



# Nericell: Rich Road and Traffic Monitoring using Mobile Smartphones

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# Traffic Monitoring

- GPS based tracking is adequate
- Infrastructure support exists



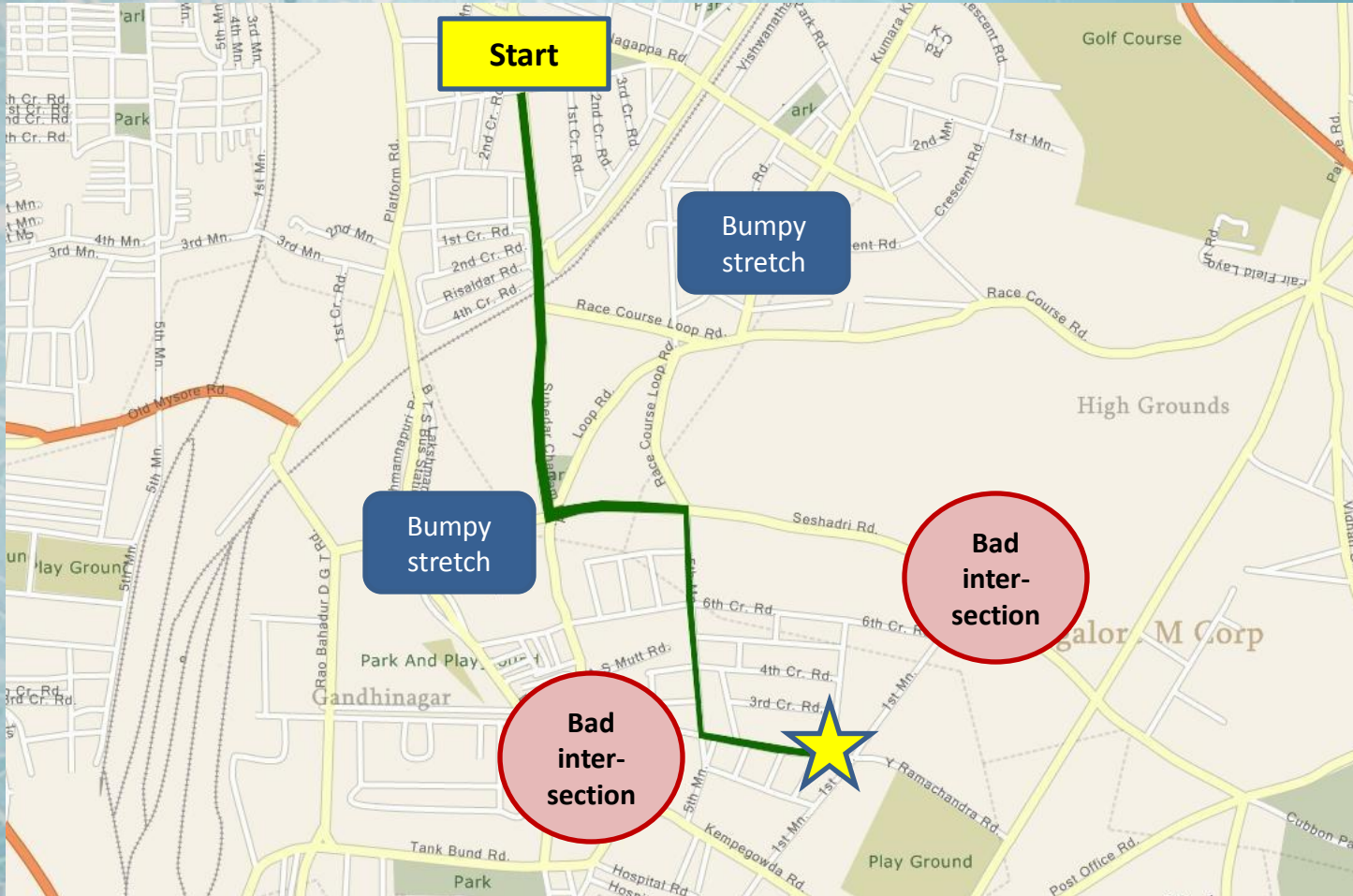
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# Beyond Traffic Monitoring

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



# Why Rich Monitoring?



Find least stressful route

# Widespread distribution of mobile phones

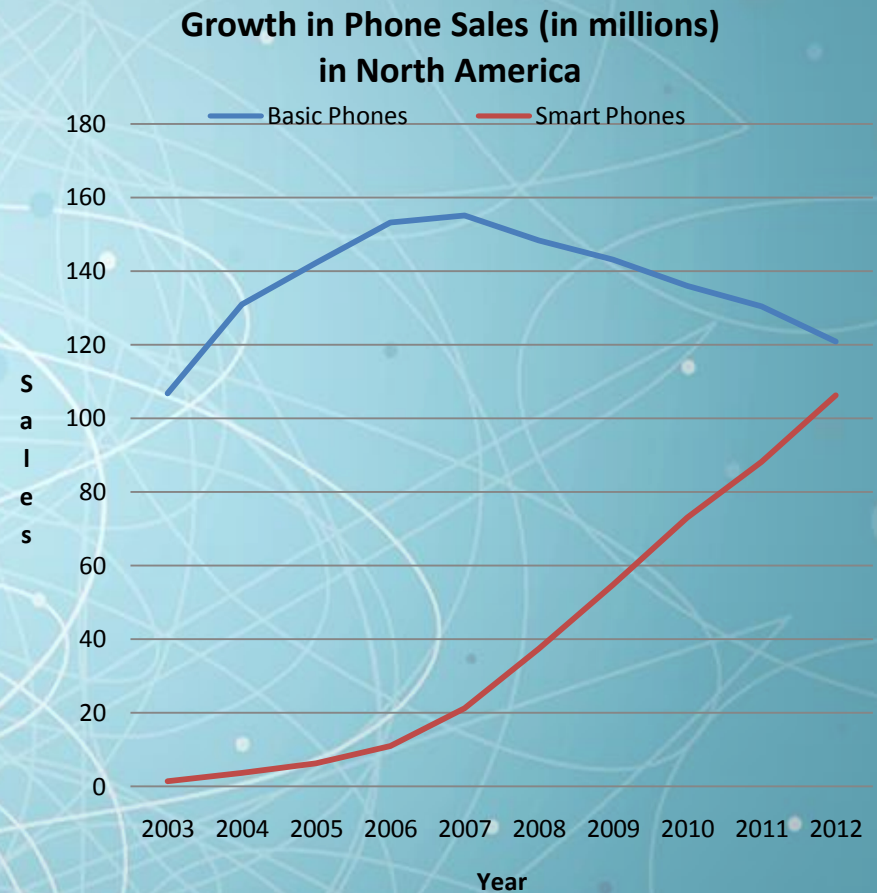


## Road and Traffic Monitoring

- 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  $\Rightarrow$  drive quality



- Microphone  $\Rightarrow$  honking



- GSM radio and GPS  $\Rightarrow$  localization

- Using sensors in combination

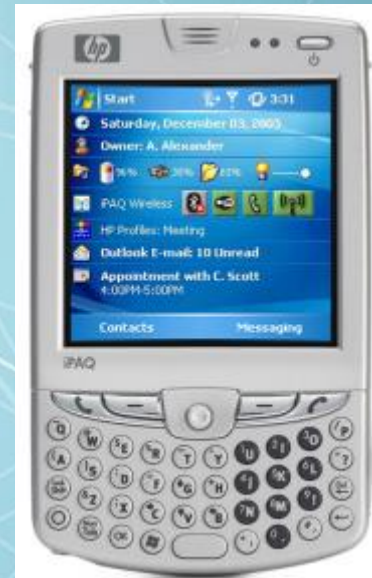
- Virtual reorientation of accelerometer

- 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**

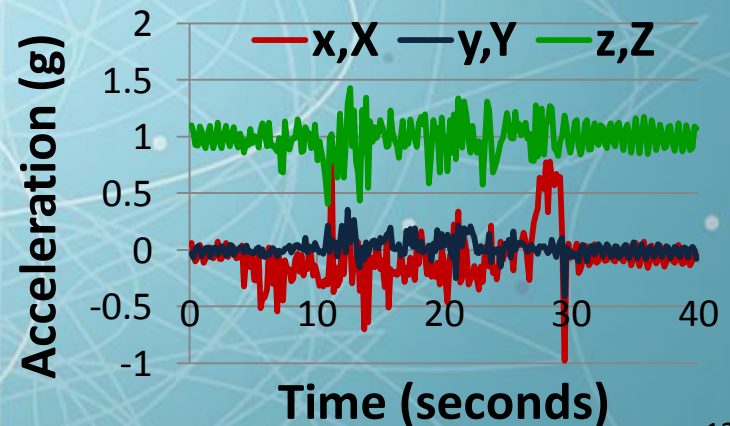
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- **Accelerometer based detection**
- **Virtual Reorientation**
- Microphone based detection
- Triggered Sensing
- Conclusion

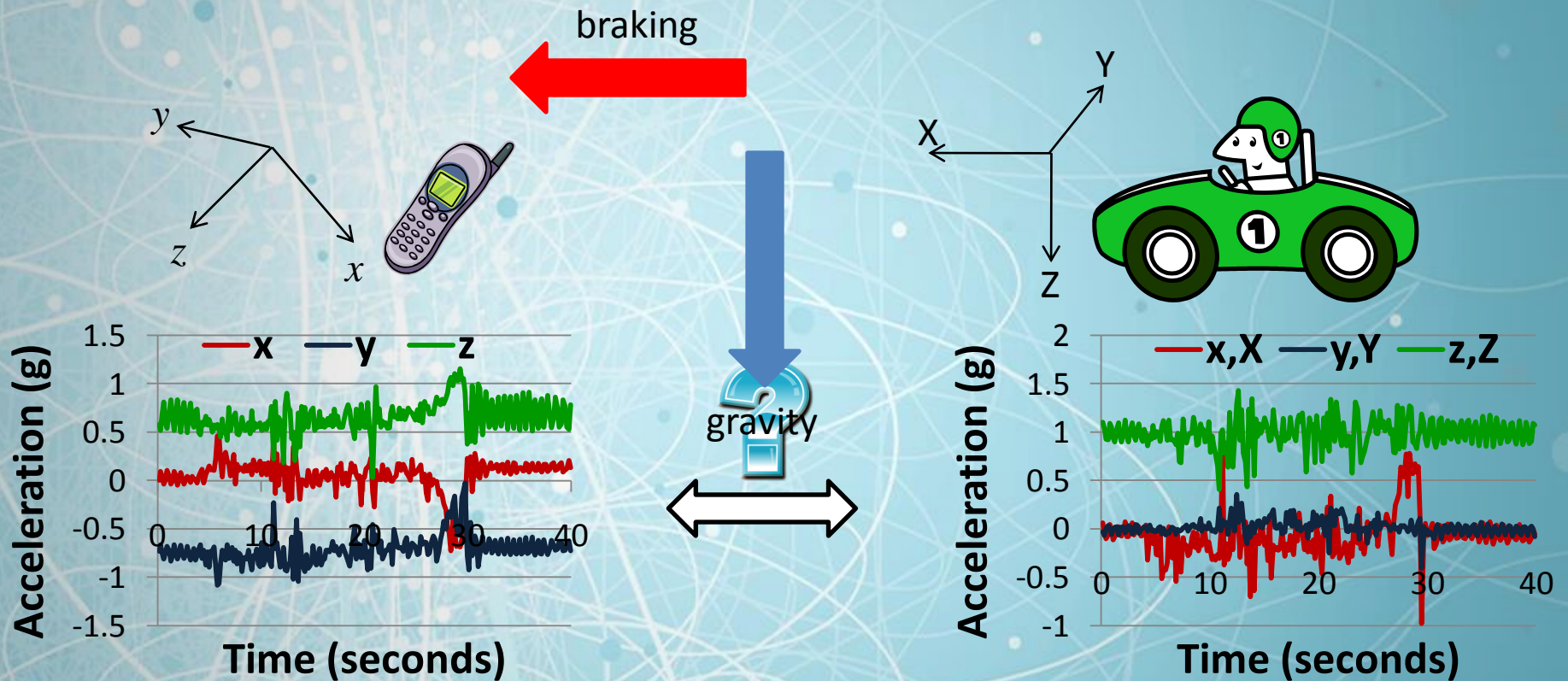
# Braking Detection

- 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
<b>0.12</b> (4 sec)	11%	16%



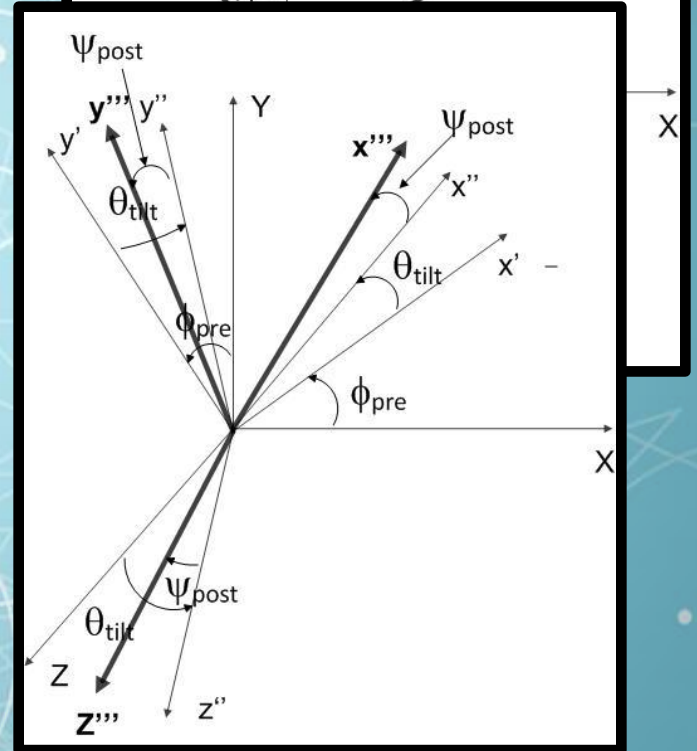
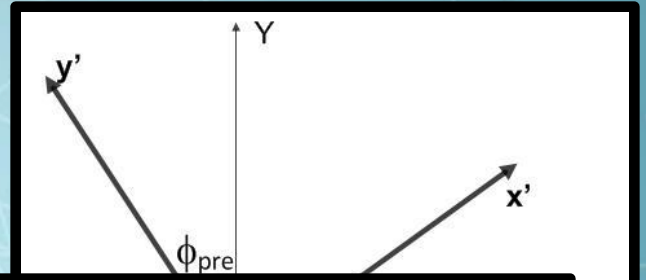
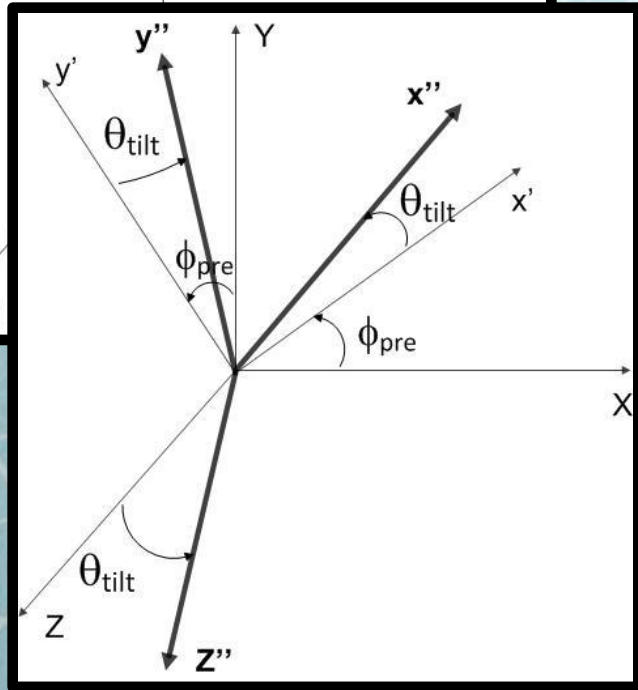
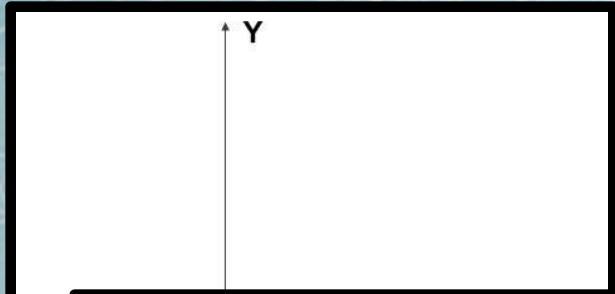
# Virtual Reorientation



# 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 ( $\phi_{\text{pre}}$ ),
  - tilt ( $\theta_{\text{tilt}}$ ),
  - post-rotation ( $\psi_{\text{post}}$ )
- 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  $a_x$ ,  $a_y$ ,  $a_z$
- $a_z = a_z \cos (\theta_{\text{tilt}})$

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

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

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

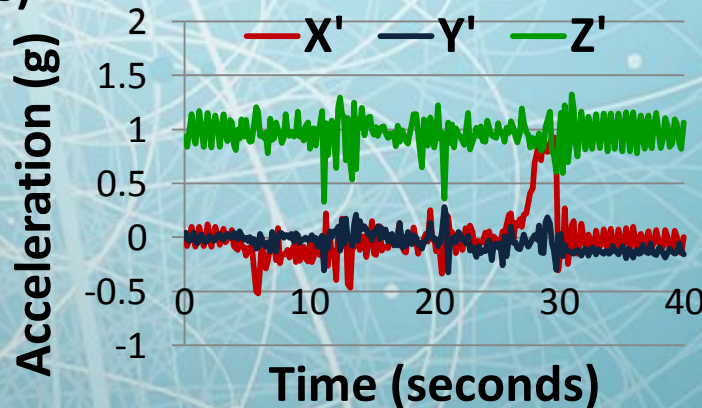
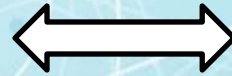
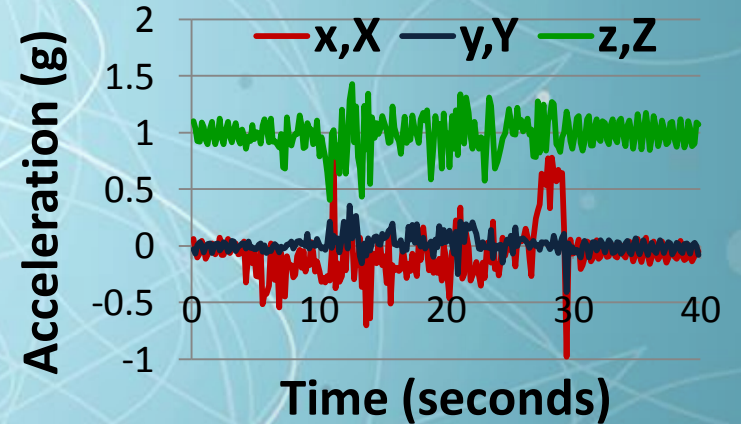
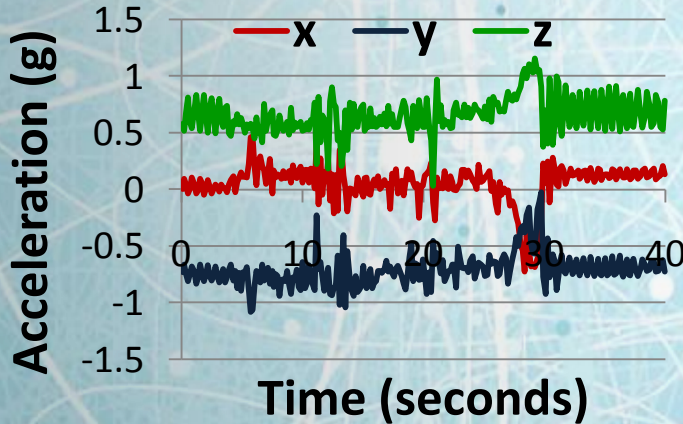
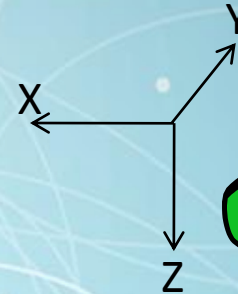
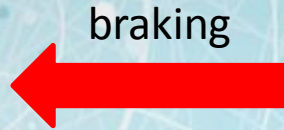


# Virtual Reorientation Using Braking

- Use GPS to identify braking
- Ideal orientation (X,Y,Z):  $a_x = \text{large}$ ;  $a_y=0$ ;  $a_z=1(g)$ ;
- Current orientation (x,y,z) with force  $a_x$ ,  $a_y$ ,  $a_z$  and angles  $\theta_{\text{tilt}}$  and  $\phi_{\text{pre}}$
- Find  $\psi_{\text{post}}$  such that force along X is maximized

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

# Automatic Virtual Reorientation



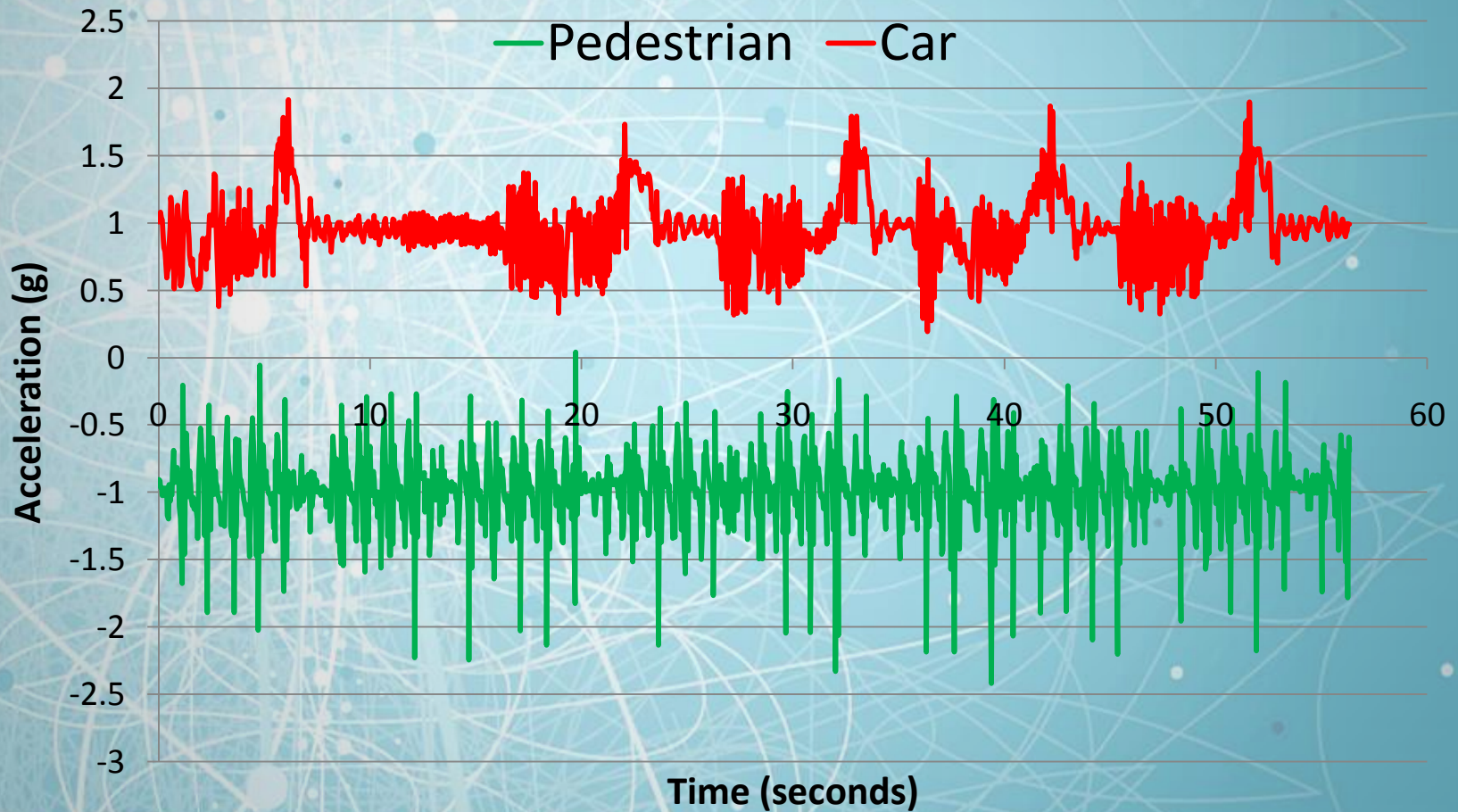
# Results: Virtual Reorientation

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%

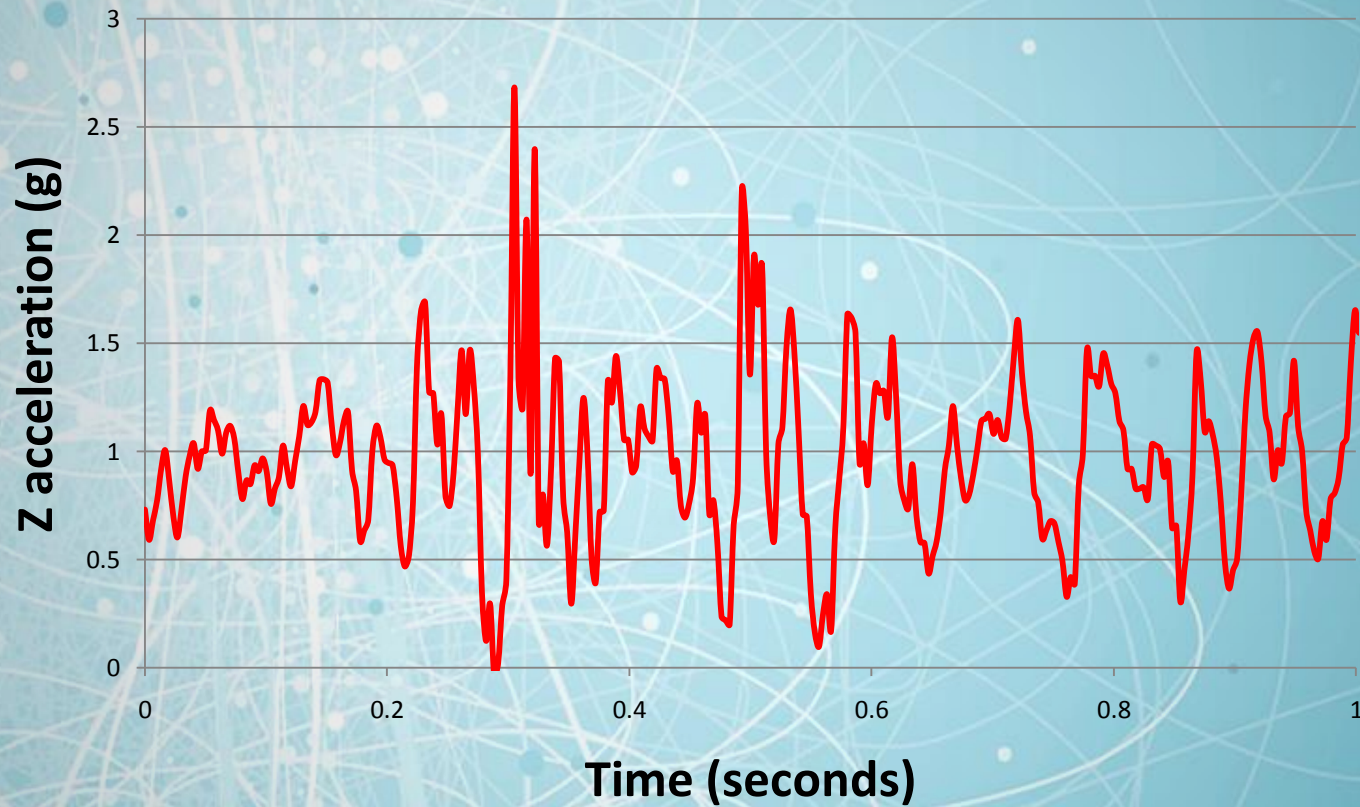
# Differentiating pedestrians from stop-and-go traffic



# Pothole Detection



# Pothole Detection



High speed ( $\geq 25$  kmph)

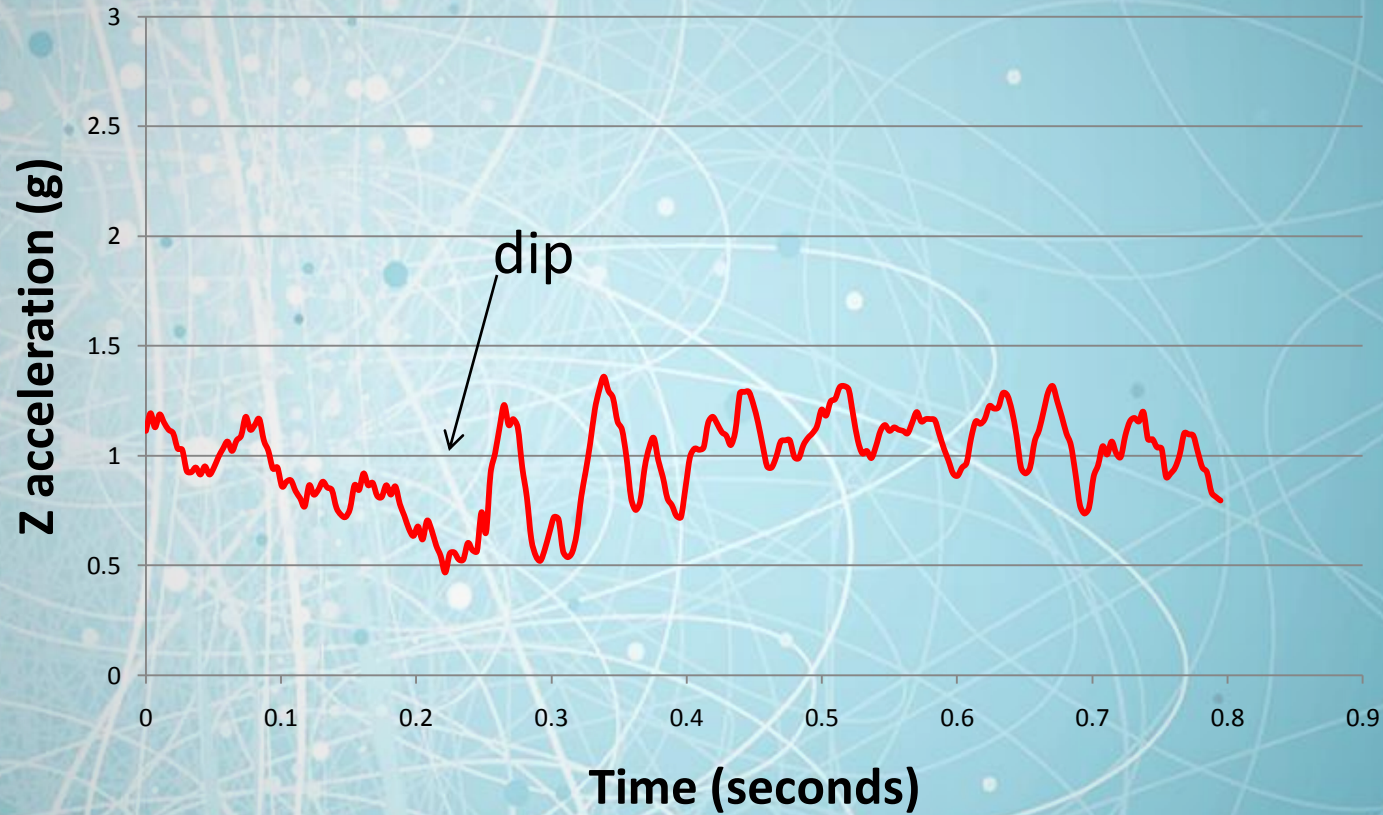
*z-peak*: look for significant spike

# 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%

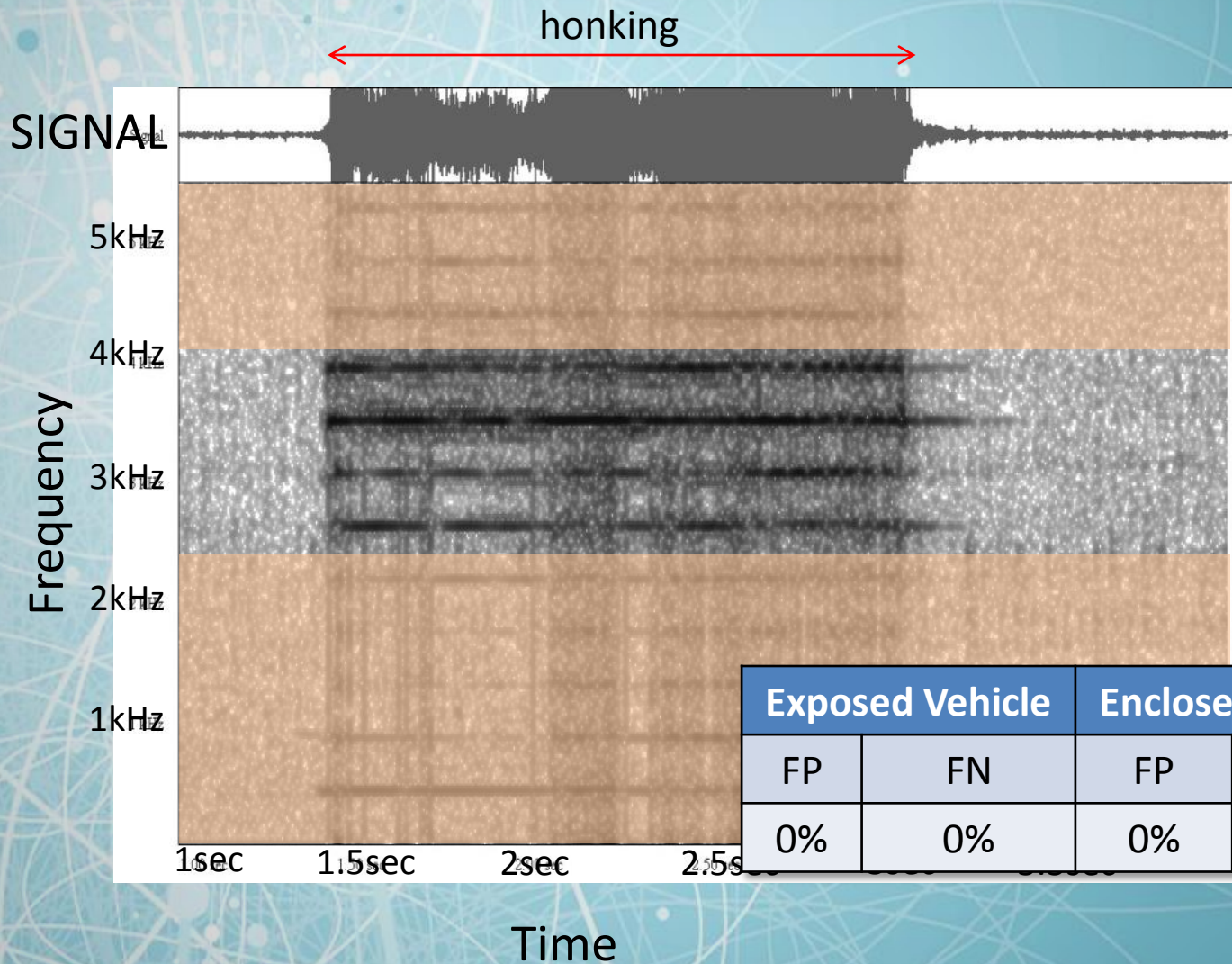
# Locate a Pothole

- 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<sup>th</sup> %tile: 610m
  - Speed: median error: 3.4 kmph, 90<sup>th</sup> %tile: 11.2 kmph
- Trigger GPS when GSM indicates zone of interest

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# Honk Detection



# 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/>