DAISY

Data Analysis and Information SecuritY Lab

Detecting Driver Phone Use Leveraging Car Speakers

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ACM MobiCom 2011

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Cell Phones Distract Drivers

- Cell phone as a distraction in 2009 on U.S. roadways
  - 18% of fatalities in distraction-related crashes involved reports

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Talking or

✓Visual — E

✓Cognitive -

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

Cell Phones Distract Drivers

Minds off driving.

Cognitive load distract driver!

Do hands-free devices solve the problem?

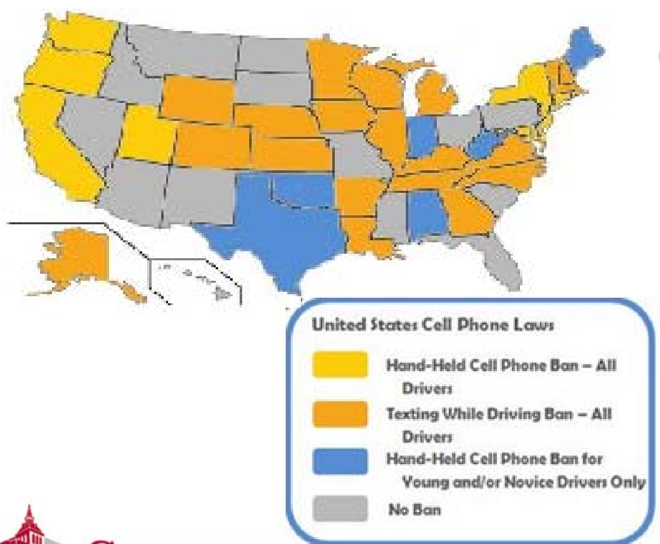
✓Real-world accidents indicated that hands-free and handheld users are as likely to be involved in accidents

J. Caird, C. Willness, P. Steel, and C. Scialfa. *A meta-analysis of the effects of cell phones on driver performance. Accident Analysis & Prevention*,40(4):1282–1293, 2008.

P. Treffner and R. Barrett. *Hands-free mobile phone speech while driving degrades coordination and control. Transportation Research* Part F: Traffic Psychology and Behaviour, 7(4-5):229–246, 2004.

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!"

ZoomSafer
We don't let friends drive distracted

izup

CellSafety

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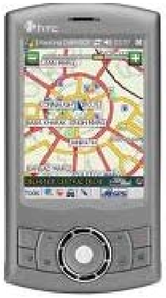
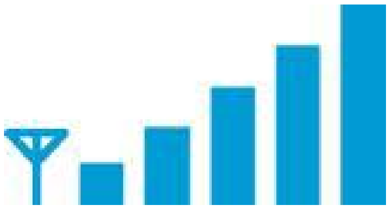
What's Being Done?
- Is a Cell Phone in a Moving Vehicle ?

- ❑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

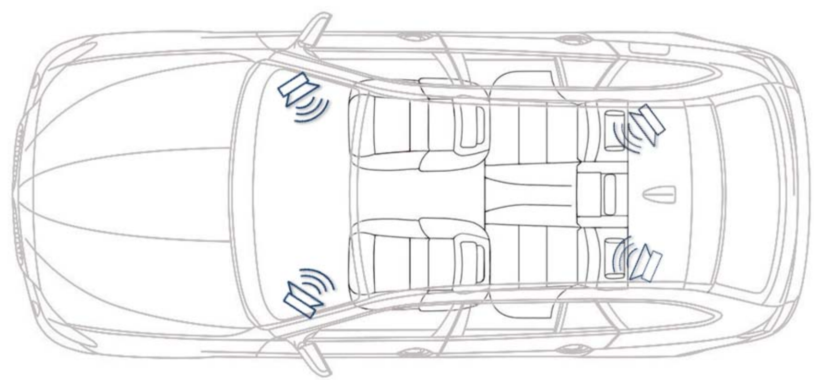
38% of automobile trips include passengers !

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

Our Basic Idea

- An Acoustic Ranging Approach
  - No need of dedicated infrastructure
    - Car speakers
    - Bluetooth
  - Classifying on which car seat a phone is being used
    - No need for localization or fingerprinting
      - ✓ Exploiting symmetric positioning of speakers

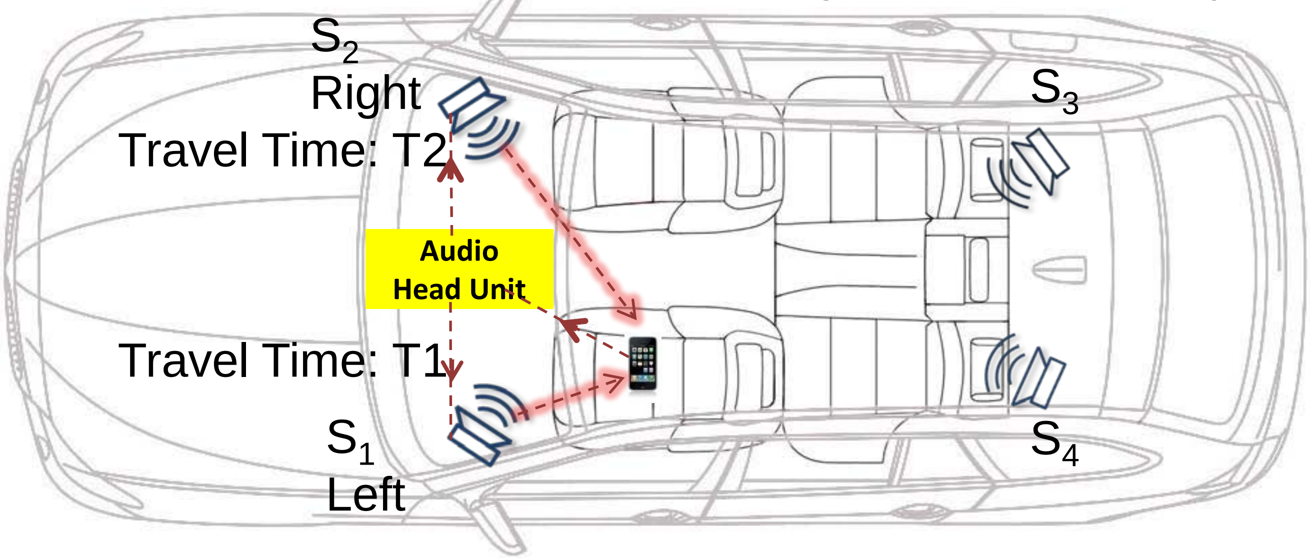
Phone connecting with head unit



Symmetric positioning of speakers

How Does It work?

S1, S2 emit signal simultaneously



Time of Arrival - Absolute ranging:

- clock synchronization
- unknown processing delays

Relative time difference: T2 – T1

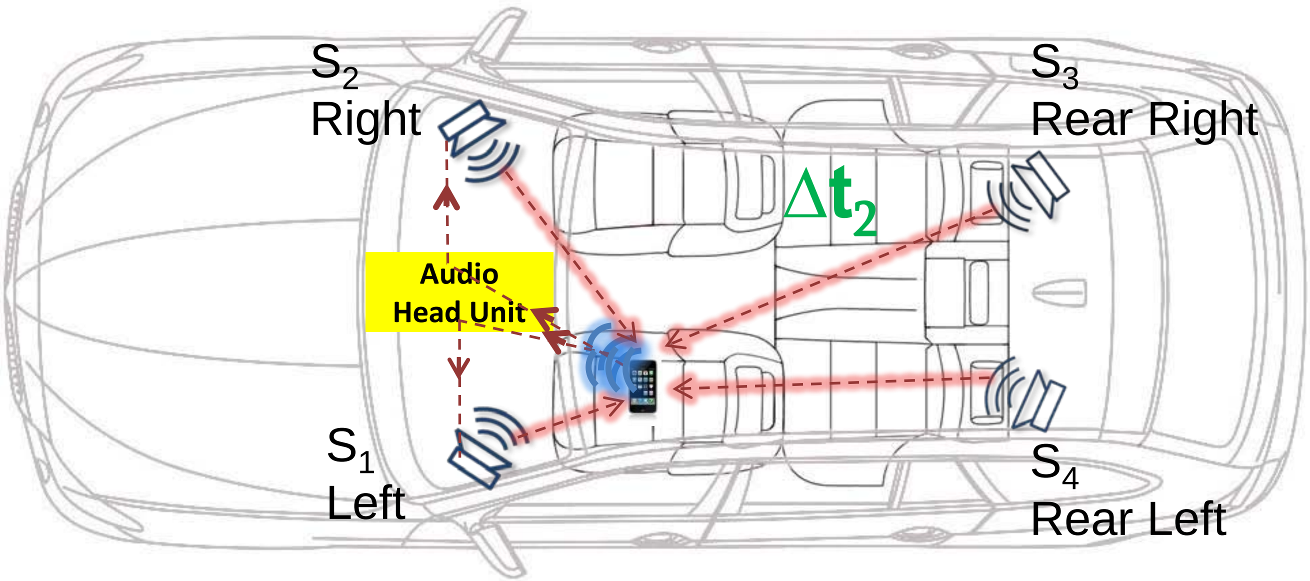
- No clock synchronization
- Need to distinguish signal from S1 and S2

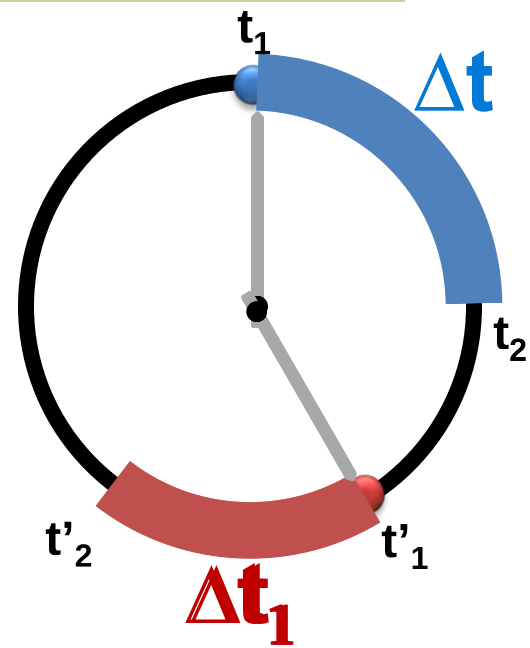
Insert a fixed time interval Δ**t** between two channels

- S1 always come first
- S2 always come second

No need of signal identifier!
No interference from different speakers!

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)

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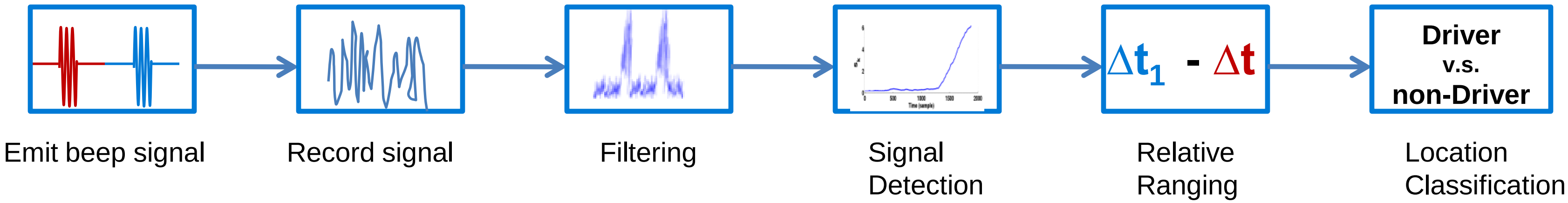
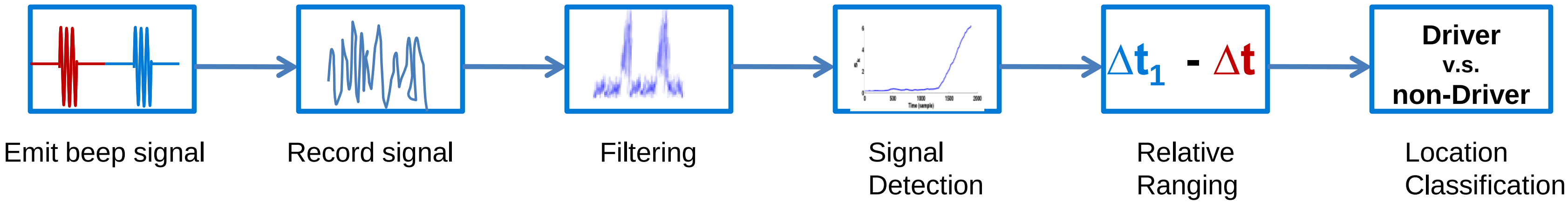
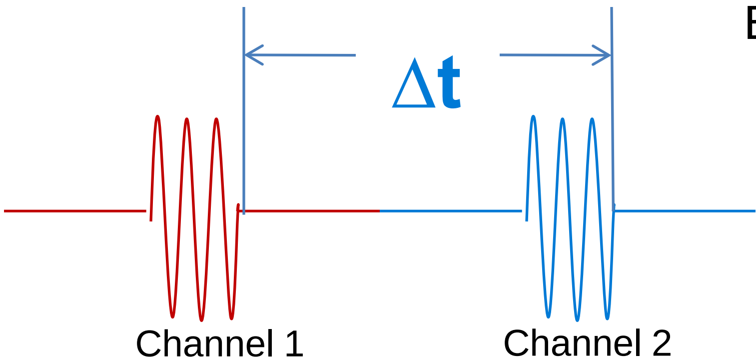
Walkthrough of the detection system



Walkthrough of the detection system





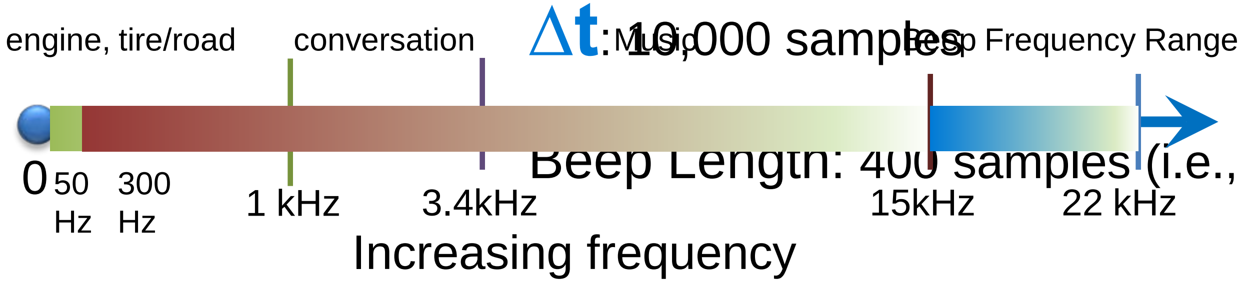
Beep signal: two channels

Beep signal design

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

High frequency beep

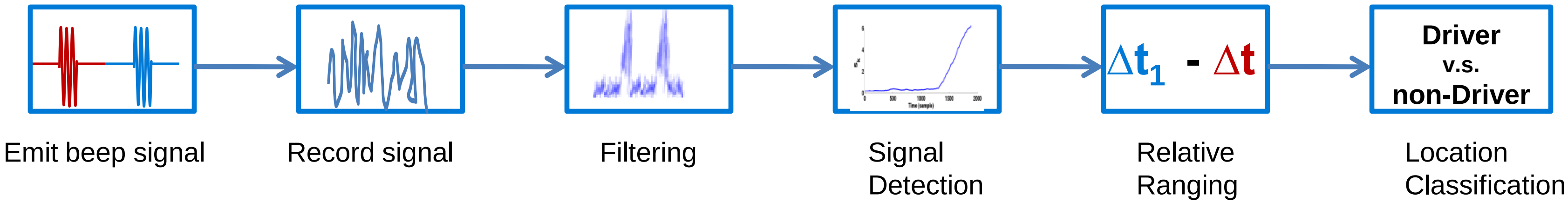
- ➢Robust to noise:
  - ✓engine, tire/road, conversation, music
- ➢Unobtrusiveness
  - ✓Close to human's hearing limit



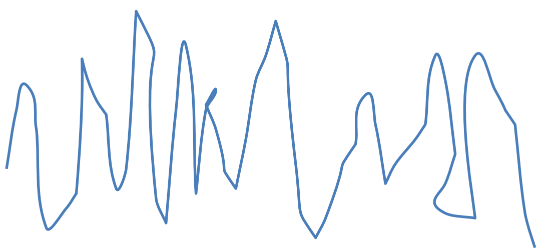
Δt: 10,000 samples

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

Walkthrough of the detection system



Where is the beep signal?



Recorded signal

Signal distortion:

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

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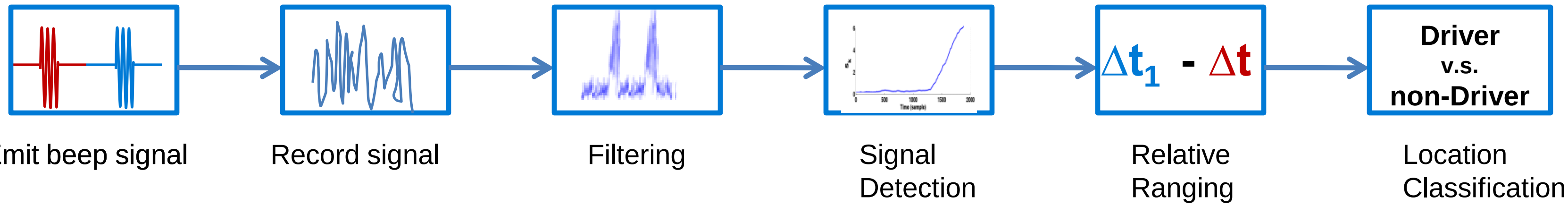
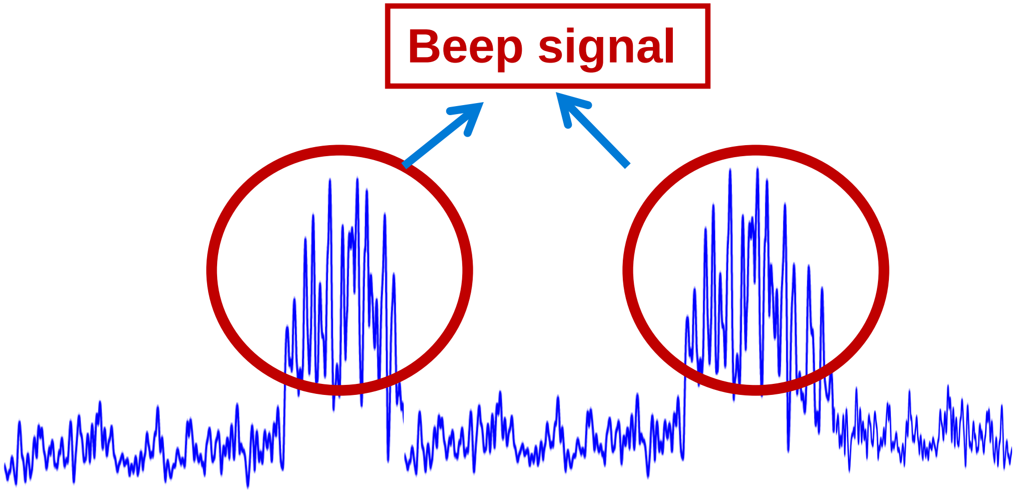




Signal after Filtering

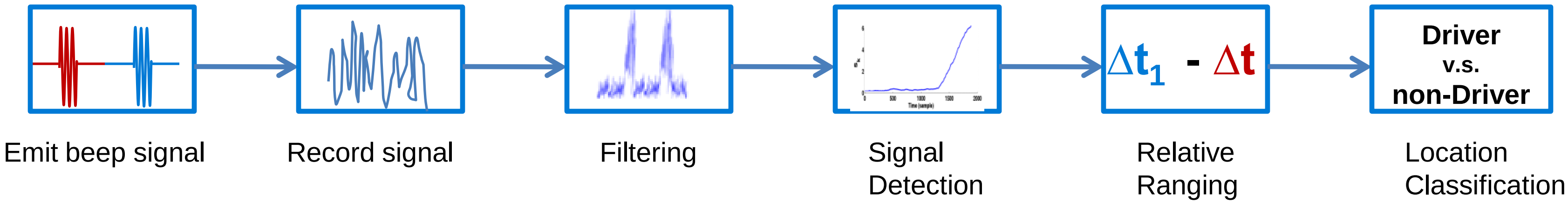
Filter out background noise

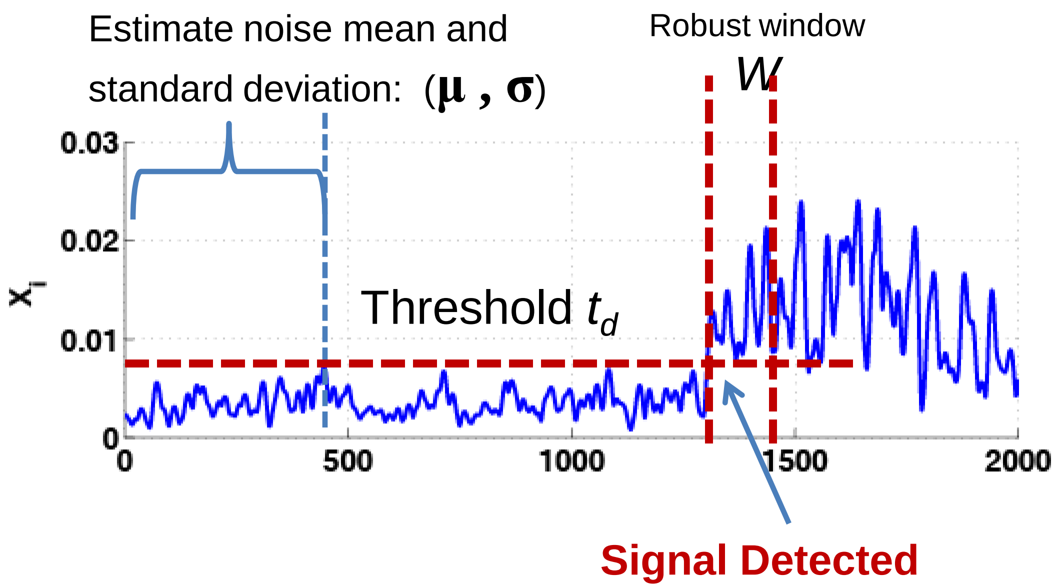
- Noise mainly located below 15kHz
- Beep signal frequency is above 15kHz

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

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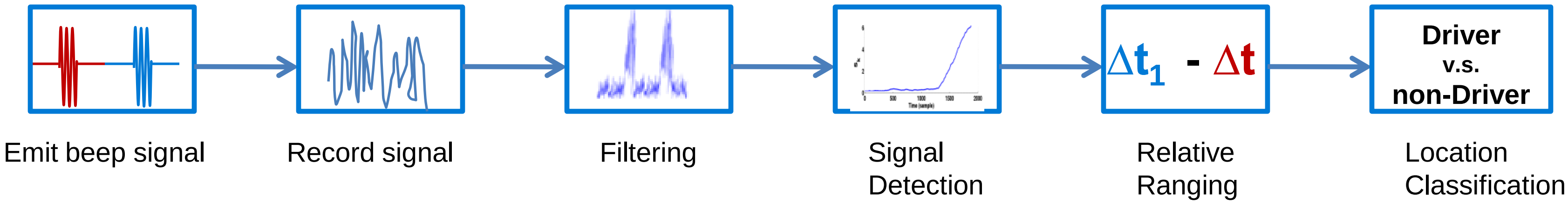
Walkthrough of the detection system



$$\Delta t_1 - \Delta t$$

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

Δt_1 - Δt: Relative ranging -> cell phone to two speakers

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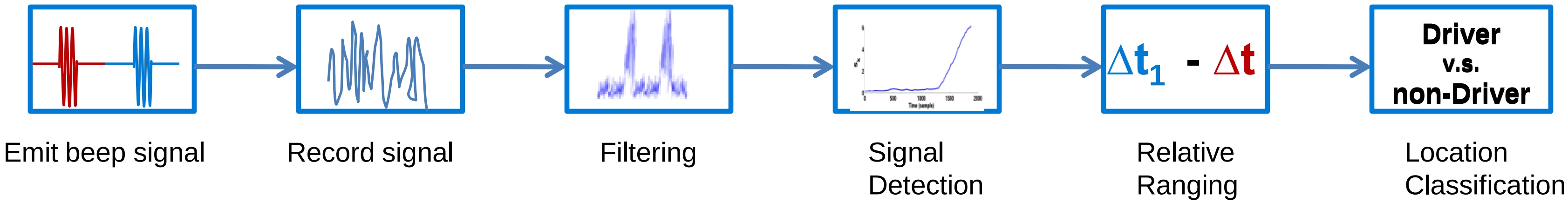
Walkthrough of the detection system



Driver v.s. Passenger

With two-channel audio system:

- $\Delta t_1 - \Delta t > 0$ => **Left Seats (Driver Side)**
- $\Delta t_1 - \Delta t < 0$ => **Right Seats**

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

- $\Delta t_2 - \Delta t > 0$ => **Front Seats**
- $\Delta t_2 - \Delta t < 0$ => **Rear Seats**

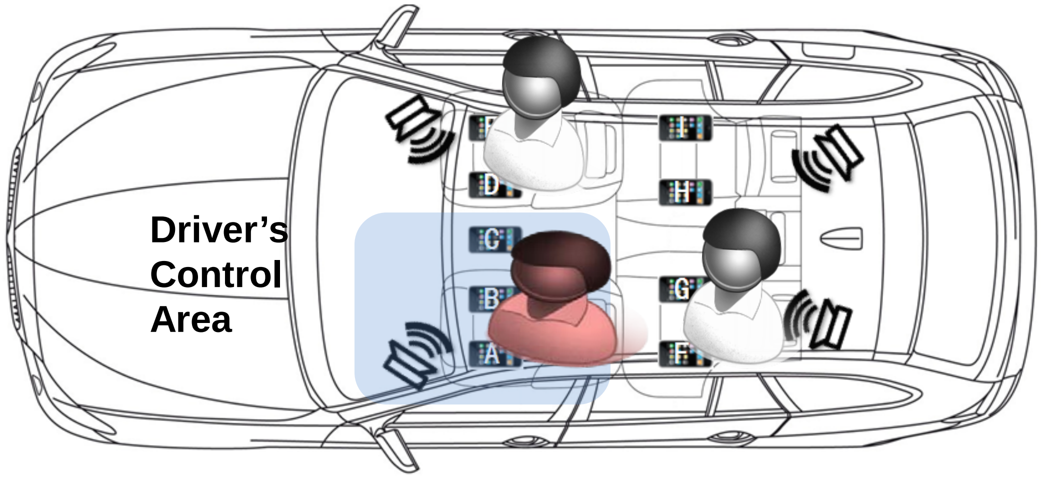
Automobile trips:

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

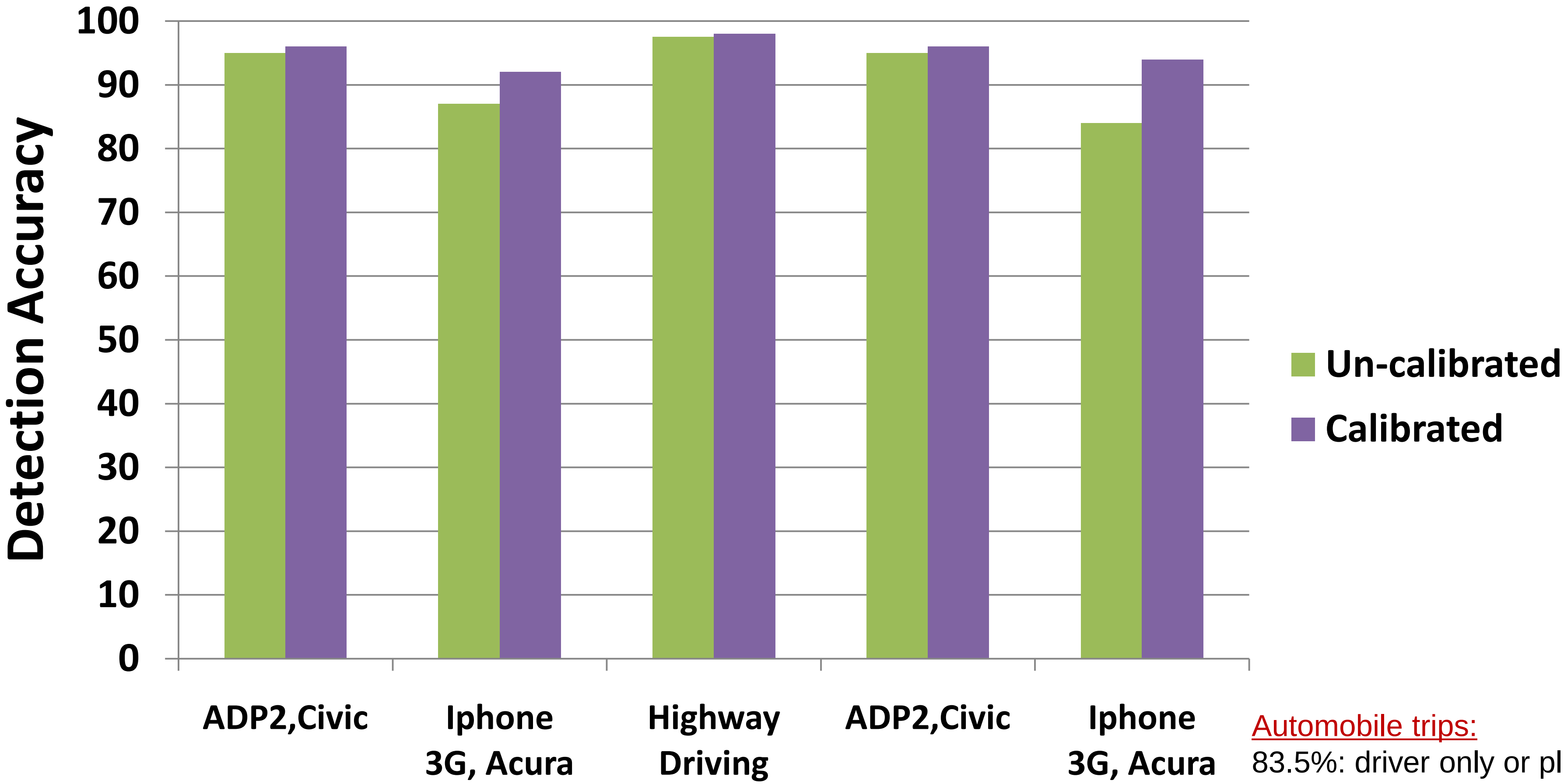
❑Cars

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: Driver v.s. Passenger Phone Use

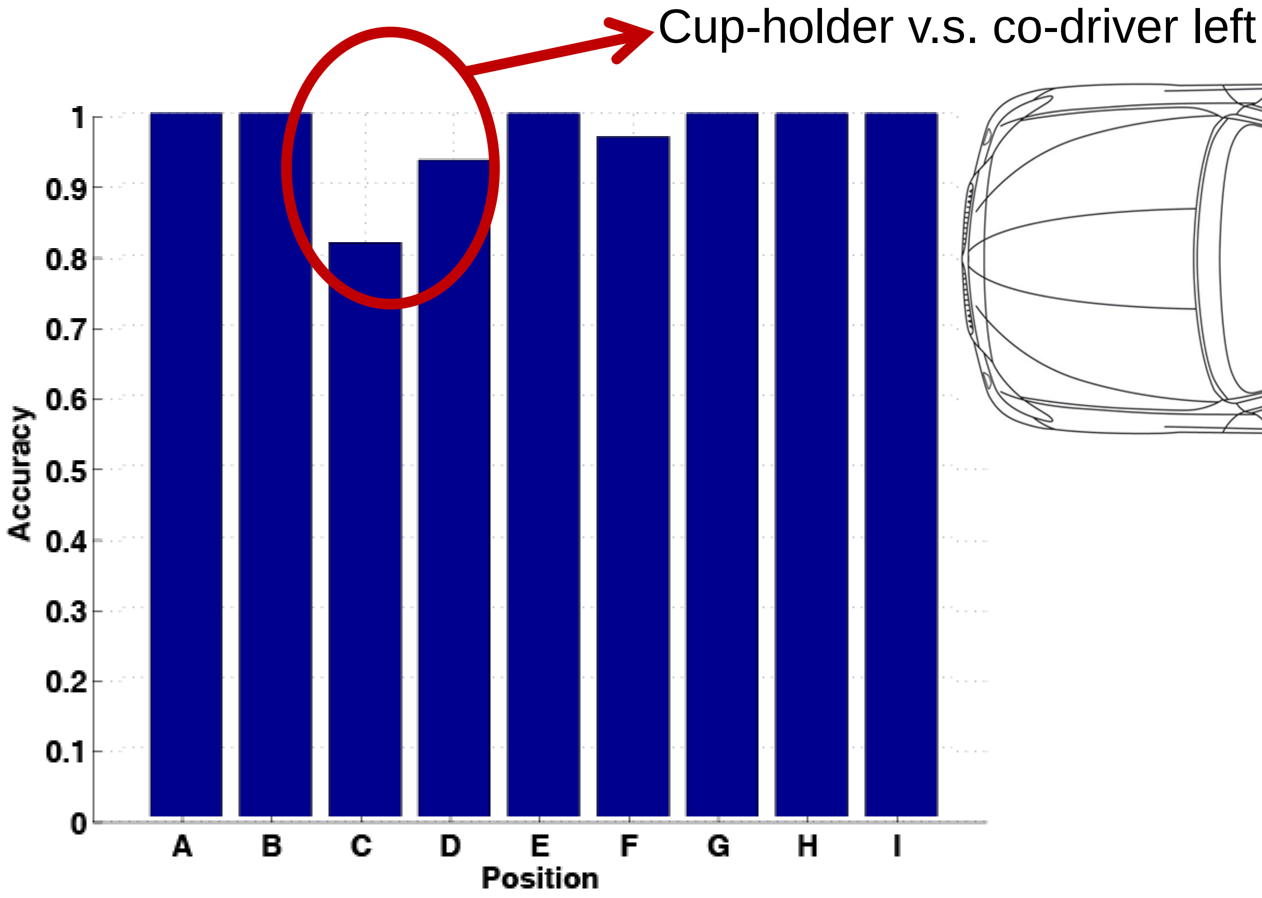


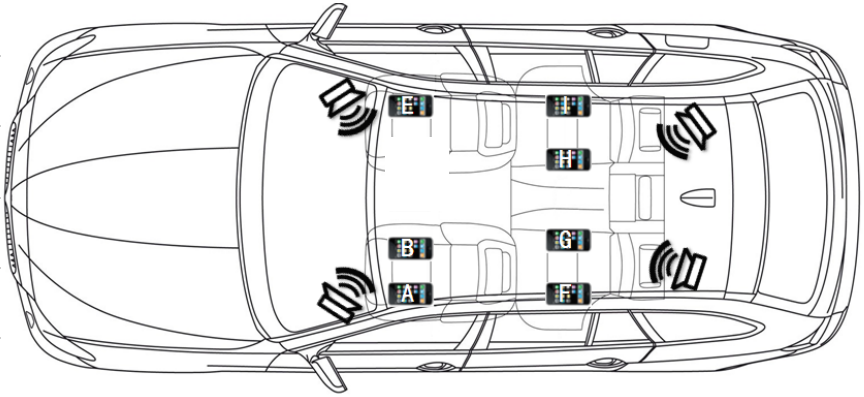
2 channel, front seats

4 channel, all seats

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

Results: Position Accuracy





Conclusions

- Limitations
  - Phone is inside a full bag or under heavy winter coat
  - Driver places the phone on an empty passenger seat
  - Probabilistic nature of our approach – not intend for enforcement actions
- Enabled a first generation system of detecting driver phone use through a smartphone app
  - Practical today in all cars with built-in Bluetooth
  - Leveraging car speakers – without additional hardware
  - Computationally feasible on off-the-shelf smartphones
- Demonstrated the viability of distinguishing between driver's and passenger's phone use within the confines of the existing hands-free audio infrastructure
  - Validated with two kinds of phones and in two different cars
  - Classification accuracy of over 90%, and around 95% with some calibrations

Thank You!

&

Questions

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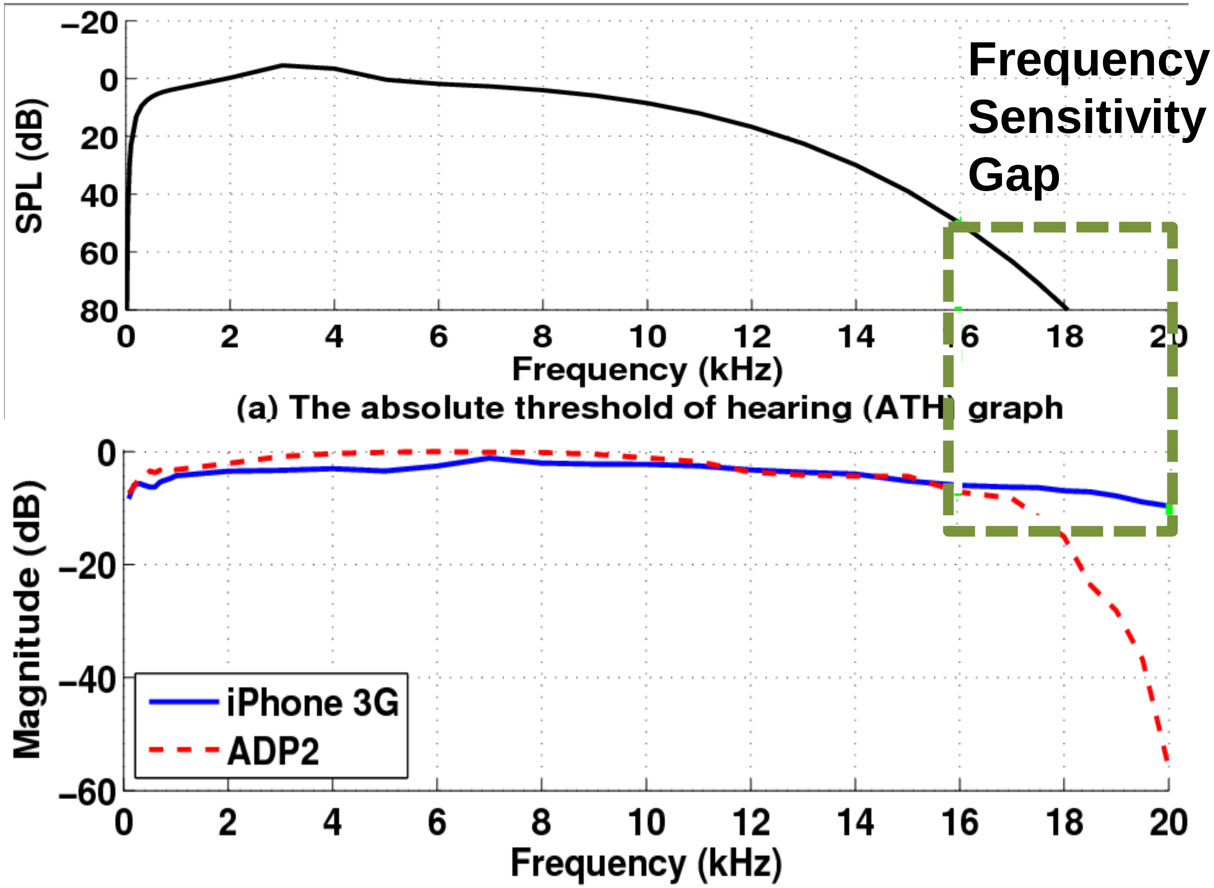
Challenges in Acoustic Approach

- Unobtrusiveness
  - The sounds emitted by the system should not be perceptible to the human ear, so that it does not annoy or distract the vehicle occupants.
- Robustness to Noise and Multipath
  - Noise: Engine noise, tire and road noise, wind noise, and music or conversations
  - Multipath: A car is a small confined space creating a challenging heavy multipath scenario
- Computational Feasibility on Smartphones
  - Standard Smartphone platforms should be able to execute the signal processing and detection algorithms with sub-second runtimes.

Beep Signal Design

- **Unobtrusiveness:** **high frequency beeps**
  - Close to the limits of human perception, at about 18 kHz
  - At the edge of the phone microphone frequency response curve



(a) The absolute threshold of hearing (ATH) graph

(b) Freuqency response of iPhone 3G and ADP2

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Detecting Beep Arrival Time

❑Hard to detect the beep signal in time domain

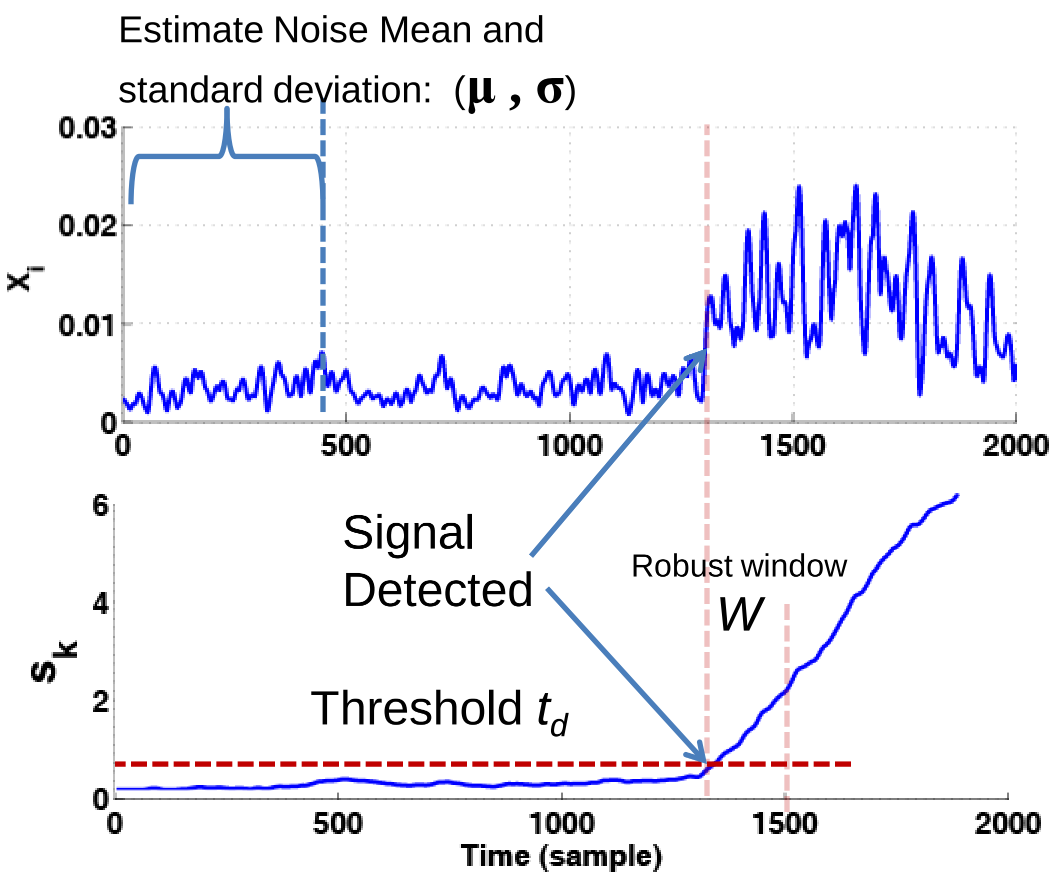
- ❖ Heavy multipath in-car environments
- ❖ The use of a high frequency beep signal leads to distortions due to the reduced microphone sensitivity in this range

❑Idea: detecting the first strong signal in beep frequency band

- ❖ Filtering: applying STFT in each moving window to extracting beep signal energy at beep signal frequency band
- ❖ Signal Detection: Identifying the first arriving beep signal that deviates from the noise

Detecting First Arriving signal

❑Illustration



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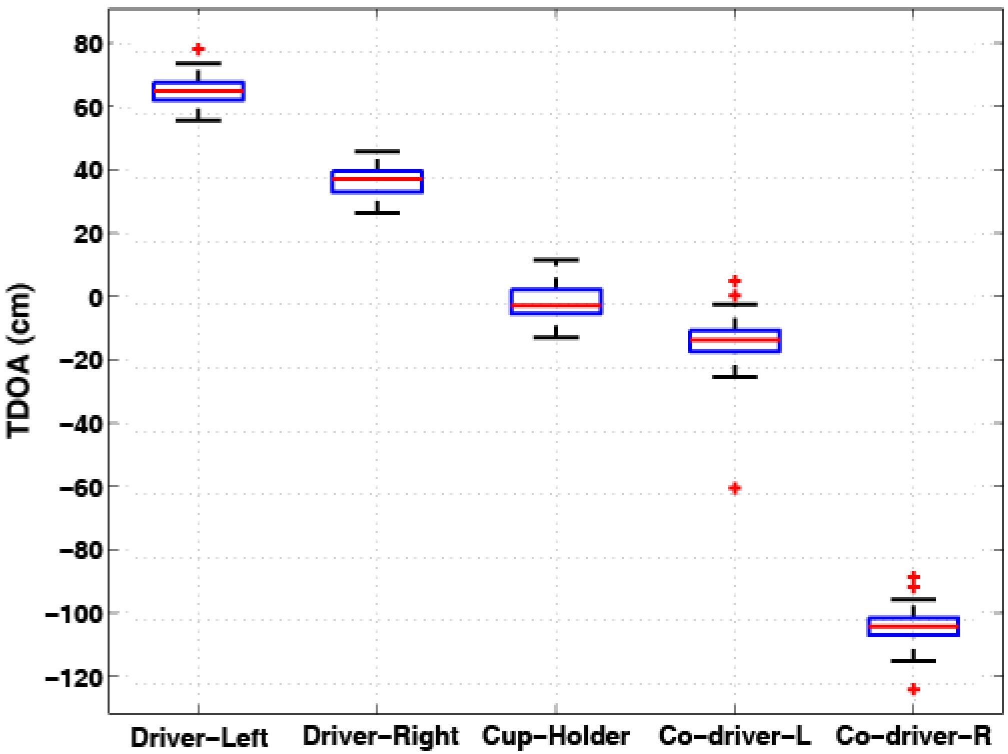
Results: Left v.s. Right Classfication



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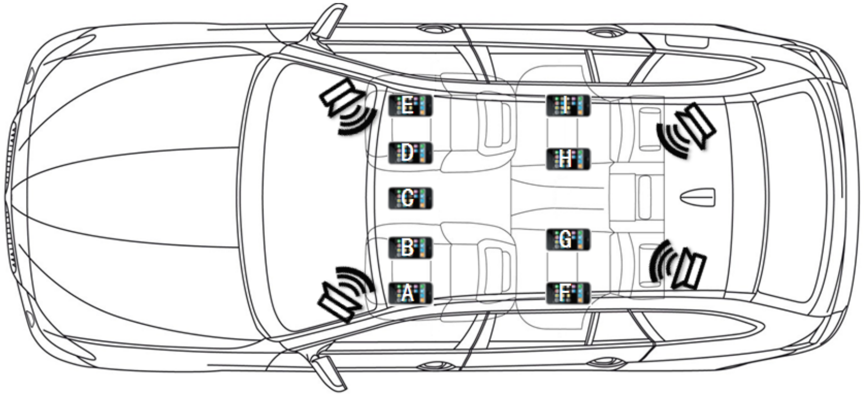
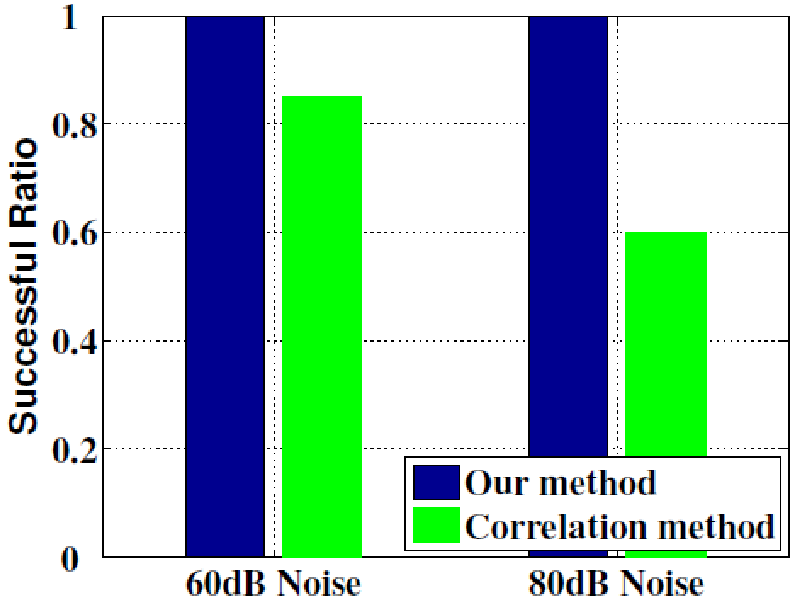


Results of Relative Ranging

- Experimental set up
  - Line of sight in-car environments -> heavy multipath
  - Music playing at 60dB and 80dB, respectively -> moderate noise and loud noise
- Correlation based method
  - Chirp signal -> robust to moderate noise
  - Signal detection: correlating chirp signal with recorded signal
- Metric
  - Successful ranging ratio: ranging error less than 10cm



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Computational Complexity

- Bounded by the length of the audio signal needed for analysis
  - STFT: $O(n \bullet m \bullet \log m)$,
    - m is the STFT window = 32, n is the number of samples analyzed = 1000 samples/beep sound
  - Signal detection algorithm: $O(n)$

- Run Time
  - ADP2 with Jtransforms library
  - Average processing time:
    - ✓ 0.5 second for two-channel system
    - ✓ 1 second for four-channel system