Nericell: Rich Road and Traffic Monitoring using Mobile Smartphones

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Traffic Monitoring

- GPS based tracking is adequate
- Infrastructure support exists

Courtesy: FreeDigitalPhotos.net

Beyond Traffic Monitoring

- Potholes
- Road bumps
- Varied vehicle types
- Liberal honking
- Chaotic intersections
- …

Why Rich Monitoring?

Find least stressful route

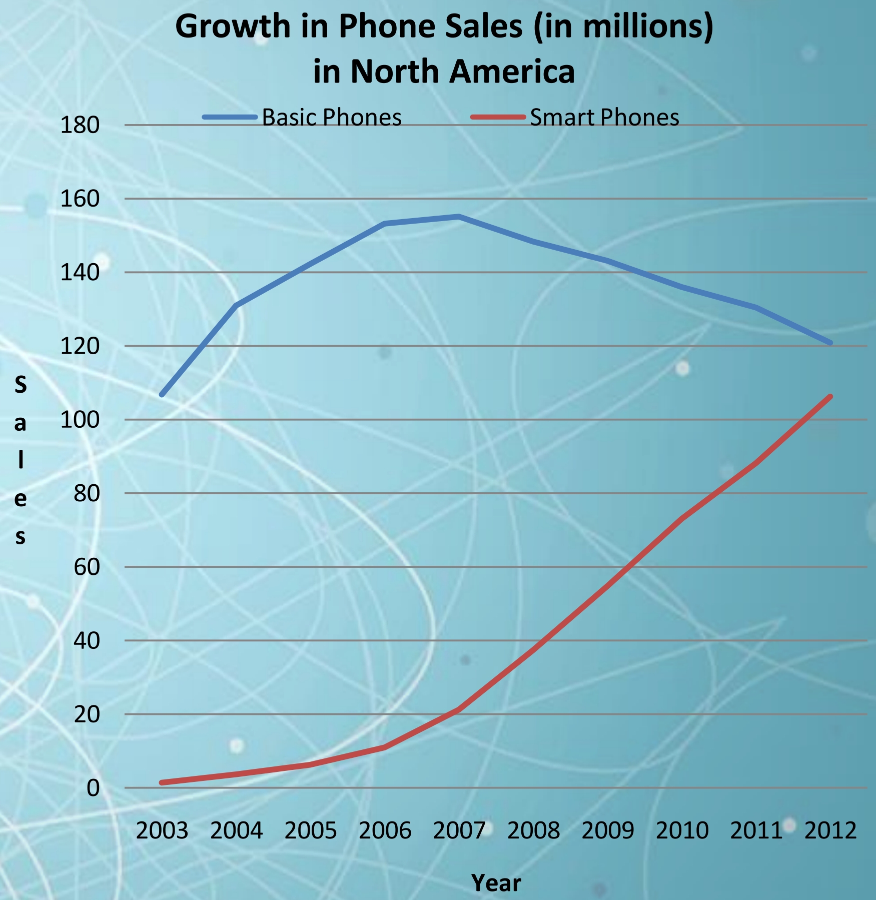
Widespread distribution of mobile phones

Road and Traffic Monitoring

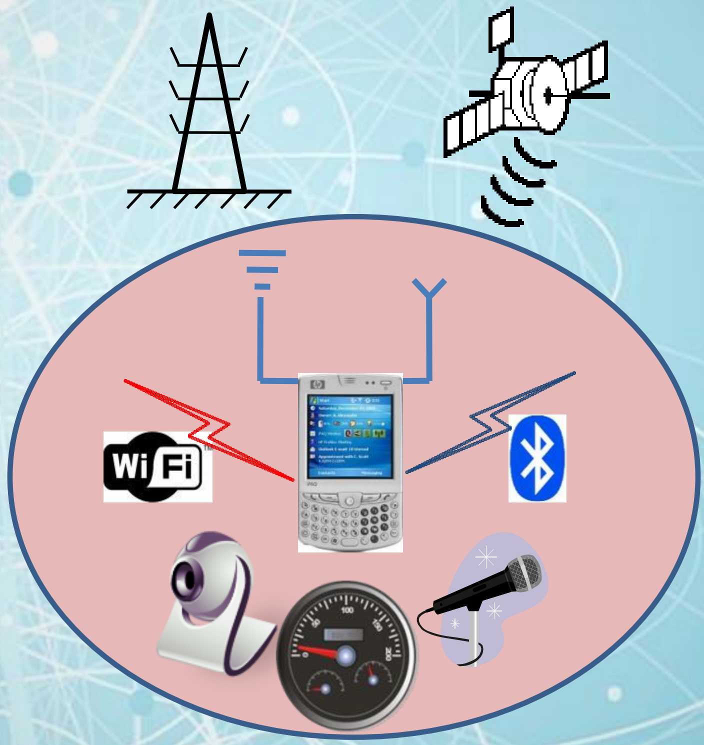
- Without deployed infrastructure
- Using existing mass of mobile phones

Mobile Phones

- ~3 billion phones worldwide
- ~300 million phones in India
- ~10 million new connections every month in India
- 115 million of 1 billion phones sold worldwide in 2007 were smartphones
- Smartphone market share expected to reach nearly 50% by 2012 in North America



Smartphone under the hood



Smartphone: Computing + Communication + Sensing

Outline

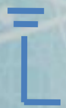
- Overview
- Accelerometer based detection
- Virtual Reorientation
- Microphone based detection
- Triggered Sensing
- Conclusion

Nericell Overview

- Using sensors individually

  - Accelerometer ⇒ drive quality

  - Microphone ⇒ honking

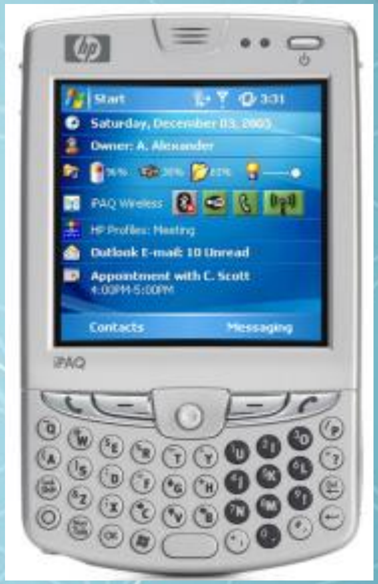


  - GSM radio and GPS ⇒ localization
- Using sensors in combination
  - Virtual reorientation of accelerometer
  - Distinguishing pedestrians from stop-and-go traffic
  - Triggered sensing

Energy is a key challenge

Resource	Power (mW)
Bluetooth	20
Wi-Fi	770
GPS	620
Microphone	225
Accelerometer	2

Energy consumption on iPaq hw6965



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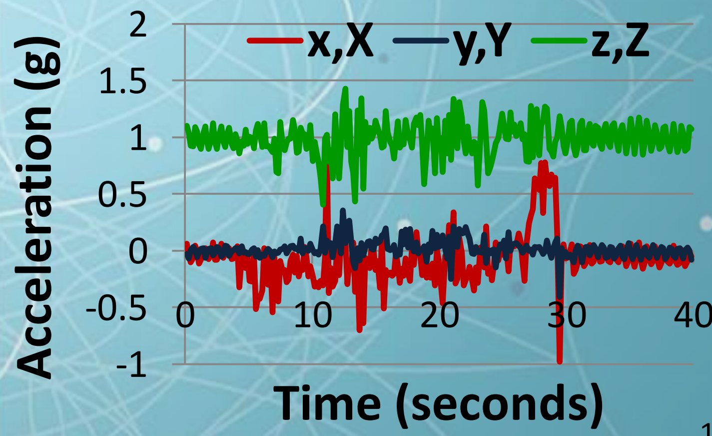
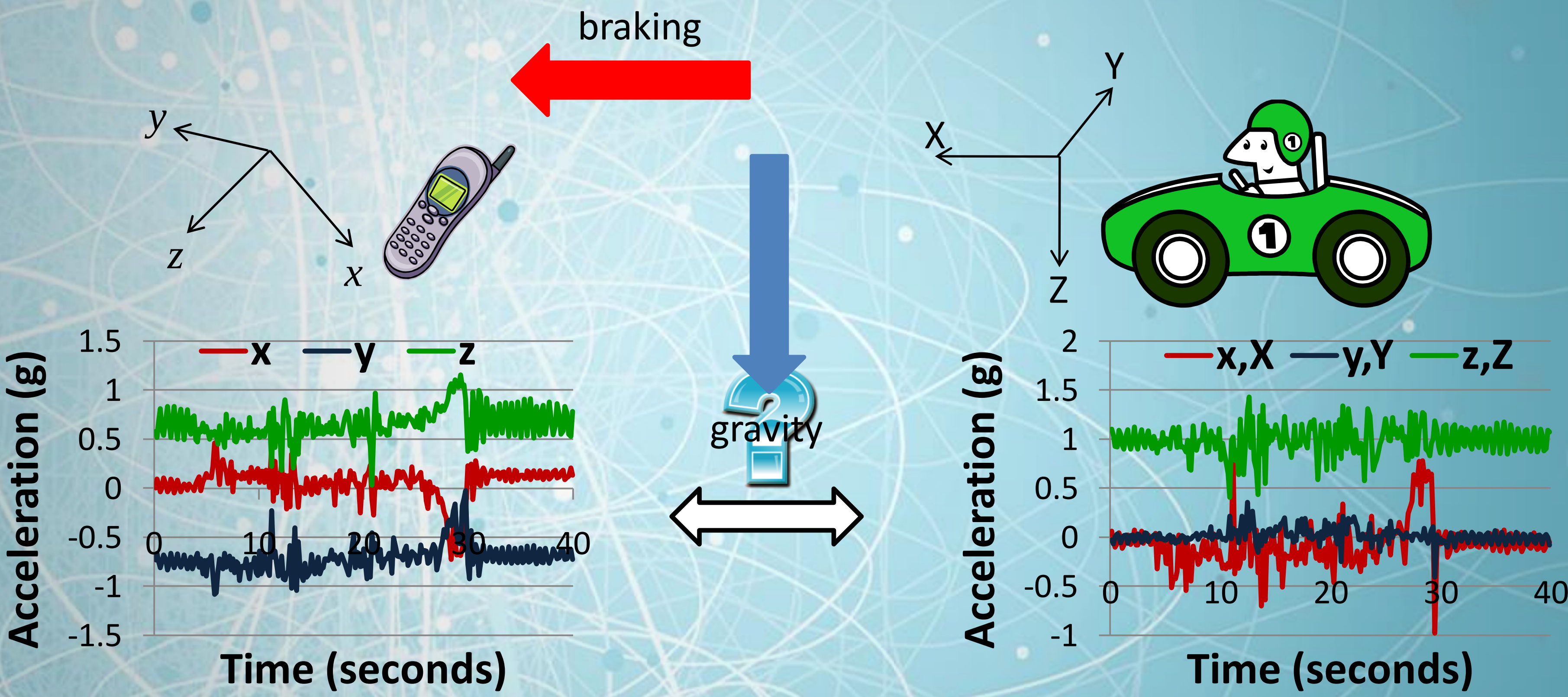
Braking Detection

- Braking impacts drive quality
- Two approaches:
  - GPS: high energy cost (600 mW on iPAQ hw6965)
  - Accelerometer: much cheaper (2 mW + 30mW)
- Accelerometer-based braking detection:

Threshold T(g)	False Negative	False Positive
0.12 (4 sec)	11%	16%



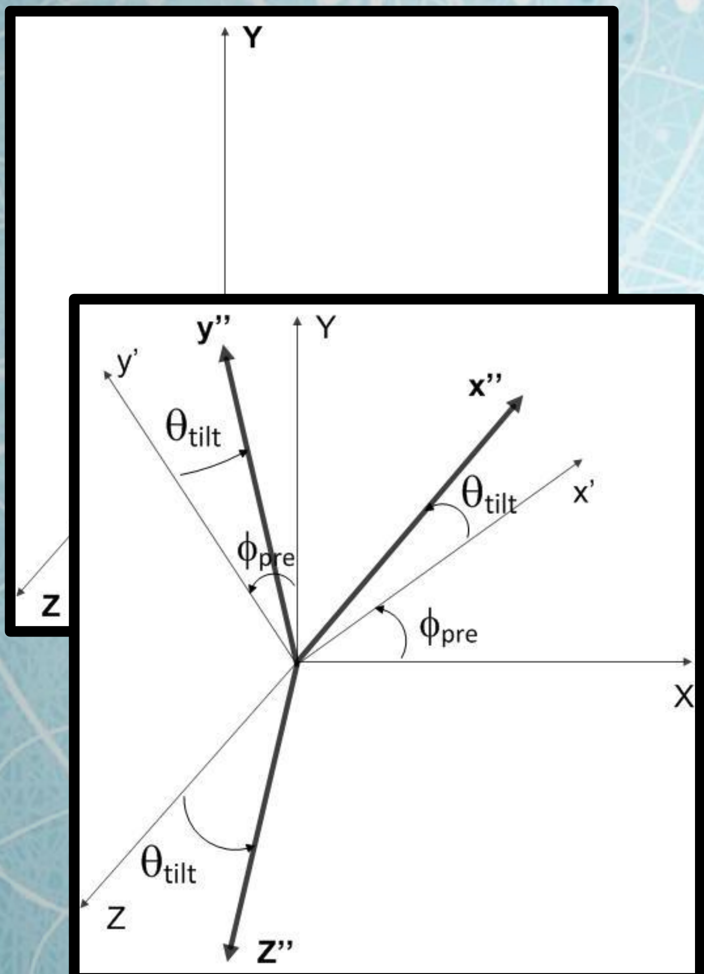
Virtual Reorientation

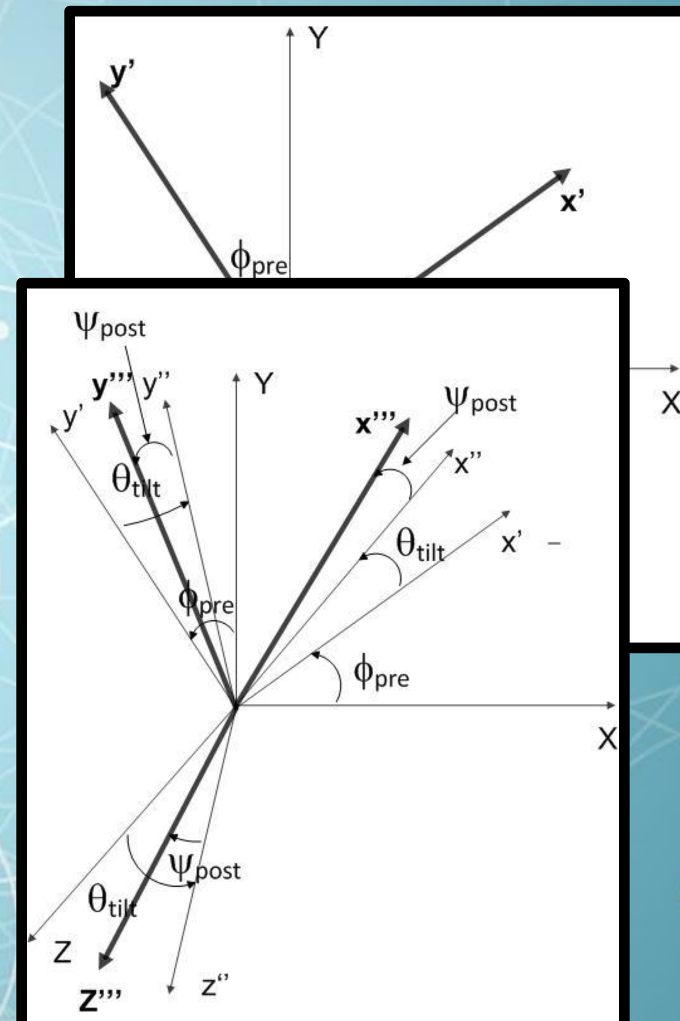


Virtual Reorientation

- Euler Angles:
  - Any orientation of the accelerometer can be represented by Z-Y-Z (and other equivalent) rotations
- Three Unknowns (angles):
  - pre-rotation (ϕ_{pre}),
  - tilt (θ_{tilt}),
  - post-rotation (ψ_{post})
- Knowns:
  - Gravity along Z
  - Braking along X

Euler Angles





Virtual Reorientation Using Gravity

- Ideal orientation (X,Y,Z): $a_X = 0$; $a_Y=0$; $a_Z=1(g)$;
- Current orientation (x,y,z) with force a_x , a_y , a_z
- $a_z = a_Z \cos(\theta_{tilt})$

$$\theta_{tilt} = \cos^{-1}(a_z)$$

- $a_x = a_Z \cos(\phi_{pre}) \sin(\theta_{tilt})$
- $a_y = a_Z \sin(\phi_{pre}) \sin(\theta_{tilt})$

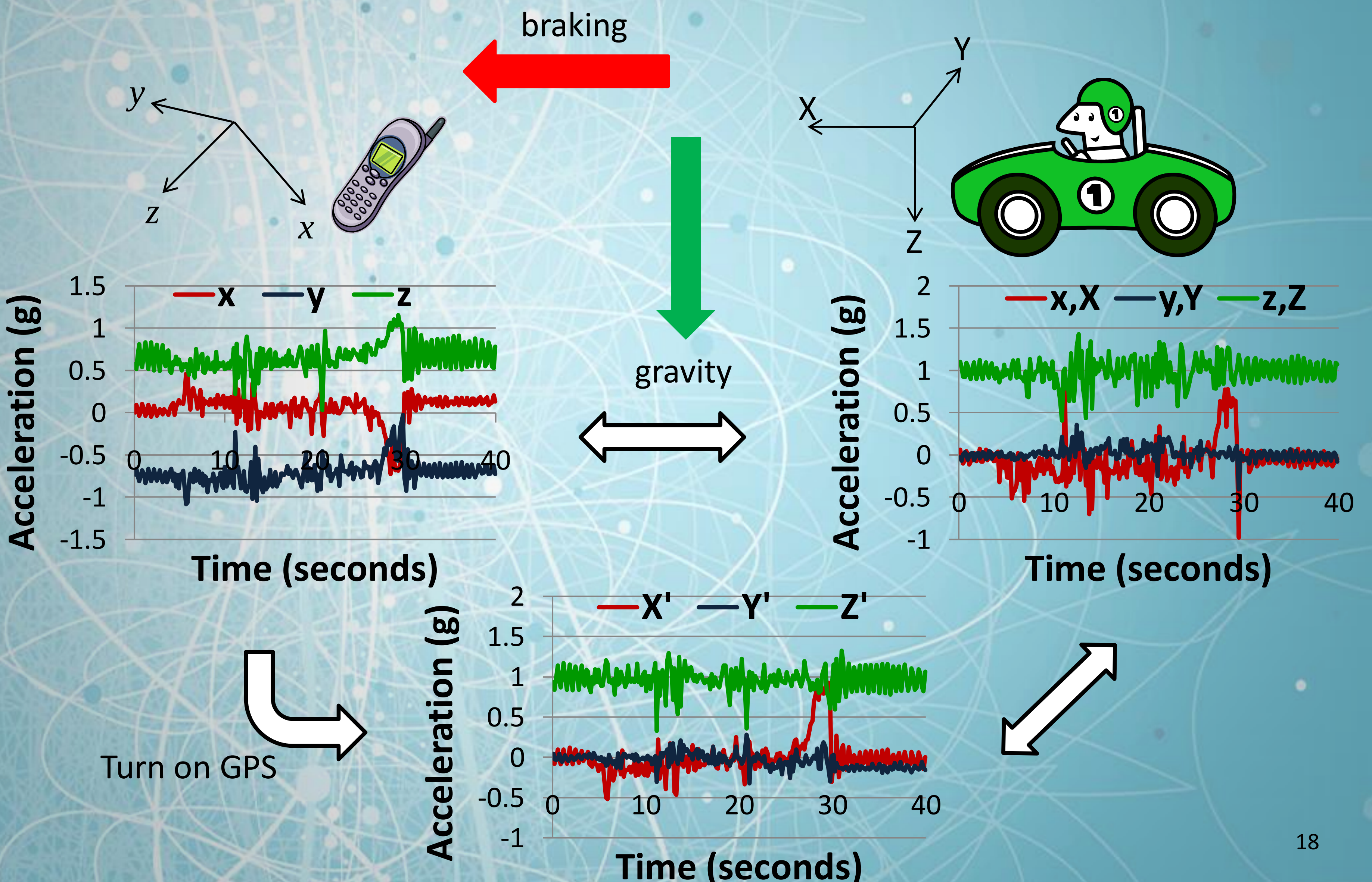
$$\phi_{pre} = \tan^{-1}(a_y / a_x)$$

Virtual Reorientation Using Braking

- Use GPS to identify braking
- Ideal orientation (X,Y,Z): a_X = large; a_Y=0; a_Z=1(g);
- Current orientation (x,y,z) with force a_x , a_y , a_z and angles θ_{tilt} and ϕ_{pre}
- Find ψ_{post} such that force along X is maximized

$$\psi_{post} = \tan^{-1}\left(\frac{-a_x \sin(\Phi_{pre}) + a_y \cos(\Phi_{pre})}{(a_x \cos(\Phi_{pre}) + a_y \sin(\Phi_{pre}))\cos(\theta_{tilt}) - a_z \sin(\theta_{tilt})}\right)$$

Automatic Virtual Reorientation



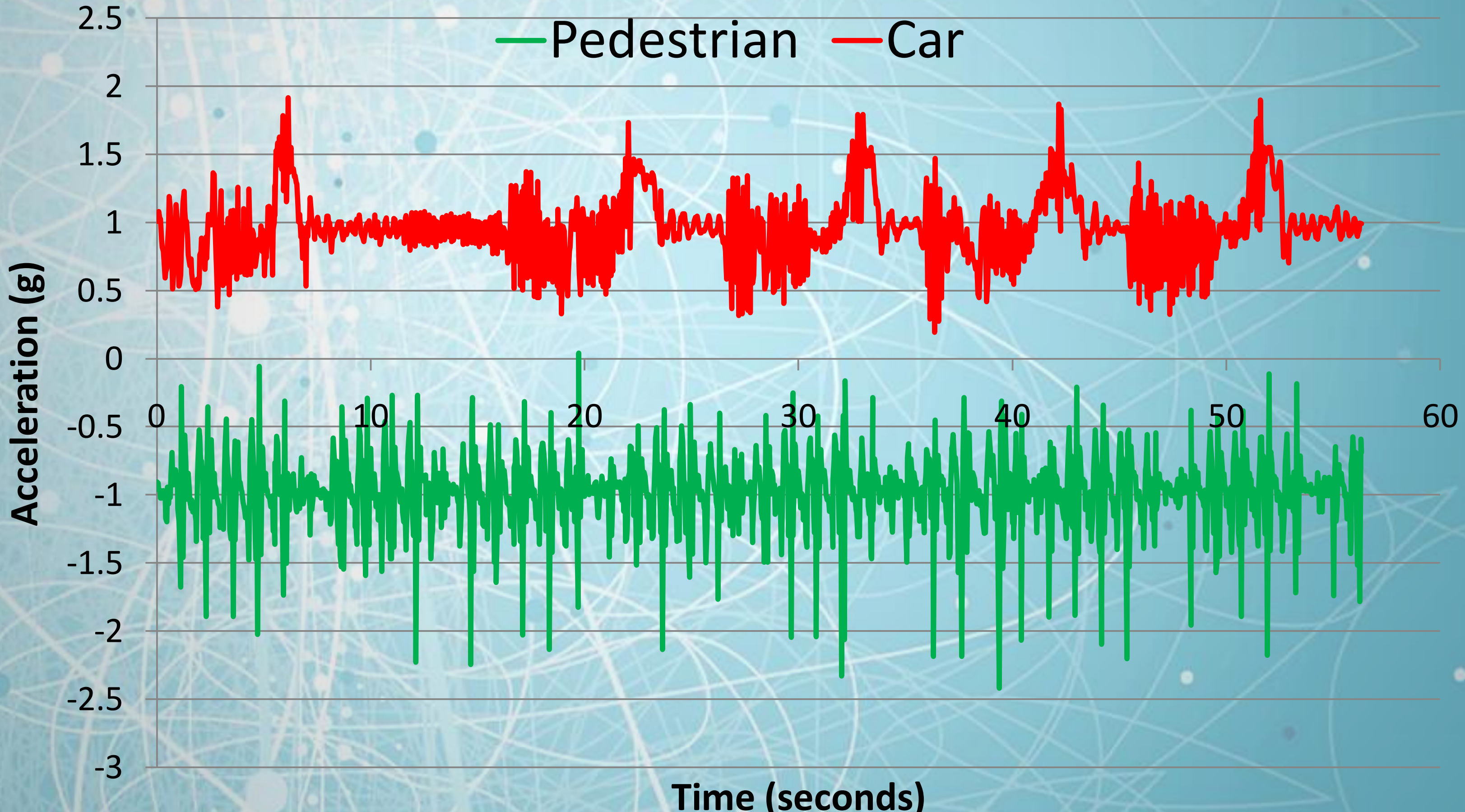
Results: Virtual Reorientation

Sr No	$\Phi_{pre}/\theta_{tilt}/\psi_{post}$	Cross correlation	
		Well oriented – Well oriented	Reoriented – Well oriented
1	7° /38° /106°	0.90	0.91
2	174° /34° /-107°	0.75	0.87
3	174° /34° /-107°	0.94	0.90
4	4° /42° /12°	0.74	0.68
5	3° /44° /-1°	0.76	0.79
6	-80° /42° /121°	0.78	0.73

Braking detection with Virtual Reorientation

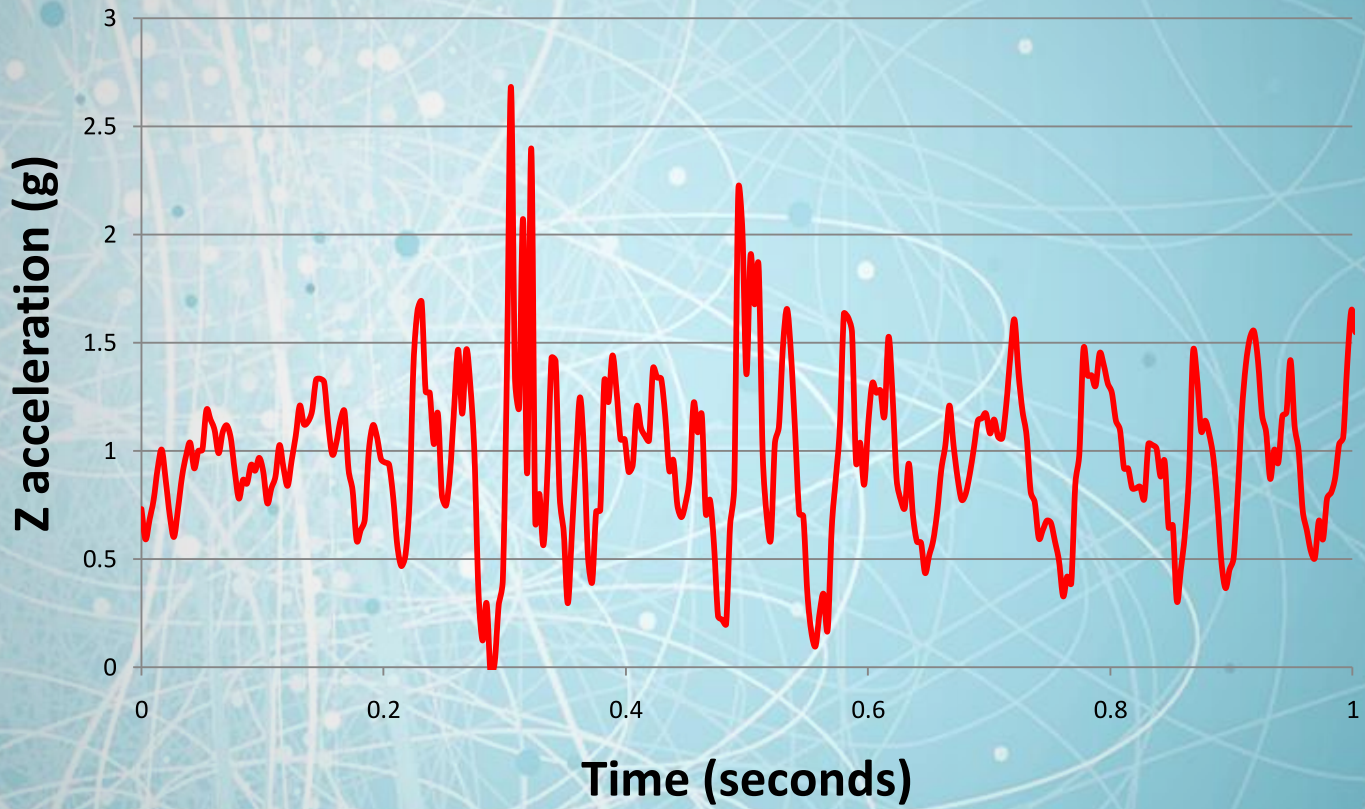
	False negatives	False positives
Well-oriented	11%	16%
Virtually reoriented	11%	18%

Differentiating pedestrians from stop-and-go traffic



Pothole Detection

Pothole Detection

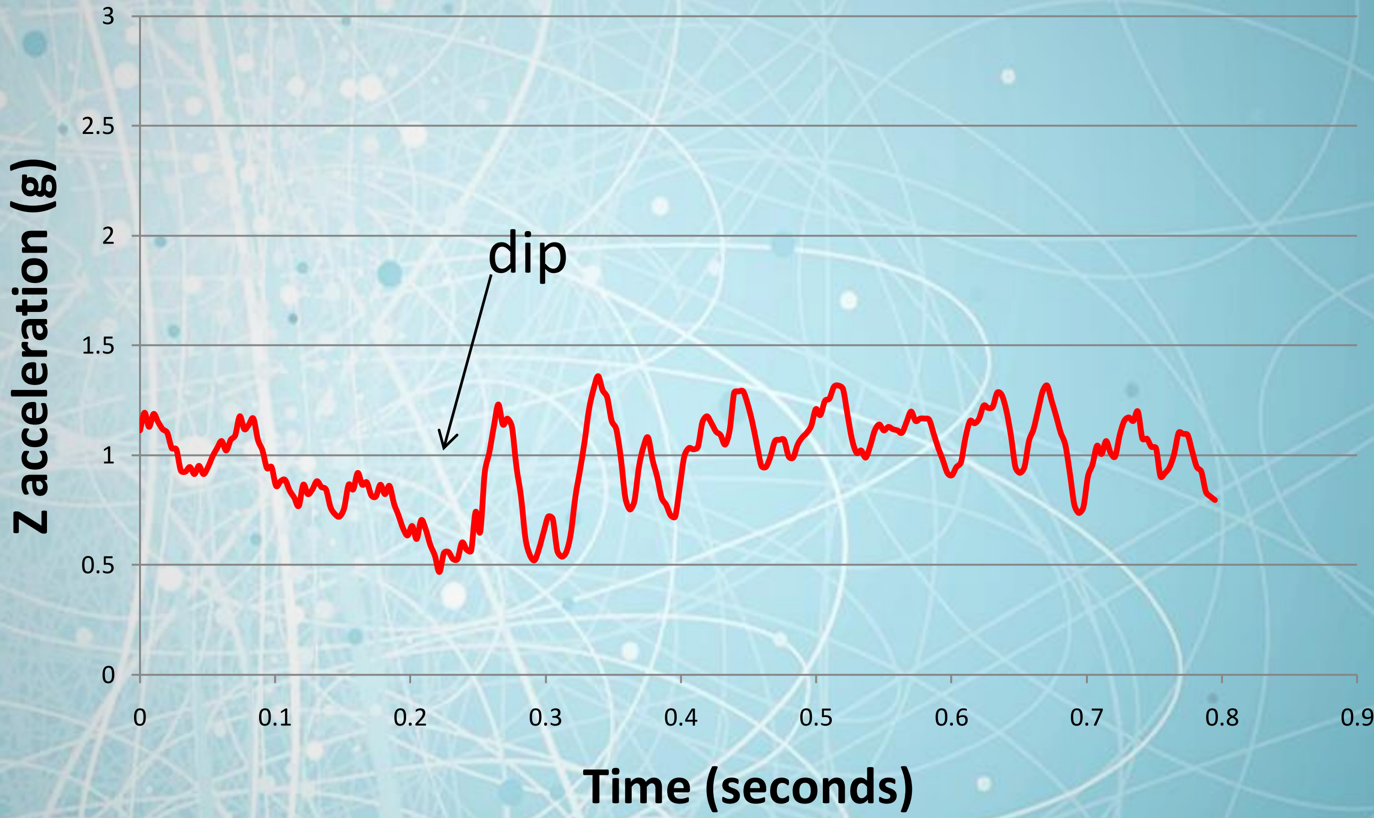


High speed (≥ 25 kmph)

z-peak: look for significant spike

Pothole Detection

Pothole Detection



Low speed (< 25 kmph)

z-sus: look for sustained dip

Results: Pothole Detection

Training data: 5km long drive with 44 bumps
Test data: 35km long drive with 101 bumps

Threshold	Speed < 25 kmph		Speed > 25 kmph	
	False Neg	False Pos	False Neg	False Pos
Z-sus (0.8g, 20ms)	37%	14%	0%	136%
Z-peak (1.45g)	65%	21%	3%	49%
Z-Peak (1.75g)	83%	0%	41%	8%

Locate a Pothole

- Why not just GPS?
  - coverage (indoors, urban canyons, inside a bus)
  - time to lock (~26 secs even with warm start)
  - energy (~600 mW on iPAQ 6965)
  - not all phones have it
- GSM tower based localization
  - widely accessible, fast, “zero” energy
  - Location: median error: 130m, 90^{th} %tile: 610m
  - Speed: median error: 3.4 kmph, 90^{th} %tile: 11.2 kmph
- Trigger GPS when GSM indicates zone of interest

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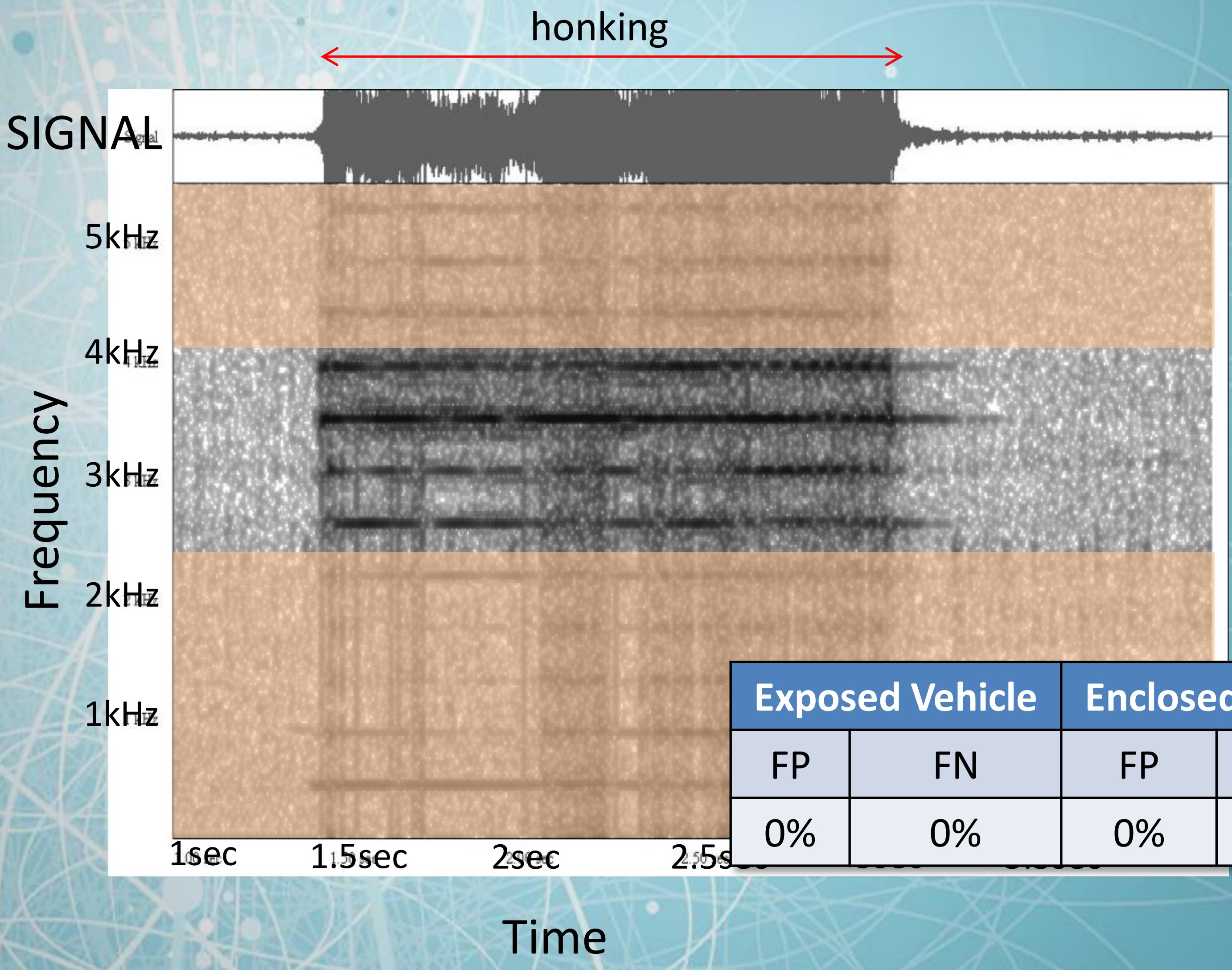
Honk Detection



Exposed Vehicle		Enclosed Vehicle	
FP	FN	FP	FN
0%	0%	0%	23%

Triggered Sensing

- Idea: Use low energy sensors to selectively trigger the activation of expensive sensors
- Examples:
  - Virtual Reorientation: accelerometer → GPS
  - Localization: GSM → GPS
  - Honk detection: accelerometer → audio

Related Work

- GPS based traffic monitoring
  - OnStar (GM)
  - Clearflow (MSR)
  - Surface street traffic estimation (UMich)
- Rich monitoring on vehicles
  - Cartel, Pothole Patrol (MIT)
- Dedicated sensor deployment
  - SmartTrek, Busview (WA State DOT)
  - INRIX
- Cell infrastructure based monitoring
  - BTIS (Bangalore city)
- Participatory sensing
  - MetroSense (Dartmouth) , Urban Sensing (UCLA)

Conclusion

- Smartphone: Computing + Comm + Sensing
- Mobile smartphone based sensing:
  - Accelerometer $\Rightarrow$ Bump, Braking detection
  - Microphone $\Rightarrow$ Honk detection
  - GSM + GPS $\Rightarrow$ Localization
- Automatic virtual reorientation of accel
- Triggered sensing to conserve energy
- Prototype implementation on Windows Mobile
- Pilot deployment on 4 cabs in MSR India

http://research.microsoft.com/research/mns/projects/Nericell/