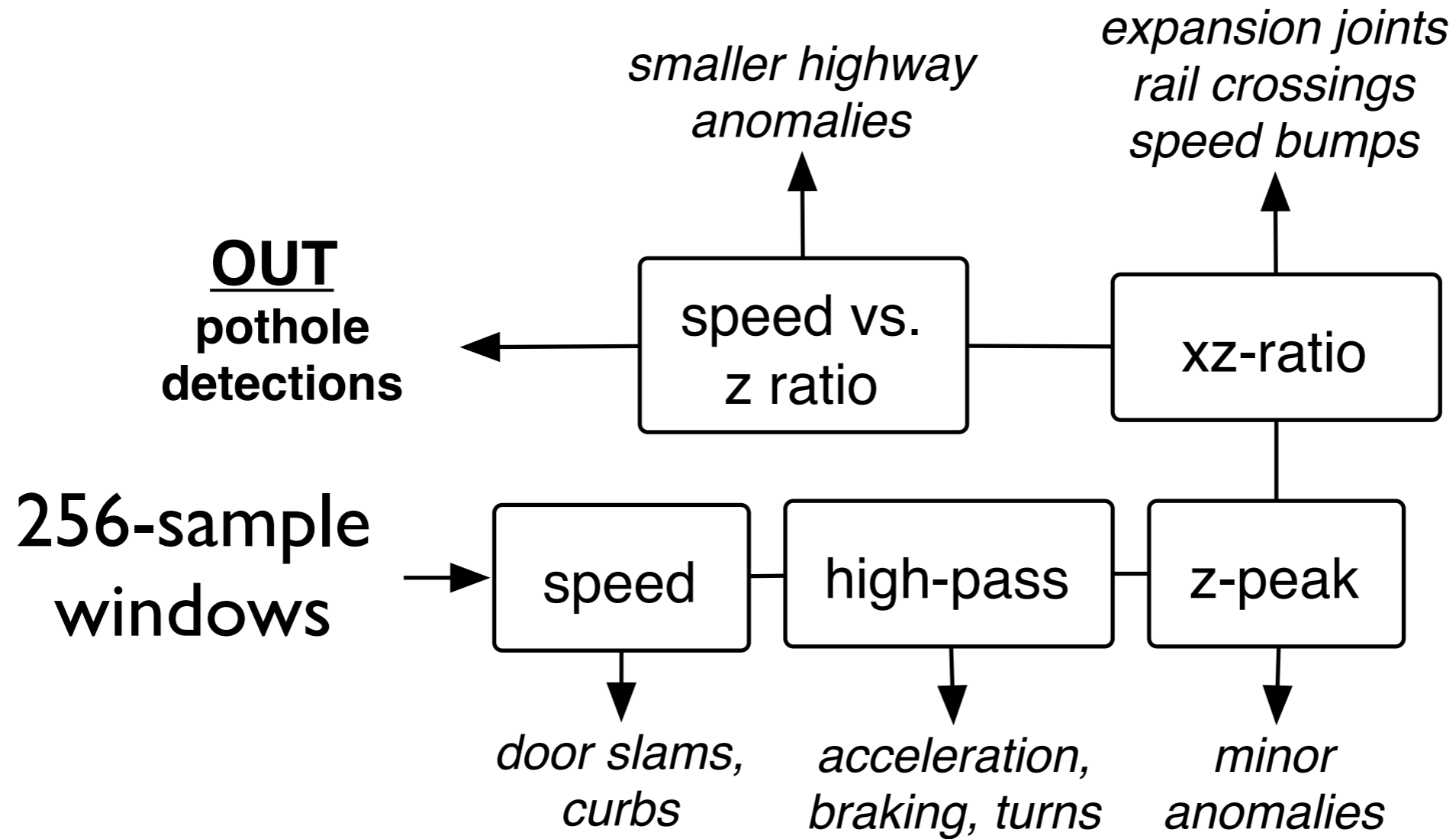
Eye alt 21 m

P² detector

256-sample
windows

Events usually of much shorter duration than 256 samples

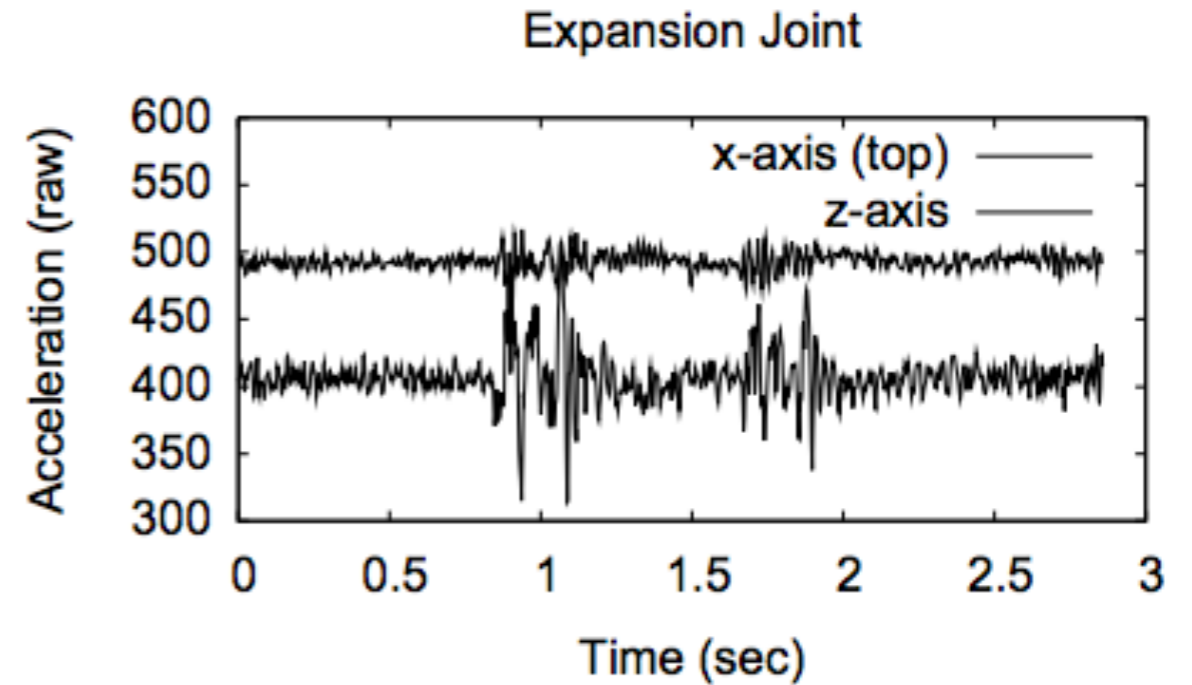
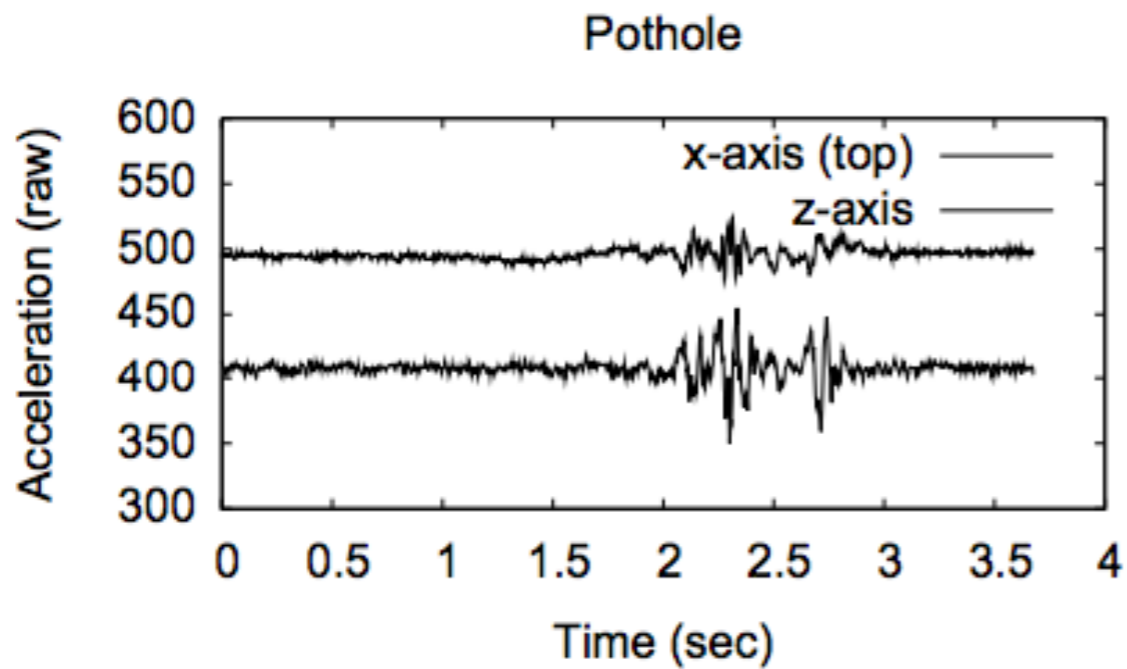
P² detector



Events usually of much shorter duration than 256 samples

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

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

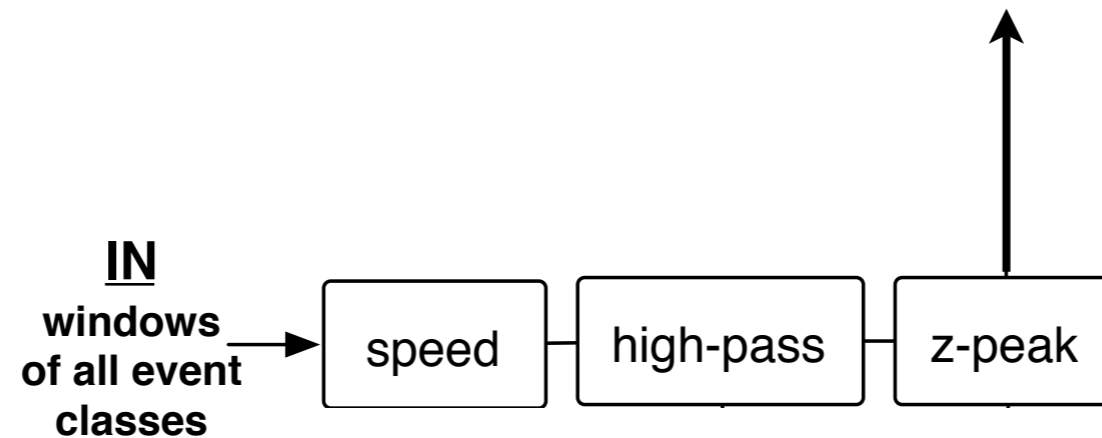
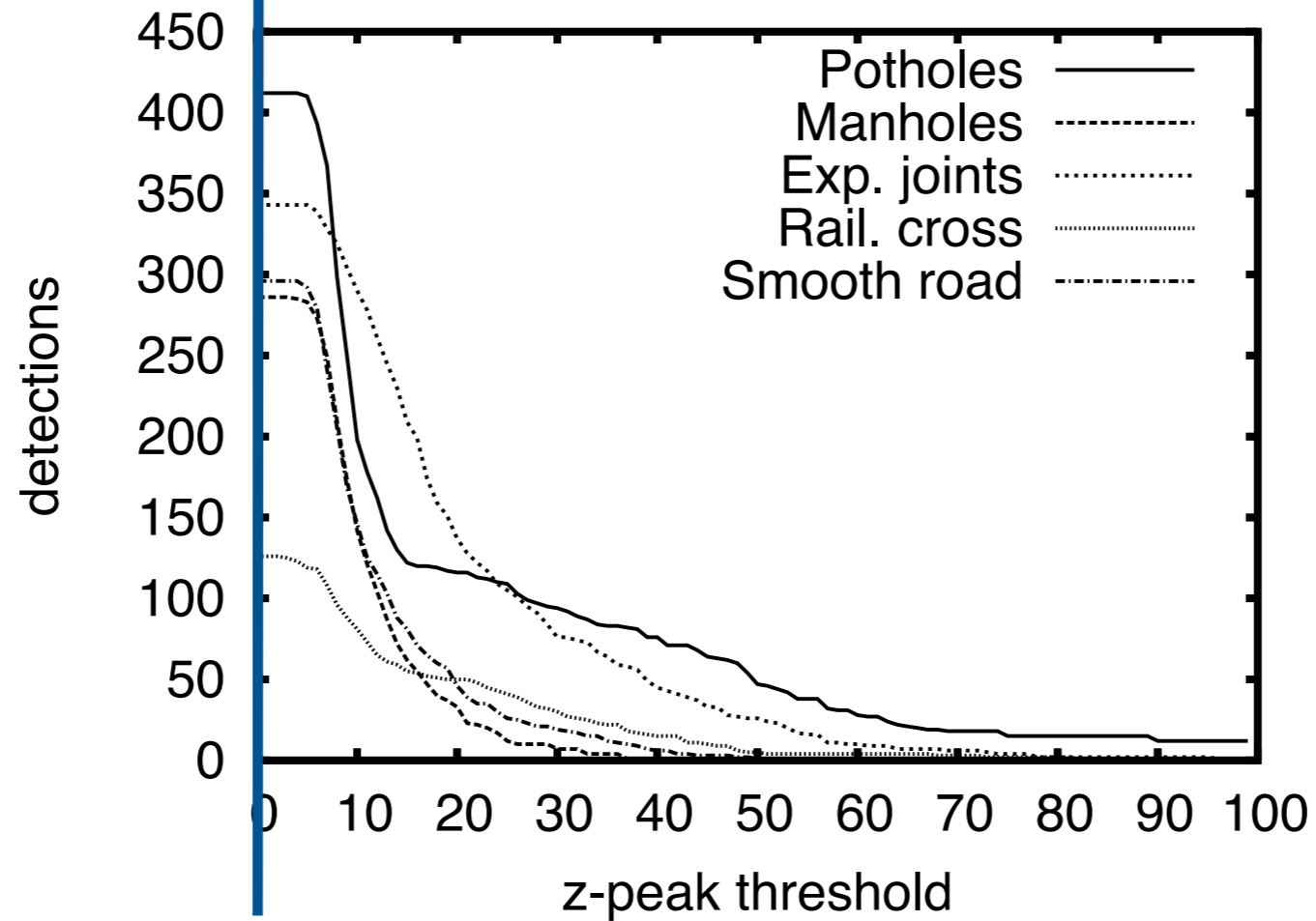
- pick an objective function

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

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

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

training the detector



detector performance

Among the segmented reported as potholes by the algorithm

Class	After training on loosely labeled data	
	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

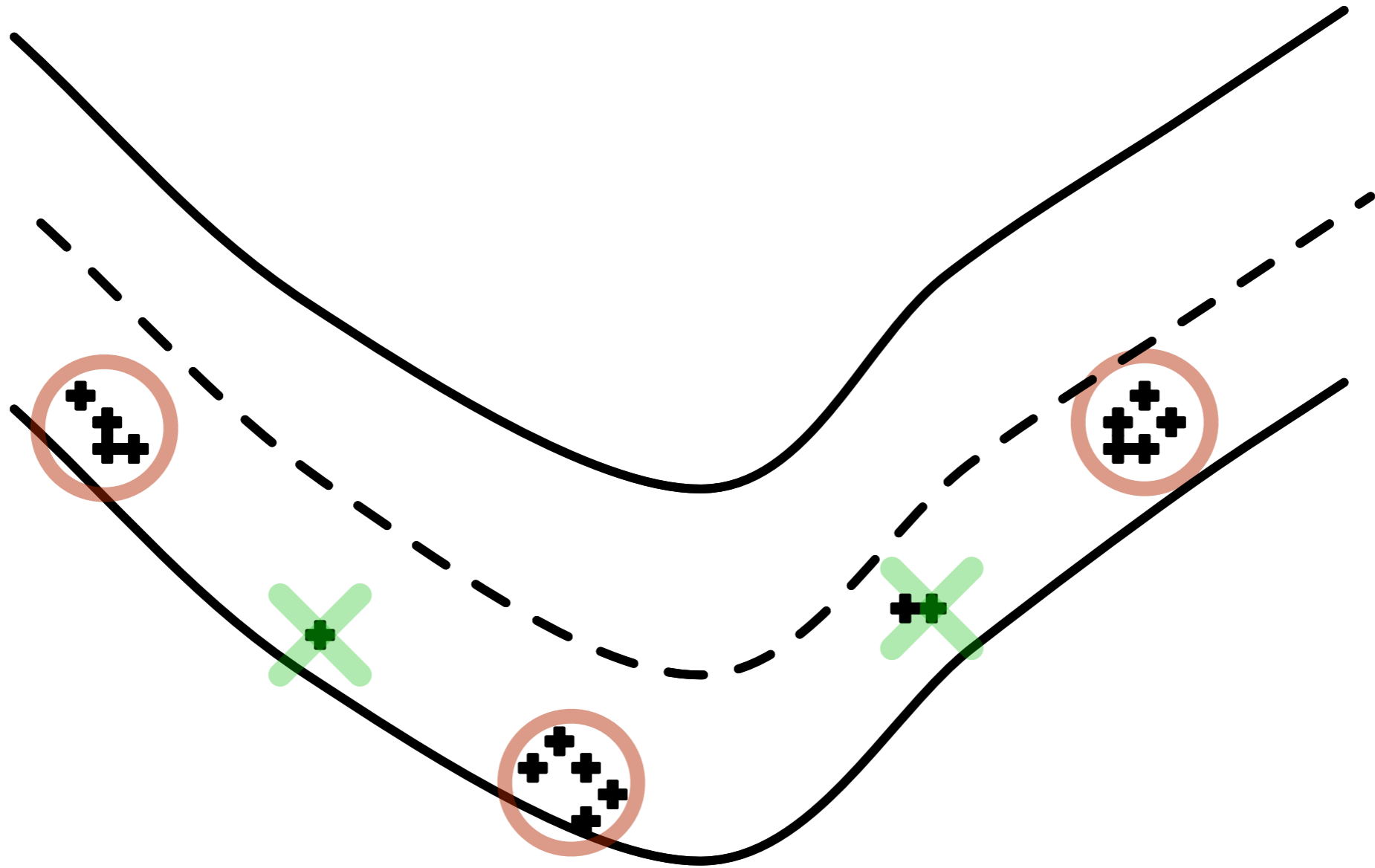


Note: Actual false positive rate is not 7.6%
Why?

estimating false +ve rate

Road	# potholes	<small># of sample windows</small> #win	#det.	<small># of detections/ # windows</small> rate	
Storrow Dr.	few	1865	3	0.16%	upper bound on FPs
Memorial Dr.	few	1781	2	0.12%	
Hwy I-93	few	2877	5	0.17%	

clustering



experiments

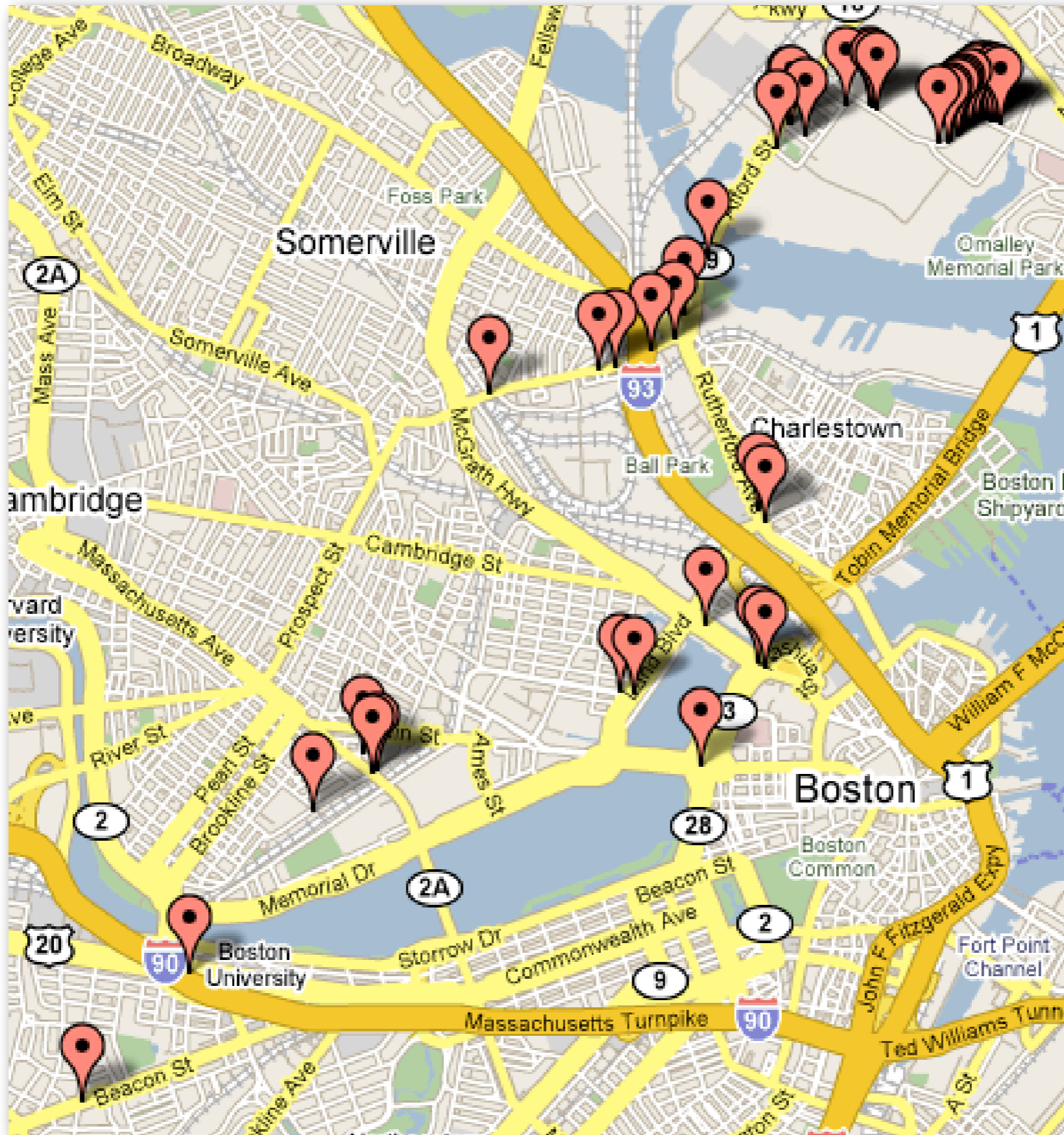
- 7 taxis over 10 days
- 9730 total km of road covered
- 2492 unique km of road covered
- 1.4 million sample windows
- 4131 severe detections
- **2709** unique locations (after clustering)

Precision & Recall

48 spot-checks

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





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

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Projects

Students have most fun & learn most from the projects

- All projects must involve system implementation
- Ideal group size: 3
- We suggested project ideas; feel free to choose your own projects

Timeline (per 6.1820 web site):

Will provide instructions on all deliverables & how to prepare for meetings with course staff

- Proposal (1-2 pages): March 31 (Tuesday)
- Meet on April 7 and April 9 (during class) to give feedback
 - May allow updating proposals based on feedback
- Last 3 weeks of classes: dedicated to project meetings
- Title and Abstract due: May 5
- Demos and presentations: May 12