PerSec
Pervasive Computing and Security Lab

Enabling Transportation Safety Services Using Mobile Devices

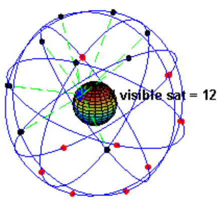
Jie Yang
Department of Computer Science
Florida State University

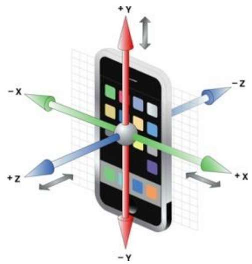
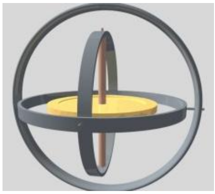
Oct. 17, 2017
CIS 5935 Introduction to Research

FLORIDA STATE UNIVERSITY

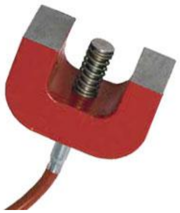
Background: Mobile Devices

- **Mobile devices**
  - Smartphones, tablets, Google glasses, smart watches, wearable devices…
- **Rich sensors**







. . .

- **Wireless technologies**




. . .

Background: Driving Safety & Efficiency

1 billion highway vehicles

SAFETY

- 1.2 million traffic fatalities per year

ENERGY

- 30% of world Energy

EMISSIONS

- 25% of world CO_2 Emissions

TRAFFIC

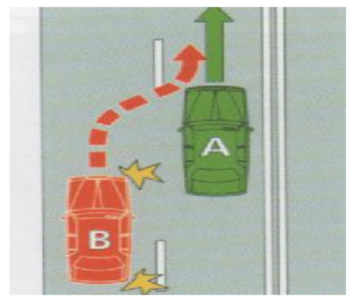
- 1.5 hours per day on a vehicle

What to Sense with Mobile/Wearable Devices?

- **Driver behaviors**
  - Cell phone distraction
  - Drowsy driving
  - Drunk driving
  - …



- **Vehicle dynamics**
  - Lane changing
  - Breaking, Acceleration
  - Making turns
  - …

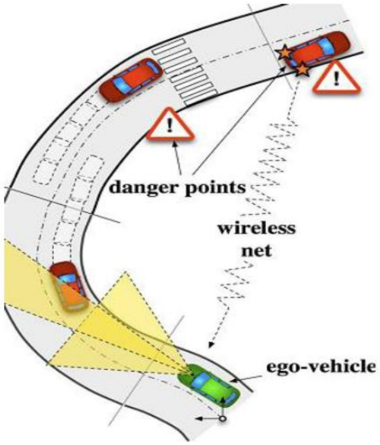


- **Surroundings**
  - Potholes
  - Nearby vehicles
  - Pedestrian crossing street
  - …



Sensing Enabled Safety Services

- ❑ **Reducing driver distraction**
  - ❖ Cell phone use, eating…
  - ❖ Drowsy driving…
  - ❖ …
- ❑ **Pedestrian safety**
  - ❖ Waling across street
  - ❖ Talking on the phone while walking
  - ❖ …
- ❑ **Driving safety assistant systems**
  - ❖ Curve speed warning,
  - ❖ Dangerous location (obstacle) warning
  - ❖ Safe distance warning
  - ❖ Lane departure and change/merge warning
  - ❖ Forward collision warning
  - ❖ …



Gyroscope and Accelerometer: Driving Behavior

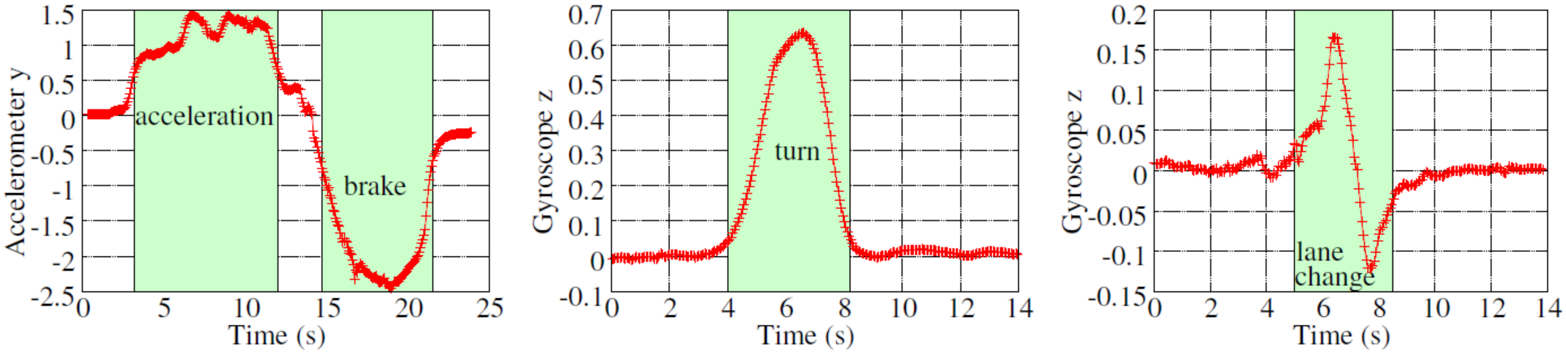


Figure 1: Driving behaviours, from left to right, they are acceleration, brake, turn and lane change.

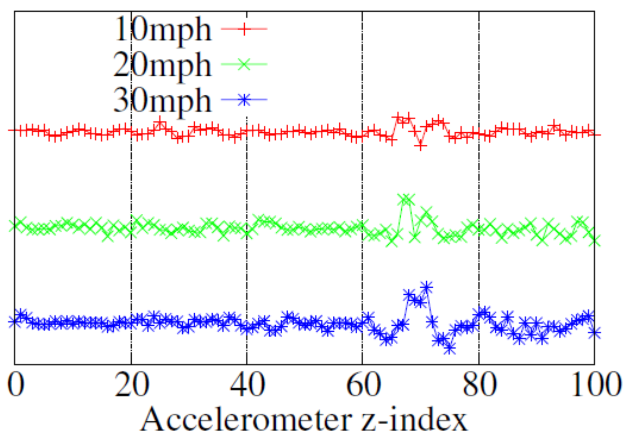


Figure 2: Driving over the same pothole from the same direction with different speeds.

Pathholes

Cameras: Driving/Walking Safety

WalkSafe: A Pedestrian Safety App for Mobile Phone Users Who Walk and Talk While Crossing Roads

Tianyu Wang[1], Giuseppe Cardone[2], Antonio Corradi[2],
Lorenzo Torresani[1], and Andrew T. Campbell[1]
Computer Science Dartmouth College 1
6211 Sudikoff Lab, 03755 Hanover, NH, U.S.A.
{tianyuw, lorenzo, campbell}@cs.dartmouth.edu
University of Bologna 2
V.le Risorgimento, 2, 40136 Bologna, Italy
{giuseppe.cardone, antonio.corradi }@unibo.it

Video: https://www.youtube.com/watch?v=Fk4xK1q5P3s

CarSafe: A Driver Safety App that Detects Dangerous Driving Behavior using Dual-Cameras on Smartphones

Chuang-Wen You[1], Martha Montes-de-Oca[2], Thomas J. Bao[1], Nicholas D. Lane[3],
Giuseppe Cardone[4], Lorenzo Torresani[1], and Andrew T. Campbell[1]

Video: https://www.youtube.com/watch?v=tAd_sSfhZTw

Case Study: Driver Phone User Detection

- Audio based approach
- Inertial sensors based detection
- Intervention

Source: Jie Yang, Simon Sidhom, Yingying Chen et al. "Detecting driver phone use leveraging car speakers." in MobiCom 2011.
Yan Wang, Jie Yang, Yingying Chen et al. "Sensing Vehicle Dynamics for Determining Driver Phone Use." in MobiSys 2013

Cell Phones Distract Drivers

- Cell phone as a distraction in 2009 on U.S. roadways
  - 18% of fatalities in distraction-related crashes involved reports of a cell phone
  - 995 fatalities
  - 24,000 injuries

Talking on Hand-held Cell

✓Visual — Eyes off road
✓Cognitive — Mind off driving

Texting on Hand-held Cell

✓Manual — Hands off wheel
✓Visual — Eyes off road
✓Cognitive — Mind off driving

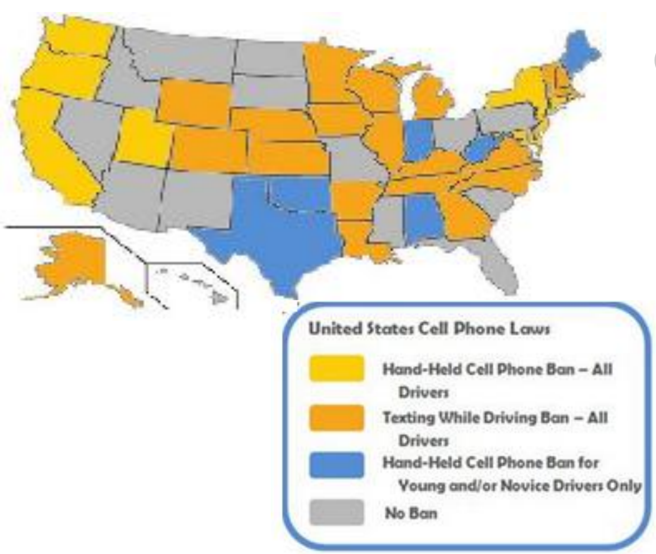
81% of drivers admit to talking on phone while driving

18% of drivers admit to texting while driving

Source: "Distracted Driving 2009" National Highway Traffic Safety Administration Traffic Safety Facts, 2009

Cell Phone Distraction: What's Being Done?

- ❑ Law
  - ❖ Several States ban handheld phone use
- ❑ Technology
  - ❖ Hard blocking: radio jammer, blocking phone calls, texting, chat …
  - ❖ Soft interaction
    - ➢ Routing incoming calls to voicemail,
    - ➢ Delaying incoming text notifications
    - ➢ Automatic reply to callers

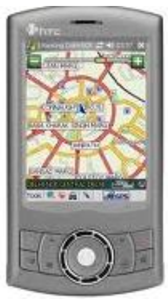


Automatic Reply: "I'm driving right now; will get back with you!"

What's Being Done?

- Is a Cell Phone in a Moving Vehicle ?

- Current Apps that actively prevent cell phone use in vehicle
  - **ONLY** detect the phone is **in vehicle** or not!



GPS

Handover

Signal Strength

Car's speedometer

The Driver-Passenger Challenge

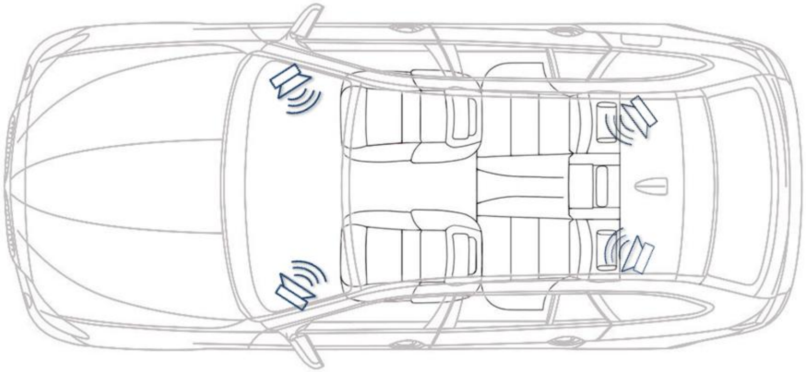
38% of automobile trips include passengers !

Source: National highway traffic safety administration: Fatality analysis reporting system

Acoustic based Approach
- Distinguish driver from passenger

- Utilize built-in audio infrastructure
  - Acoustic ranging approach: distance estimation between phone and speakers
  - Require Bluetooth hands-free system

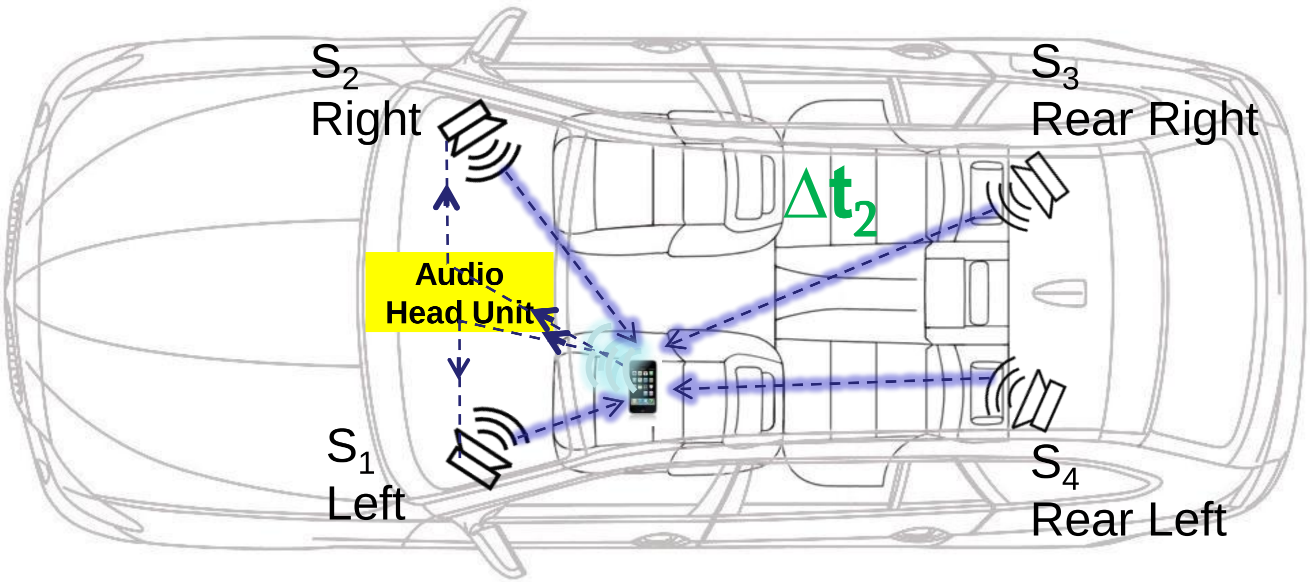
Phone connecting with head unit

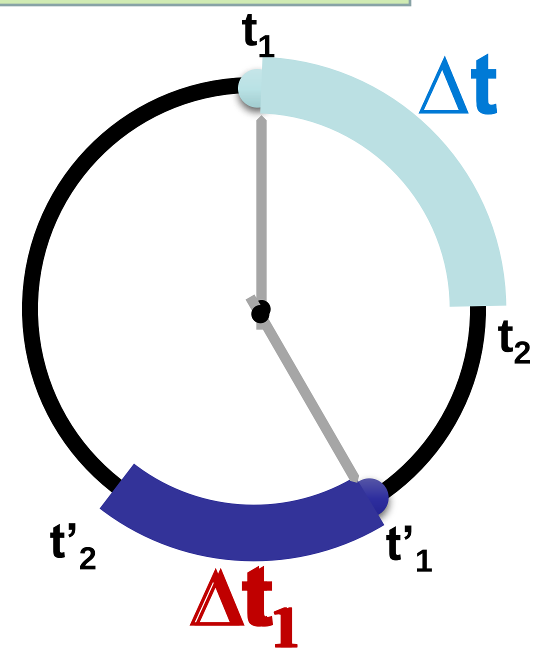


Symmetric positioning of speakers

Source: Jie Yang, Simon Sidhom, et al. "Detecting driver phone use leveraging car speakers." in MobiCom 2011.

How Does It work?



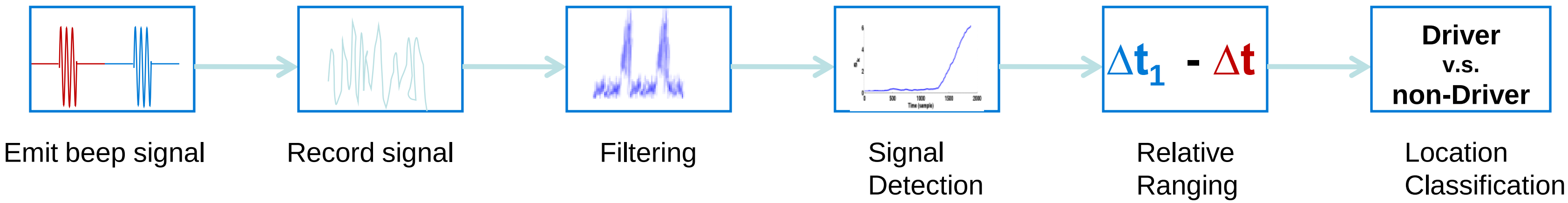


- = ?

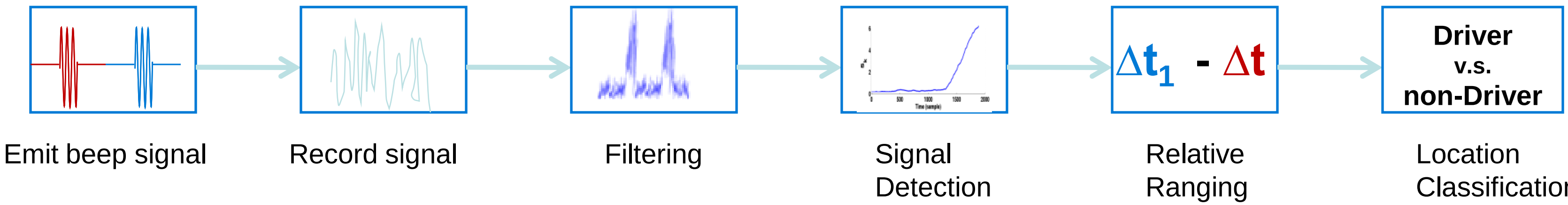
$\Delta t_1 - \Delta t > 0$ => Closer to Left Speaker (S_1)
$\Delta t_1 - \Delta t < 0$ => Closer to Right Speaker (S_2)

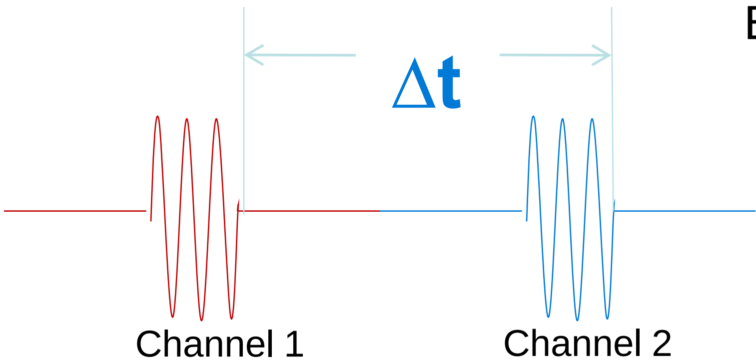
$\Delta t_2 - \Delta t > 0$ => Closer to Front Speaker (S_1, S_2)
$\Delta t_2 - \Delta t < 0$ => Closer to Back Speaker (S_3, S_4)

Walkthrough of the detection system



Walkthrough of the detection system





Beep signal: two channels

Beep signal design

- ➢Consider two challenges:
  - ✓Background noise and unobtrusiveness

High frequency beep

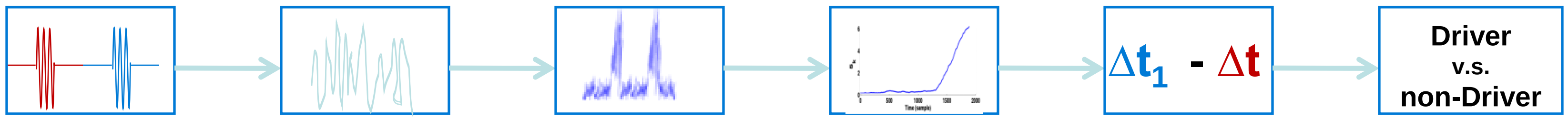
- ➢Robust to noise:
  - ✓engine, tire/road, conversation, music
- ➢Unobtrusiveness
  - ✓Close to human's hearing limit

Δt: 10,000 samples

Beep Length: 400 samples (i.e., 10 ms)

Increasing frequency

Walkthrough of the detection system



Emit beep signal | Record signal | Filtering | Signal Detection | Relative Ranging | Location Classification

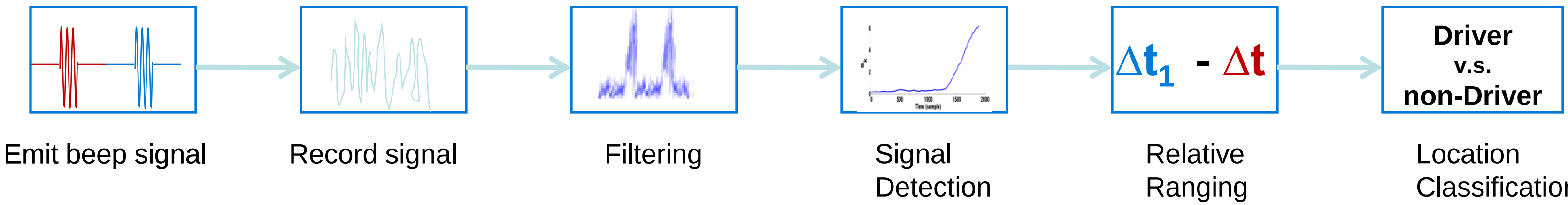
Where is the beep signal?

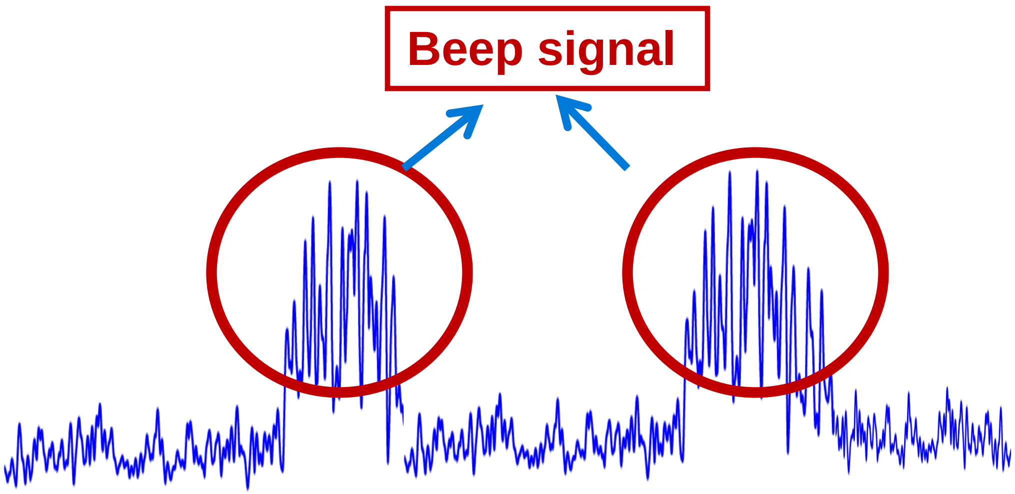
Recorded signal

Signal distortion:

- Heavy multipath in-car
- Background noise
- Reduced microphone sensitivity

Walkthrough of the detection system





Signal after Filtering

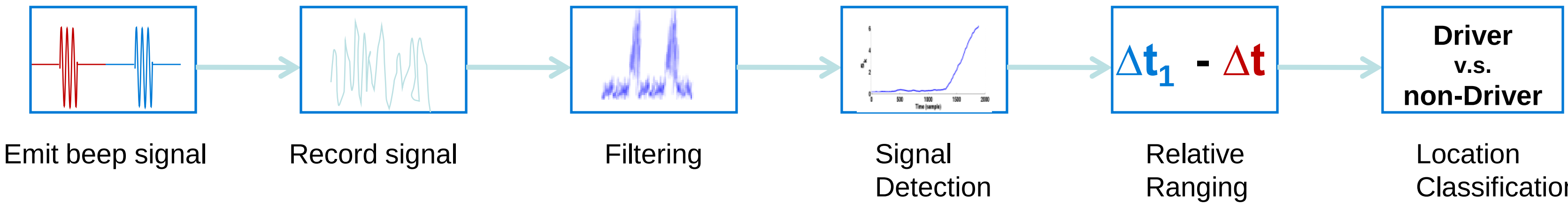
Filter out background noise

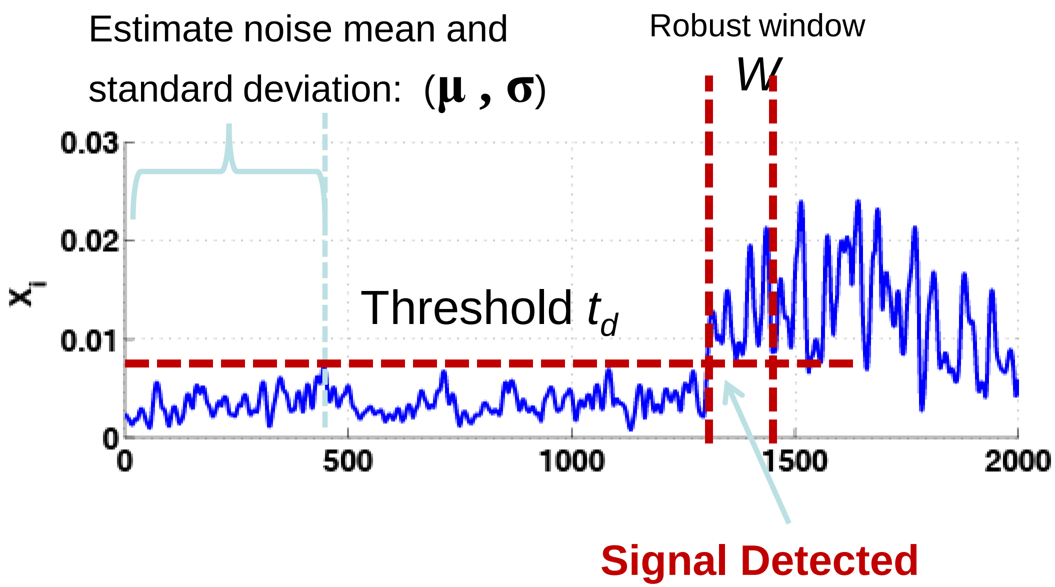
- Noise mainly located below 15kHz
- Beep signal frequency is above 15kHz

STFT Filter

- Moving window size *m:* 32 samples

Walkthrough of the detection system





Signal Detection

Change-point detection

- Identifying the first arriving beep signal that deviates from the noise

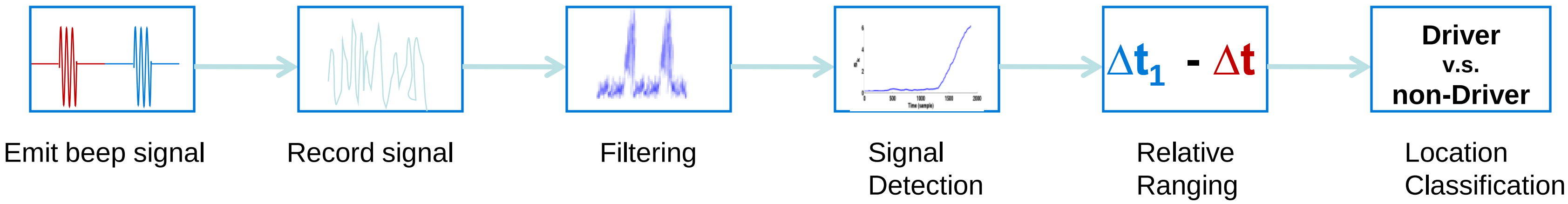
Threshold $t_{d:}$

- Based on noise: **μ + 3•σ**
- 99.7% confidence level of noise

Robust window $W_{:}$

- Reduce false detection
- 40 samples

Walkthrough of the detection system



$$\Delta t_1 - \Delta t$$

Δt: Predefined fixed time interval between two beep sounds

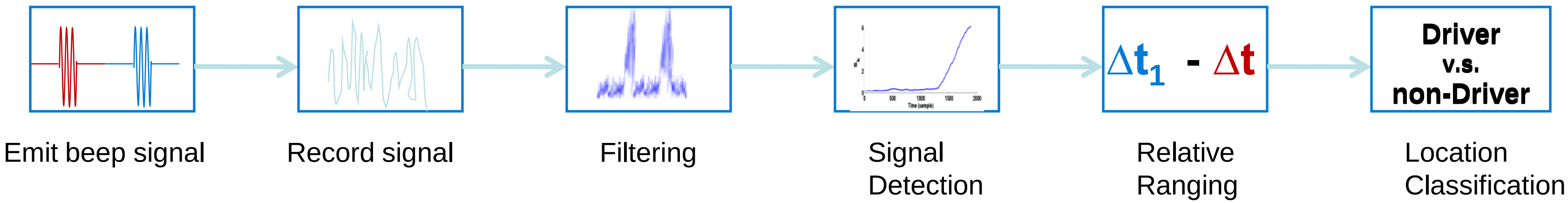
Δt_1: Calculated time difference of arrival based on signal detection

Time difference Δt_1:

- Measured by sample counting

$\Delta t_1 - \Delta t$: Relative ranging -> cell phone to two speakers

Walkthrough of the detection system



Driver v.s. Passenger

With two-channel audio system:

> **Δt_1 - Δt > 0 => Left Seats (Driver Side)**
> **Δt_1 - Δt < 0 => Right Seats**

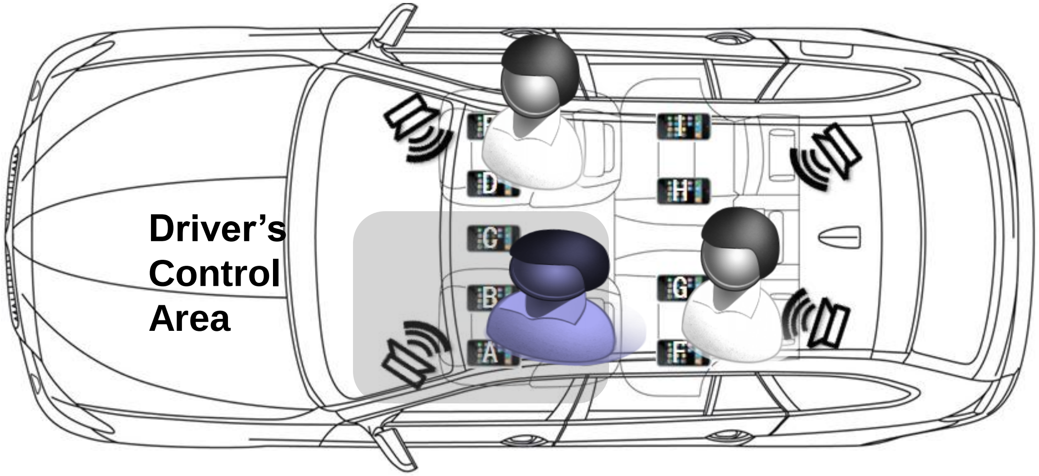
With four-channel audio system: relative ranging from the 3rd or/and 4th channels: Δt_2

> **Δt_2 - Δt > 0 => Front Seats**
> **Δt_2 - Δt < 0 => Rear Seats**

Automobile trips:
83.5%: driver only or plus one front passenger;
8.7%: a passenger behind driver seat.

Experimental Scenarios

- **Testing positions**



- **Different number of occupants**
- **Different noise conditions**
    - *Highway Driving*
        - 60MPH + music playing + w/o window opened
        - Phones at front seats only
    - *Stationary*
        - Varying background noise: idling engine + conversation

Phones and Cars

❑Phones

- Bluetooth radio
- 16-bit 44.1kHz sampling rate
- 192 RAM
- 528MHz MSM7200 processor

Android Developer Phone 2

- Bluetooth radio
- 16-bit 44.1kHz sampling rate
- 256 RAM
- 600 MHz Cortex A8processor

iPhone 3G

❑Cars

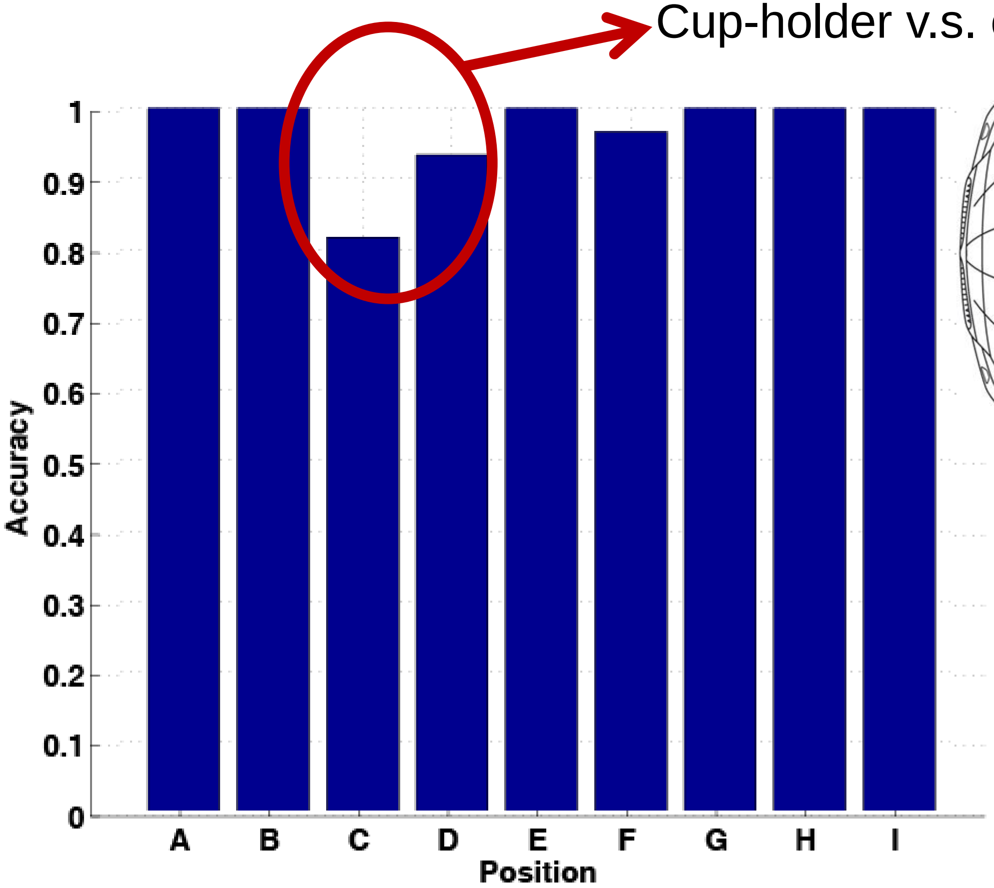
Honda Civic Si Coupe

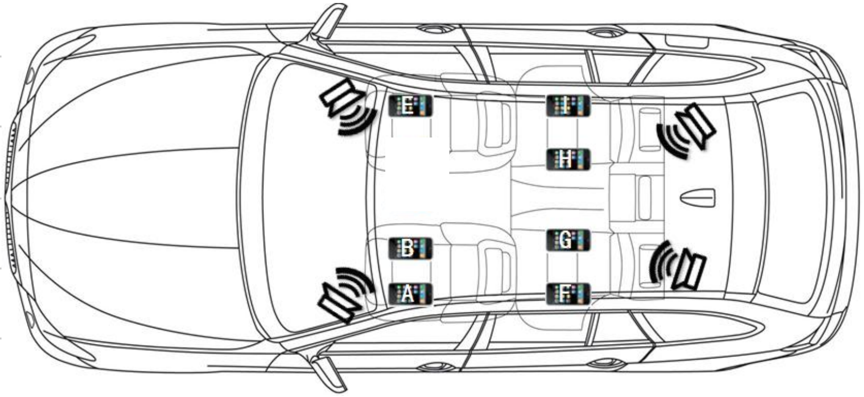
Acura sedan

- Bluetooth radio
- Two channel audio system
- two front and two rear speakers
- Interior dimension
  - ➢Car I: 175 x 183 cm
  - ➢Car II: 185x 203cm

Results: Position Accuracy

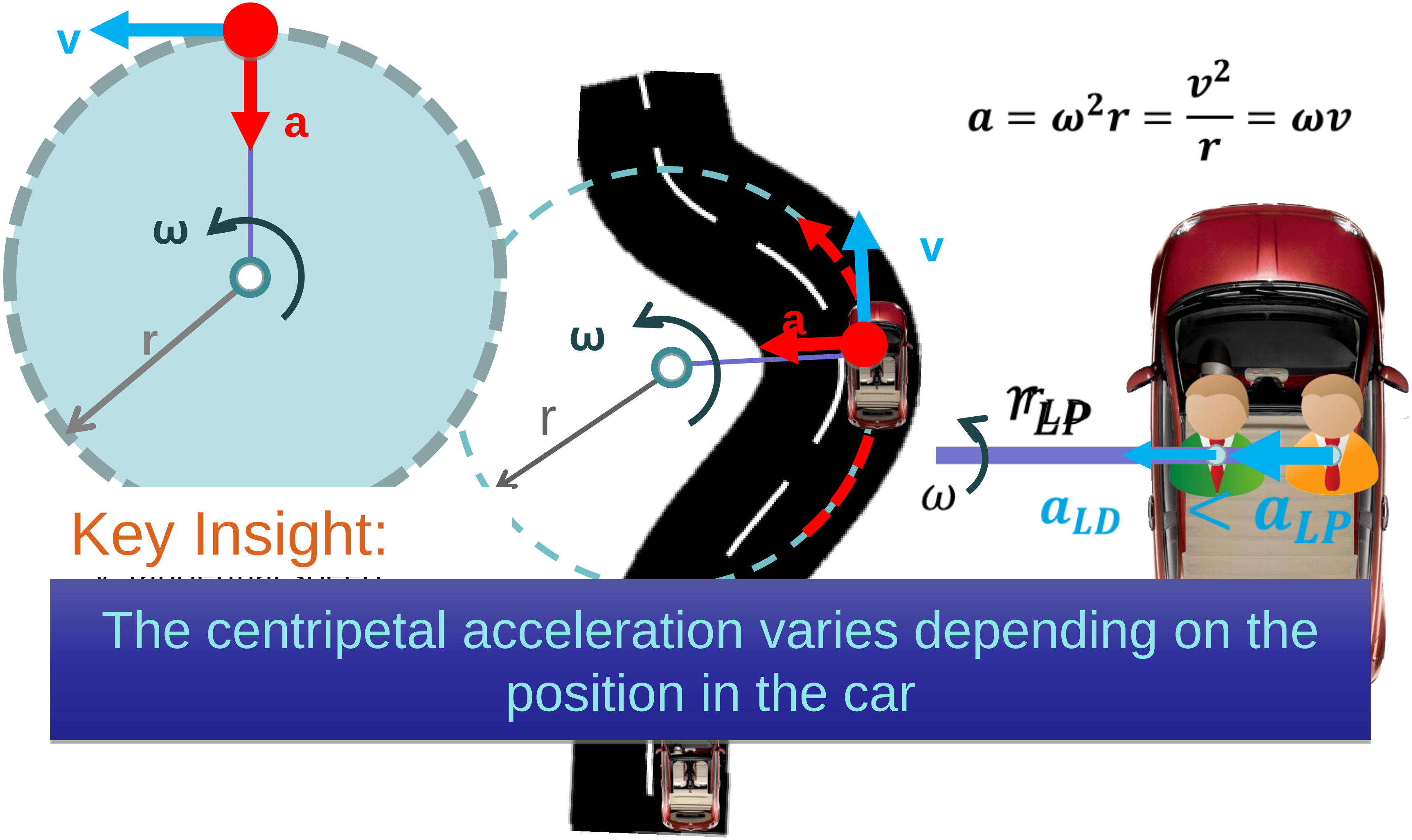
Cup-holder v.s. co-driver left





Low-Infrastructure Approach

- Using Centripetal Acceleration



Key Insight:

The centripetal acceleration varies depending on the position in the car

Source: Yan Wang, Jie Yang, et al. "Sensing Vehicle Dynamics for Determining Driver Phone Use." in MobiSys 2013.

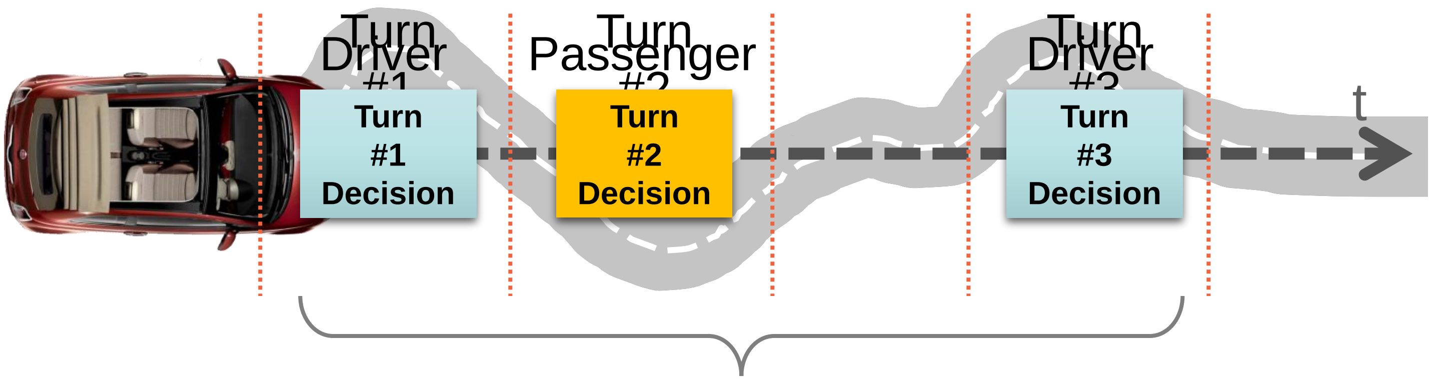
Obtaining Centripetal Acceleration from Different References

- Cigarette lighter adapter with accelerometer
  - Obtain vehicle's centripetal acceleration
- OBDII port adapter
  - Obtain vehicle's speed $\omega \times \boxed{v} = a_M$
- Second phone on the passenger side

Leveraging Multiple Turns and Mixed Turns

- Accumulate a few turns – use simple majority voting process to improve accuracy
- Utilize mixed turns – left and right turns

  - eliminate bias from reference point
    - e.g., speed from OBDII is overestimated due to worn tires
    - Use normalized centripetal acceleration difference: *independent of the bias, turn size and driving speed*



Majority vote: Driver

Experimental Setup

- Different testing positions

- Different driving environments
  - Parking Lots: 117 turns
  - Urban: 570 turns
  - Suburban: 430 turns

Phones and Cars

❑ Phones

- 1GHz ARM A8 CPU
- 512M RAM
- iOS5.2
- 20 samples/s

iPhone 4

- 1.2GHz MSM8660 CPU
- 1G RAM
- Android 2.4
- 20 samples/s

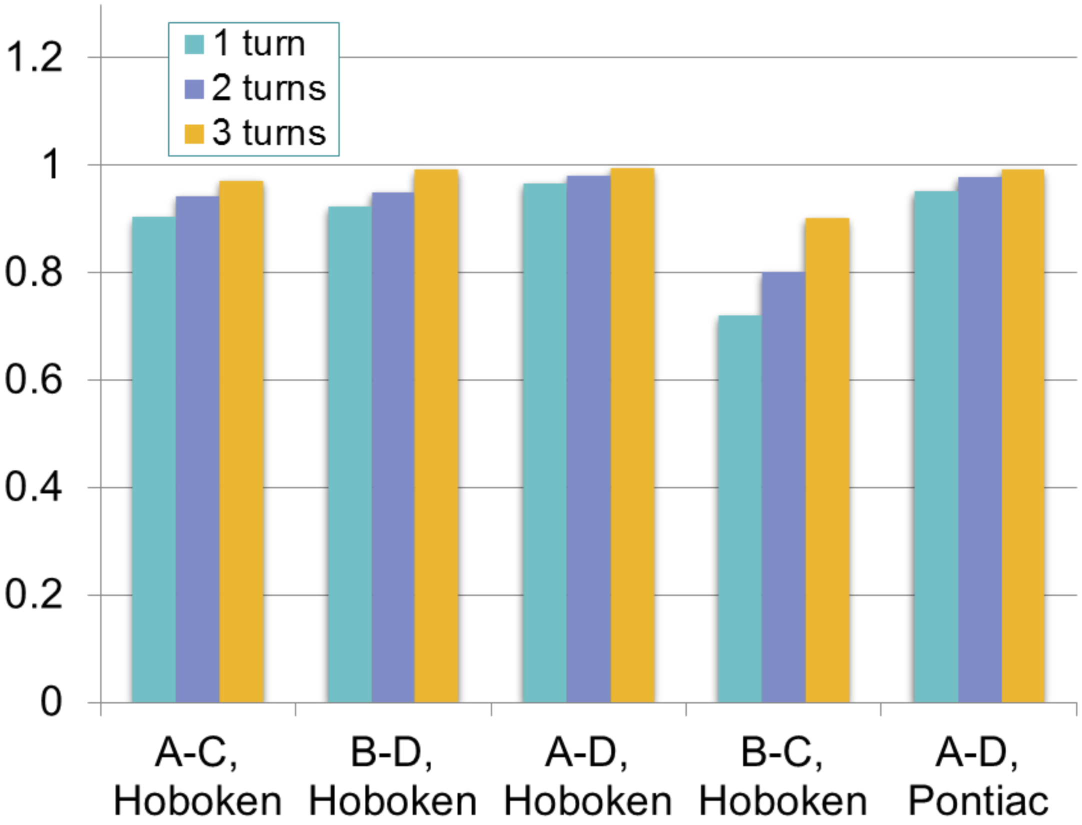
HTC 3D

❑ Cars

Honda Accord (car A)

Acura sedan (car B)

Opportunistically Using Dual Phones



- High detection accuracy at positions away from the center of the vehicle
- Robust in different driving environments

Interventions

- **Hard block**
  - Block phone calls, texting, chat…

- **Soft intervention**
  - Routing incoming calls to voicemail,
  - Delaying incoming text notifications
  - Automatic reply to callers
  - Posting driving status on social medium networks

Automatic Reply: “I’m driving right now; will get back with you!”

Thank You!

&

Questions

http://www.cs.fsu.edu/~jieyang/