Recent Advancements in Acoustic Based Signal Processing for Driver Behavior Modeling

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"International Symposium on Naturalistic Driving Research"

Aug. 31 – Sept.1, 2010

OUTLINE

- **Part 1: In-Vehicle Technology, Distraction & Safety**
- **Part 2: In-Vehicle Interactive Systems & Distraction**
  - **In-Vehicle Corpora (speech, video, CAN-bus, etc)**
  - **Basic research: Driver distraction and cognitive load**
- **Part 3: Cognitive Load / Distraction Assessment**
  - **Driver Monitoring via CAN-bus & Speech Based Systems**
- **Summary & Conclusions**

In-Vehicle Technology "Add-Ons"

Present Day Vehicle & Driver

Car Navigation Systems

Infotainmer Systems

Radio, CD, Satellite Radio, MP3, iPOD

Cell Phones (speech, text)

(2009)

Bag Phones (1980's)

DVD / Wireless Displays

Internet in Car

Vizualogic VMOD
Mobile Media Server Car
(music, video, internet)

Avis Connect (June'09)

Cadillac (March'09)

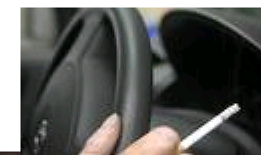
Driver & Vehicle Engagement

Multi-Tasking for Present Day Drivers

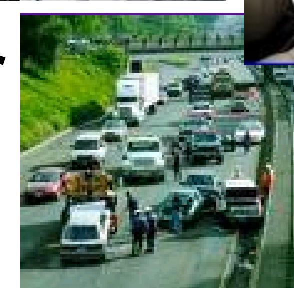
- Eating
- Drinking
- Smoking
- MP3/iPOD control
- Cell-Phone: calling, text-messaging, etc
- Engaging with Passengers
- Personnel Grooming
- Reading (maps), etc
- Other Multi-Tasking



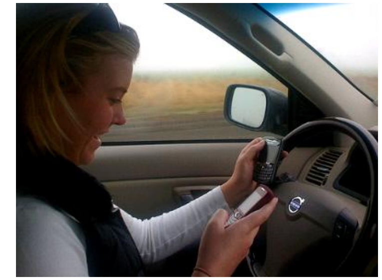






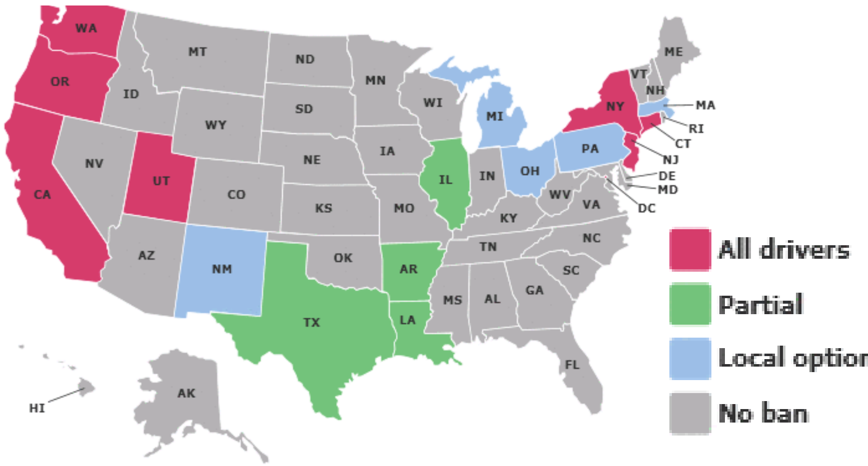


Cell-Phone Laws …

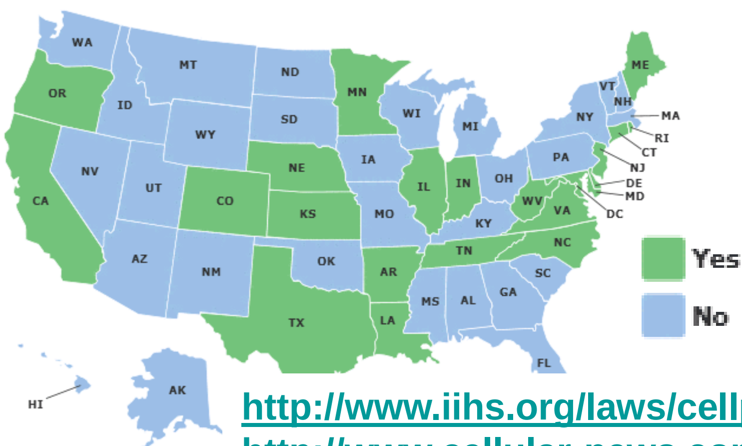


◈ Cell-Phone Laws in the USA (August 2009)

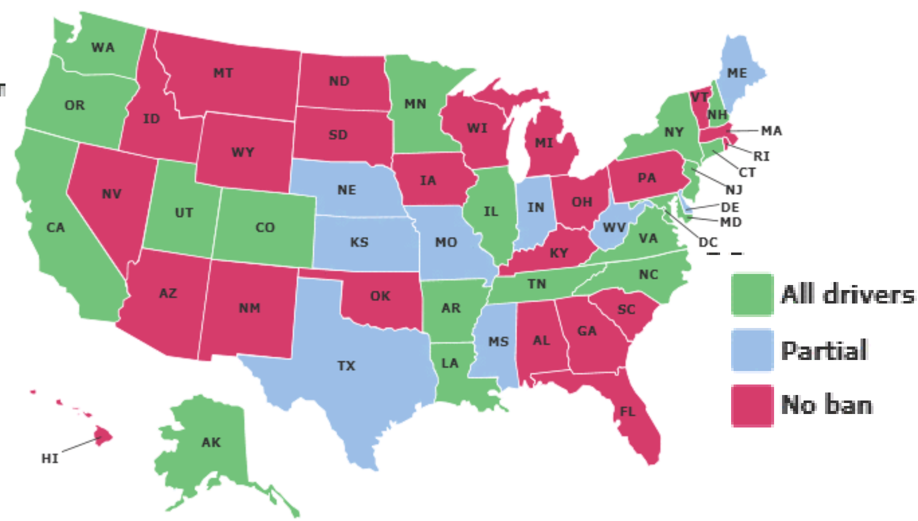
Drivers & Cell-Phone Restrictions



Young Drivers & Cell-Phone Bans



Drivers & Texting Bans



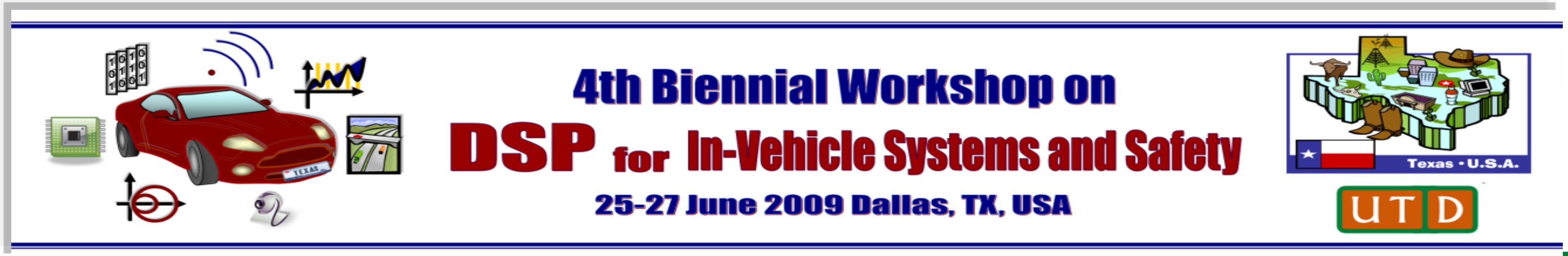
http://www.iihs.org/laws/cellphonelaws.aspx **[Cell Phone Laws in USA]**

http://www.cellular-news.com/car_bans/ **[Cell Phone Laws Worldwide]**

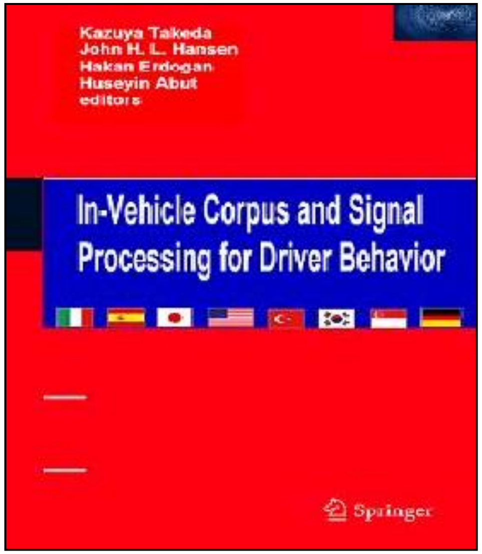
Previous Activities on DSP for In-Vehicle Environments

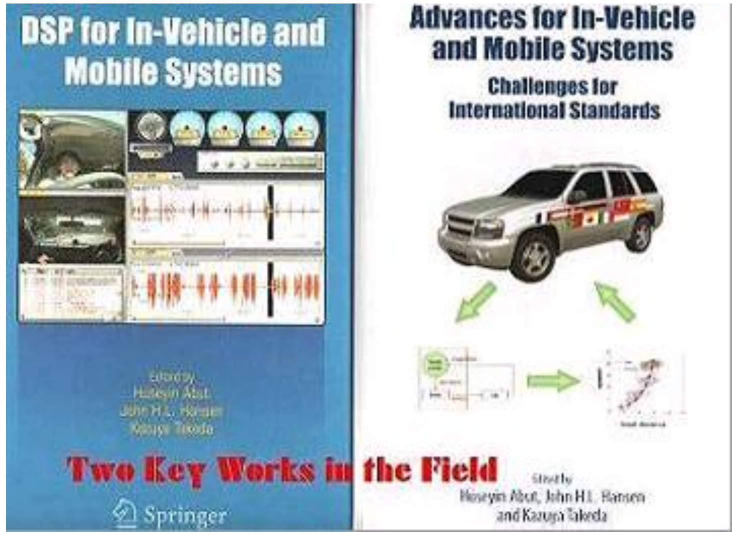
Biennial Workshop DSP for In-Vehicle Systems & Safety

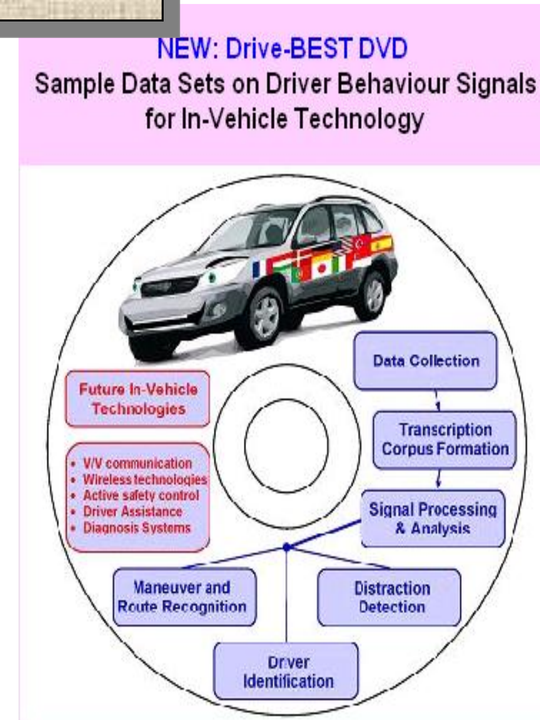
- Nagoya, Japan, March 2003
- Sesimbra, Portugal, Sept. 2-3, 2005
- Istanbul, Turkey, June 17-19, 2007
- Dallas, Texas, June 25-27, 2009



In-Vehicle DSP Publications







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[1] K. Takeda, J.H.L. Hansen, H. Erdogan, H. Abut, *In-Vehicle Corpus and Signal Processing for Driver Behavior,* Springer Publishing, 2008

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Part 2: In-Vehicle Speech/Interactive Systems

Goals:

- **Develop Human-Vehicle Interactive Systems which take into account:**
  - **Human Cognitive Load of Driver**
  - **Experience Level of the Driver**
  - **Environmental Conditions (Traffic, Weather, etc)**

Commercial Automatic Speech Recognition in the Car

2009 Ford Focus:

Ipod Nano, Navigation, Speech Recognition, Lane Assistant, Bluetooth Integrated Phone, Live Gas Prices, Movies, Weather Reports, Stocks, News Report, Trip Computer, MSN Direct

Nuance study shows speech recognition increases car safety

Jul. 10, 2008 (11:23 am) **By:** *Brian Osborne*

Voice recognition in cars is not only a cool thing to have it could potentially save lives. Nuance Communications has announced the results of a study which measured the impact to safety and response times of drivers when voice recognition was used to control in-car systems. The 2008 In-Car Distraction Study involved 30 drivers which were asked to perform tasks while also driving and switching lanes.

Tasks included selecting music on an MP3 player, making phone calls and programming an address on a GPS device. All tasks had to be performed at the same time while driving.

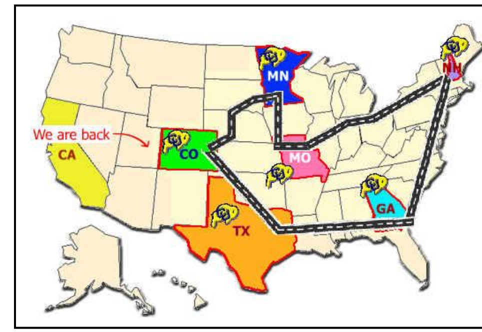
When it came to using a phone the study found that the use of speech recognition not only kept the car in an "ideal car position", 19% more than manual dialing, it also made it 40% faster to make a call. Manually selecting music on a MP3 music player made the driver 50% more distracted and doubled the amount of time necessary to change lanes. Swerving within a single lane while manually selecting music led to 60% higher levels of distraction.

In-Vehicle Corpus Development

Corpus Development for In-Vehicle Systems

- **CIAIR: Nagoya University**
  (250 Drivers)

- **CU-Move: RSPG / Univ. Colorado (UTDallas)**
  (550 Drivers, 6 US Cities)



- **UYANIK: Turkey**
  (150 Drivers)

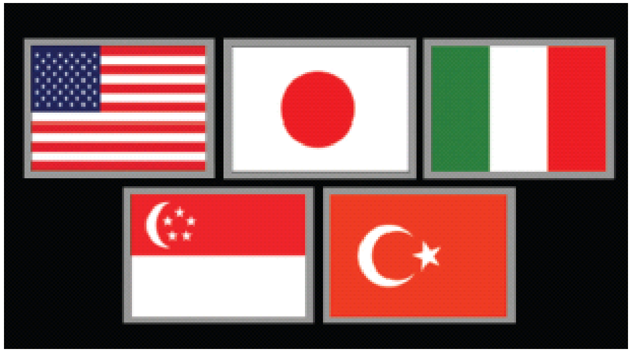
- **UTDrive: CRSS-Univ. of Texas at Dallas**
  (200 Drivers)

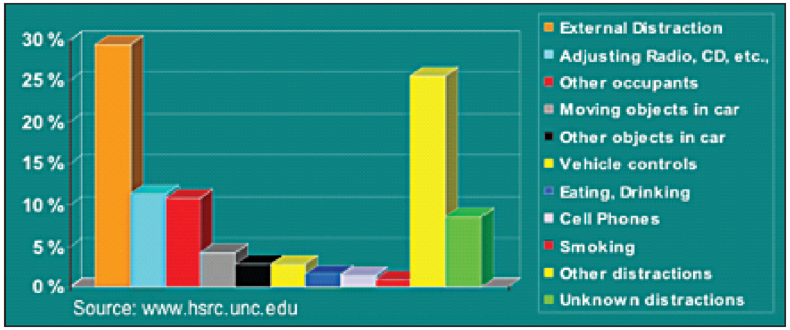
[1] N. Kawaguchi, S. Matsubara, …, K. Takeda, F. Itakura, "Construction and Analysis of a Multi-Layered In-Car Spoken Dialogue Corpus," Chapter 1 in *DSP for In-Vehicle and Mobile Systems*, Springer, 2004.
[2] J.H.L. Hansen, X.X. Zhang, M. Akbacak, et al, "CU-MOVE: Advanced In-Vehicle Speech Systems for Route Navigation," Chapter 2 in *DSP for In-Vehicle and Mobile Systems*, Springer, 2004.
[3] H. Abut, H. Erdogan, A. Ercil, et. al, "Real-World Data Collection with "UYANIK"," Chapter 3 in *In-Vehicle Corpus and Signal Processing for Driver Behavior*, Springer Publishing, 2008.
[4] P. Angkititrakul, J.H.L. Hansen, "UTDrive: The Smart Vehicle Project," Chapter 5 in *In-Vehicle Corpus and Signal Processing for Driver Behavior*, Springer Publishing, 2008.

UTDrive

http://www.utdallas.edu/research/utdrive/UTDrive-Website.htm

"UTDrive: In-Vehicle Systems for Driving Behavior & Safety"



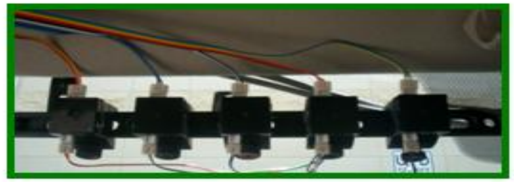


UTDrive Vehicle and Sensors

Front view

Driver

Cameras



Microphone-array

Close-talk microphone

GPS

Optical distance sensor

Gas/ Brake Pedal Pressure Sensors

CAN-Bus OBD II

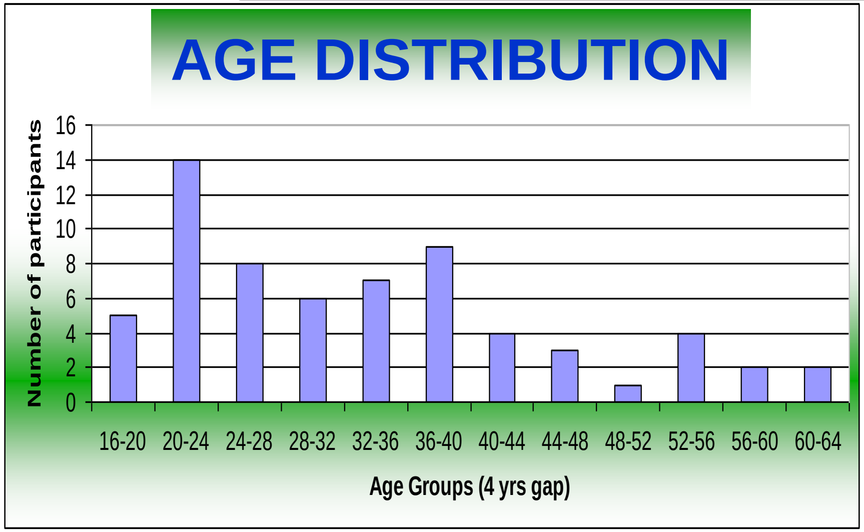
Data Acquisition Unit
(16-channel: 2 video, 6 audio, CAN-Bus; all synchronized)

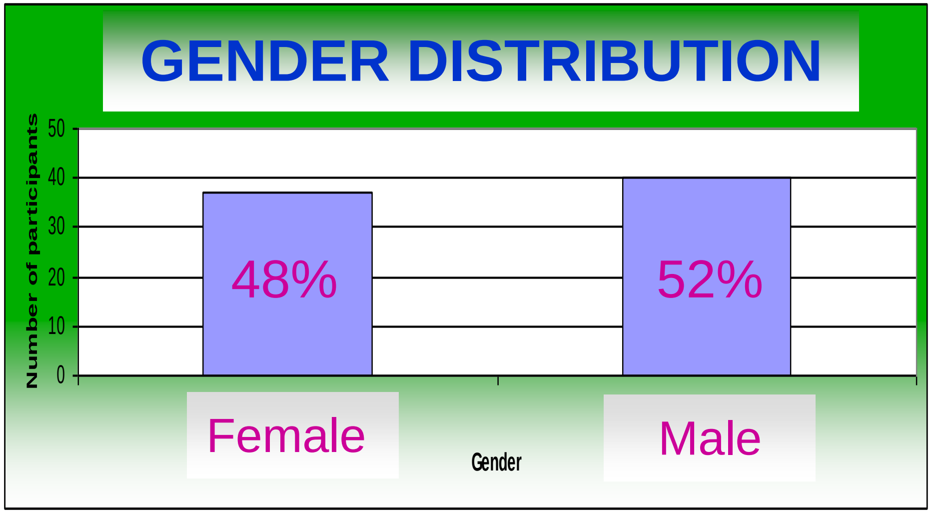
UTDrive: Data Transcription

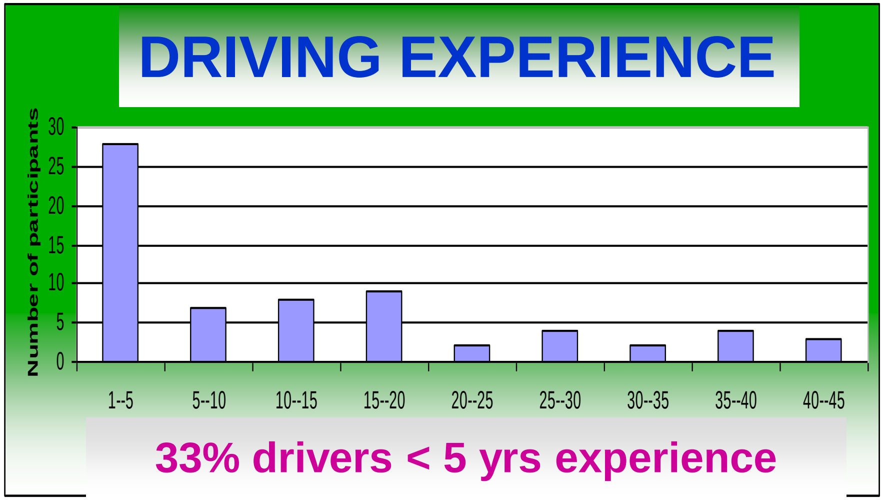
Speech
Driving Behavior
Route Info
Distraction Tasks

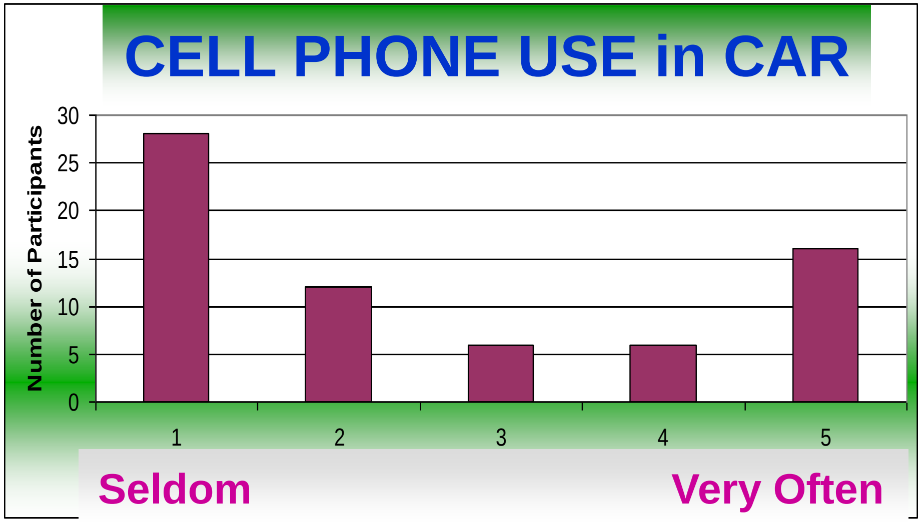
- **Speech –voice dialog in car, information access**
- **Driver –actions (head, hands, eyes, etc)**
- **Car –exterior (context of road conditions, weather, etc)**
- **Car –CAN-bus (steering angle, vehicle speed, brake, acceleration,..)**

UTDrive: Corpus Statistics







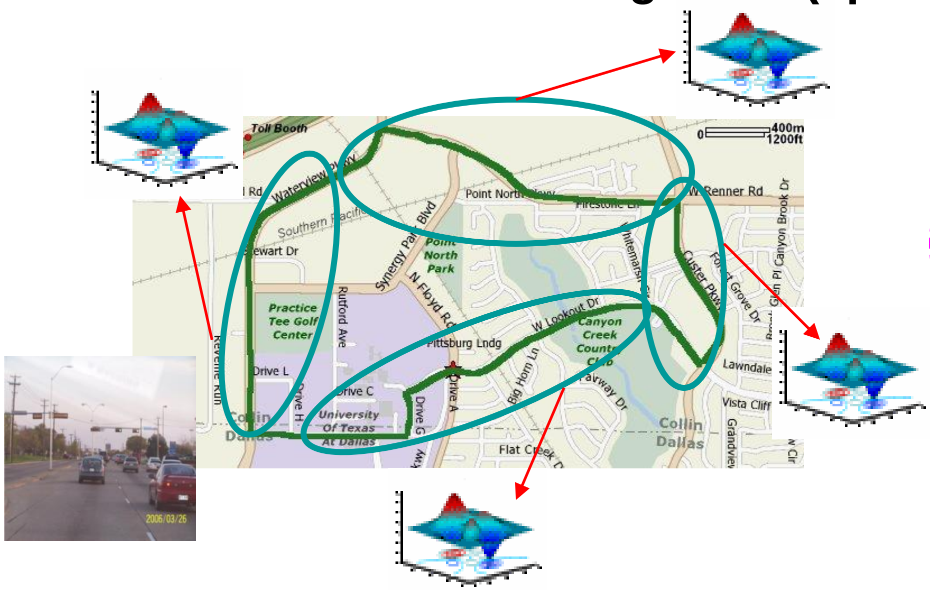


77 Drivers (this analysis), 37 Female, 40 Male ; each 6GB data stream

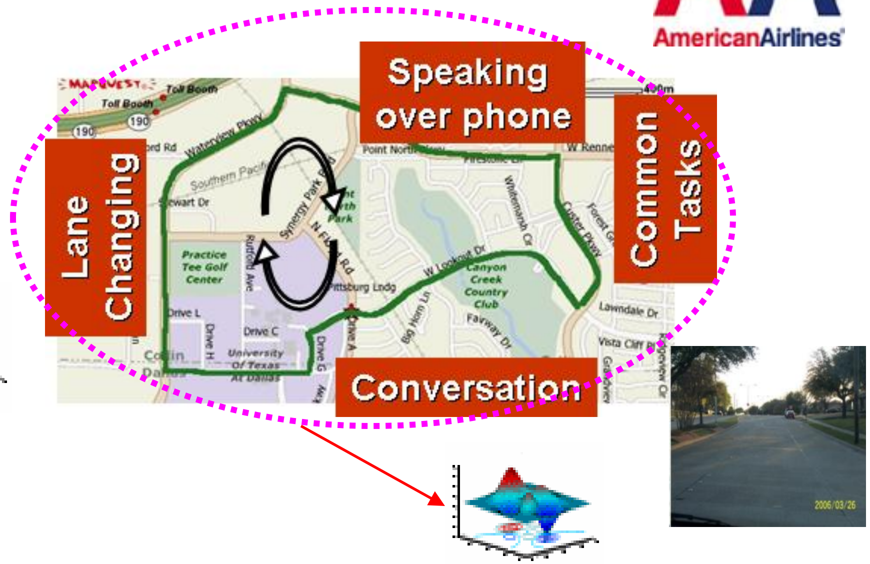
UTDrive: Distraction Detection

Tasks / Distraction:

- **Manual:** Radio tuning, AC adjustment, coin search
- **Visual:** Road sign reading
- **Audio/Cognitive:** Cell-phone call to American Airlines flight dialog systems
- Lane Changing
- Conversation with Navigator (spontaneous speech)



Route-Dependent Model

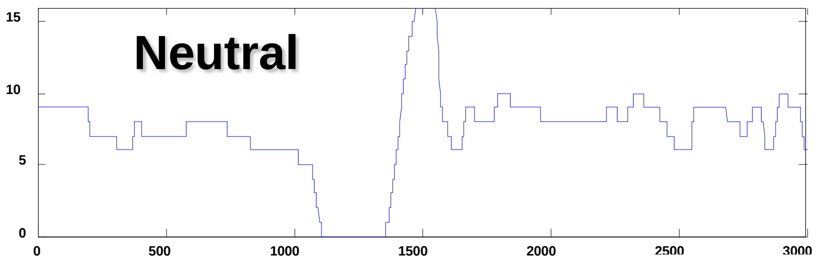


Route-Independent Model

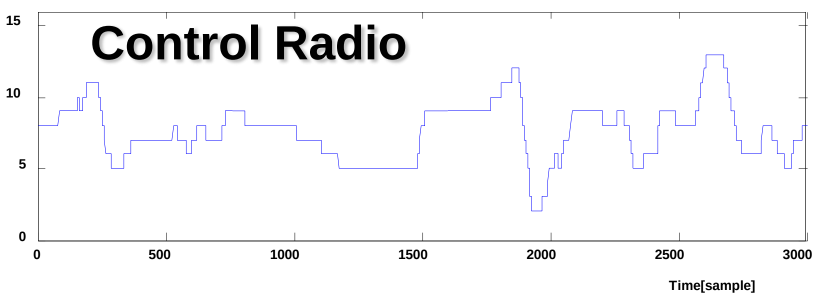
UTDrive: Distraction Detection

Steering Angle

Normalized Short-term variance = 1.21



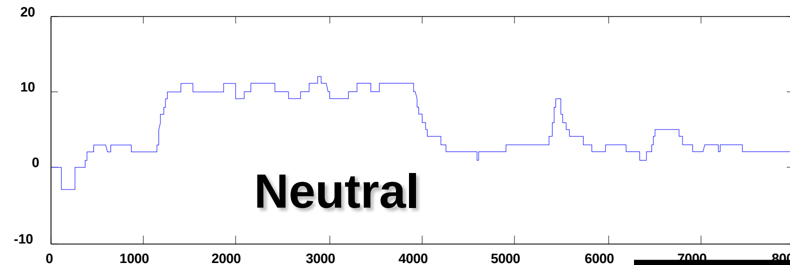
→ 30 sec



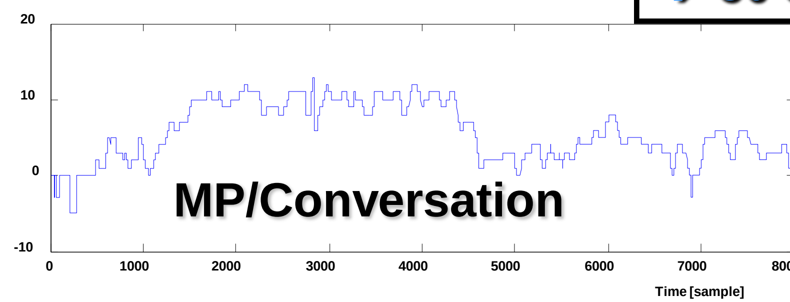
Normalized Short-term variance = 1.69

Increase 40% σ^2

Normalized Short-term variance = 0.27



→ 80 sec



Normalized Short-term variance = 0.82

Increase 203% σ^2

- **Driver maintains smoother steering degree in neutral vs. distracted driving**

UTDrive: Distraction Detection

KL2 Distance & Distraction Level

KL / DRIVER	LC	CO	MP	CT
1	10.6436	16.1577	18.5362	19.0907
2	14.2011	14.6433	19.6111	15.5726
7	15.8742	30.2861	14.4747	25.8047
8	12.9468	12.4495	14.5173	12.7812
AVG	14.1566	16.7162	20.1272	18.4377
Result	NO	LOW	HIGH	MEDIUM

Neutral Model − Distraction Task Model = Δ

$$KL(p,q)=\sum_i p_i.\log_2(p_i/q_i)$$

p - reference probability distribution
q - arbitrary probability distribution

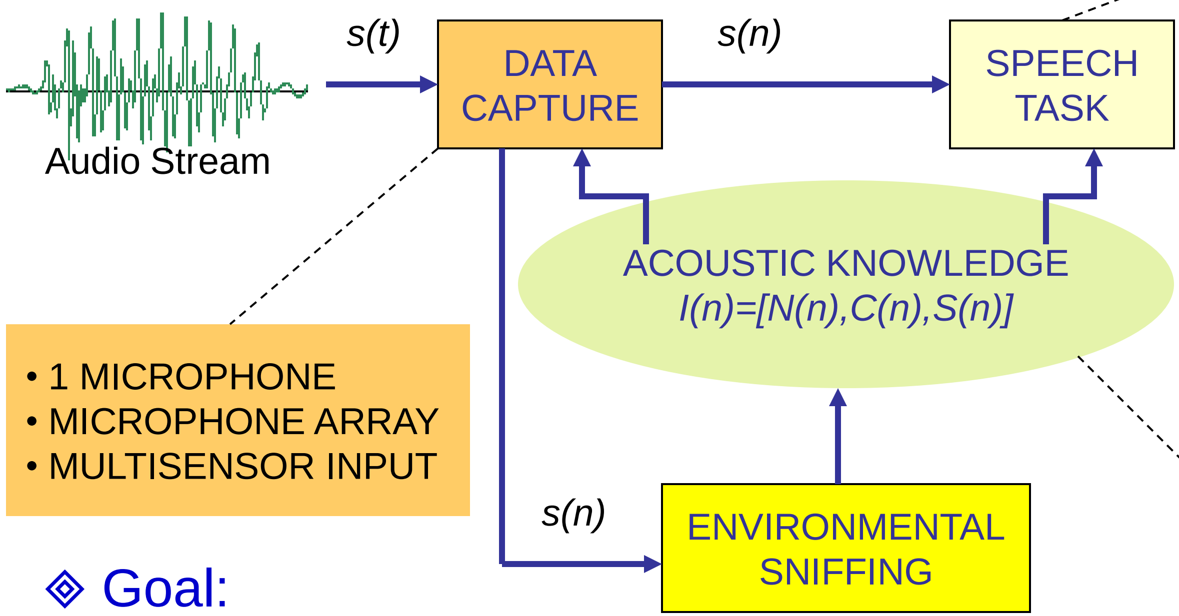
- LC – Lane Changing
- CO – Conversation
- MP – Mobile Phone
- CT – Common Tasks

(Based on CAN-bus GMM model analysis)

Environmental Sniffing

◈ General System Architecture:

- ASR
- SPEECH CODING
- SPEAKER ID
- SPEECH ENHANCEMENT
- LANGUAGE ID
- NOISE TRANSCRIPTION
- INFORMATION RETRIEVAL



- 1 MICROPHONE
- MICROPHONE ARRAY
- MULTISENSOR INPUT

- PSD ESTIMATE
- IMPULSIVE
- STATIONARITY
- PERIODICITY
- NARROWBAND/TONE
- BROADBAND

◈ Goal:

◈ Detect, classify and track acoustic conditions, extract acoustic knowledge.

◈ *PASSIVE:* Provide the acoustic knowledge.

◈ *ACTIVE:* Give smart decisions, direct subsequent speech systems.

M. Akbacak, J.H.L. Hansen, "Environmental Sniffing: Noise Knowledge Estimation for Robust Speech Systems," *IEEE Trans. Audio, Speech and Language Processing,* vol. 15, no. 2, pp. 465-477, Feb. 2007

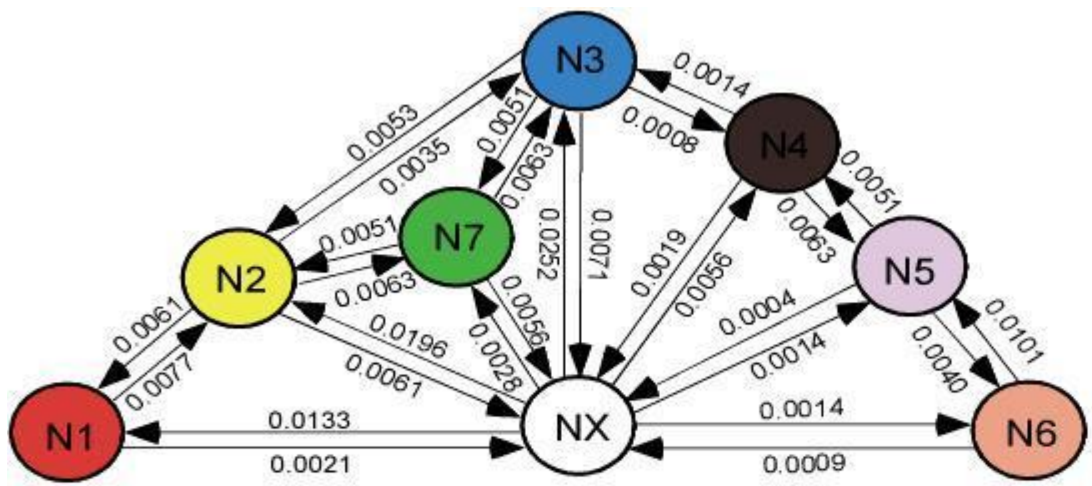
Noise Transition Model

- 4-mixture GMM is trained for each noise type using 12 MFCCs.

$$\lambda = \{\lambda_1, \lambda_2, \ldots, \lambda_r\}$$

Noise Language Modeling:

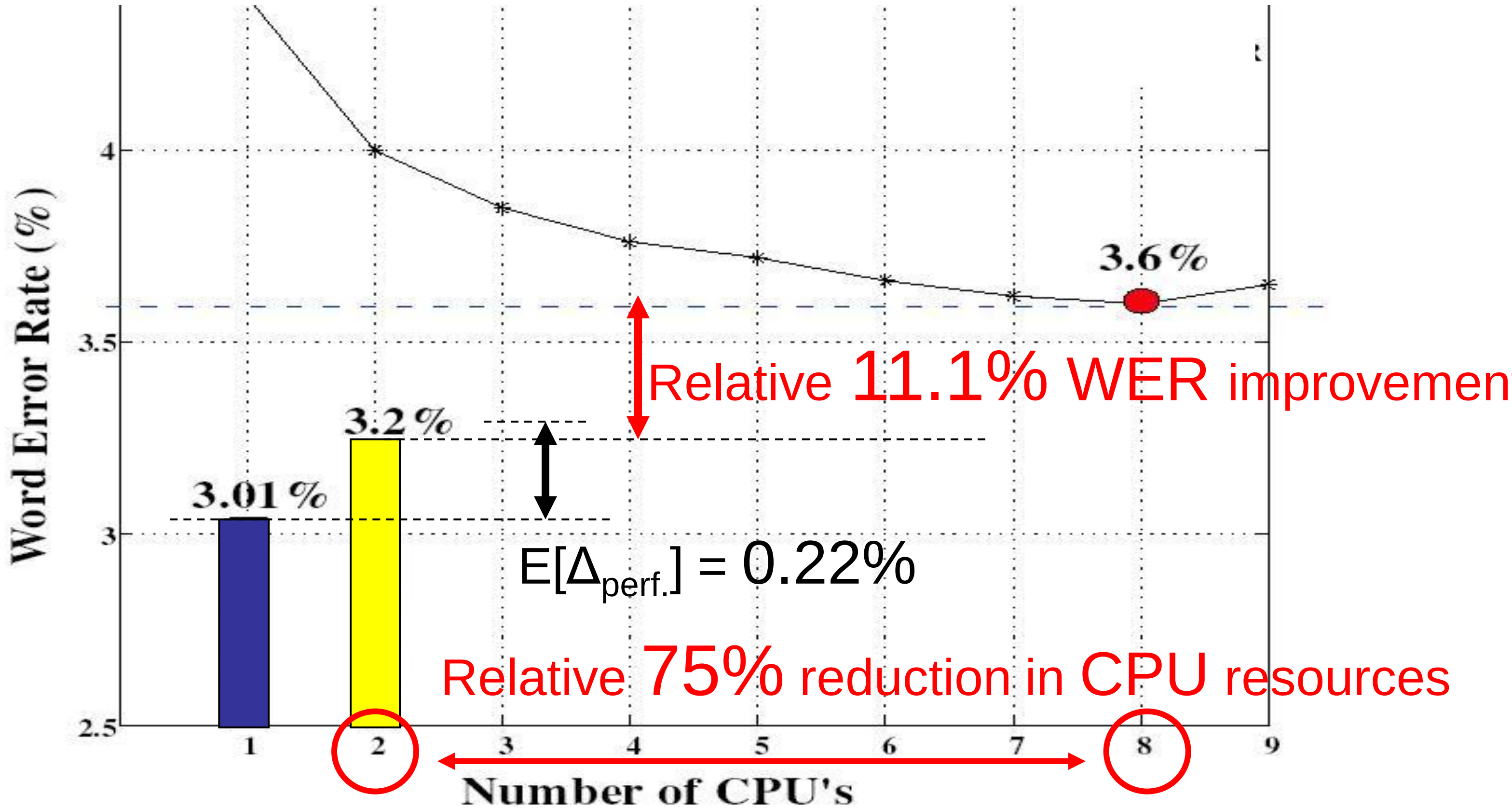
- Each 15-frame noise type is considered as a word unit.
- Bigram language model is trained using CMU-Cambridge SLM Toolkit.



- Bigram probabilities are shown in the figure.
- Self-transitions are not shown
- Outgoing transition probabilities sum to 1.

Evaluation

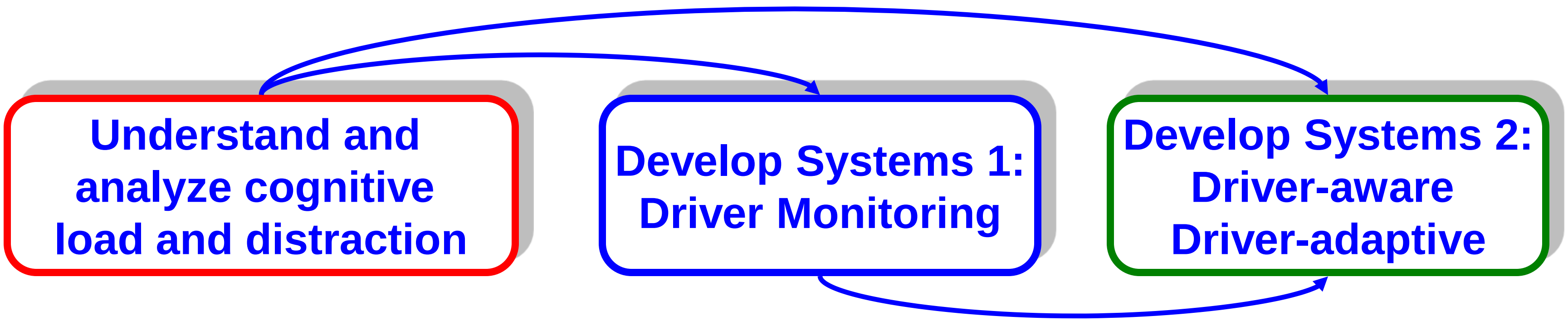
Env.Sniffing+ASR (S1) vs ASR+ROVER (S3)



- Using Environmental Sniffing:The new framework consistently outperforms the ROVER solution by 11.1% in WER, while requiring 75% less CPU resources.

PART 3: Cognitive Load Assessment, Driver Monitoring via Speech and Multi-sensor Systems

Pinar Boyraz, Amar Sathyanarayana, John H.L. Hansen



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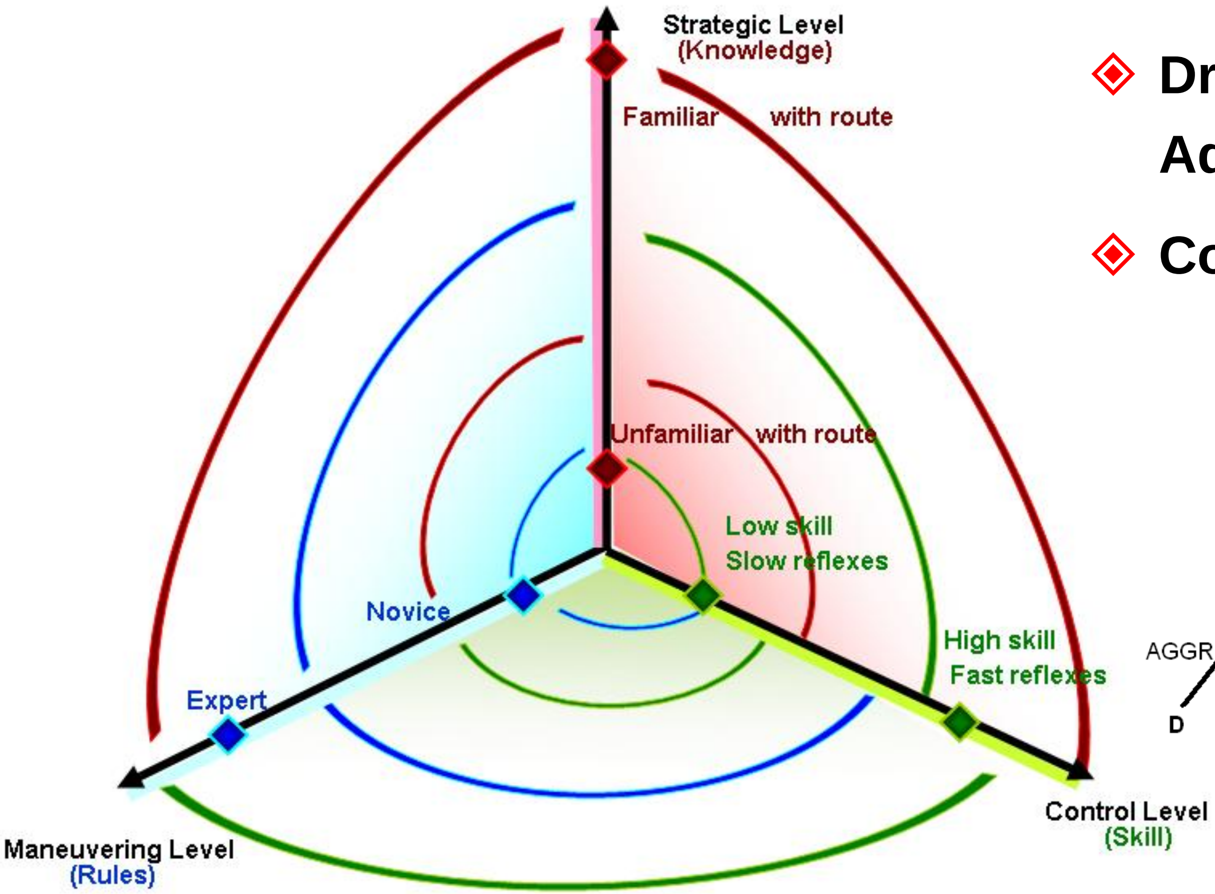
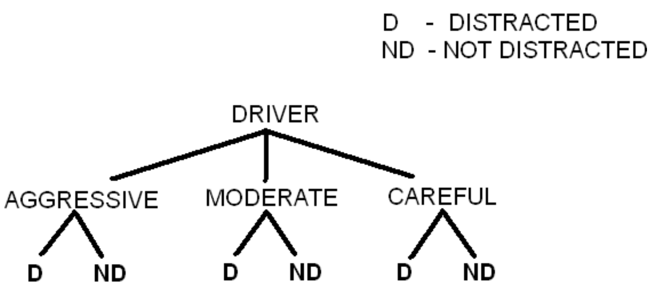
Driver Characteristics and Quantification



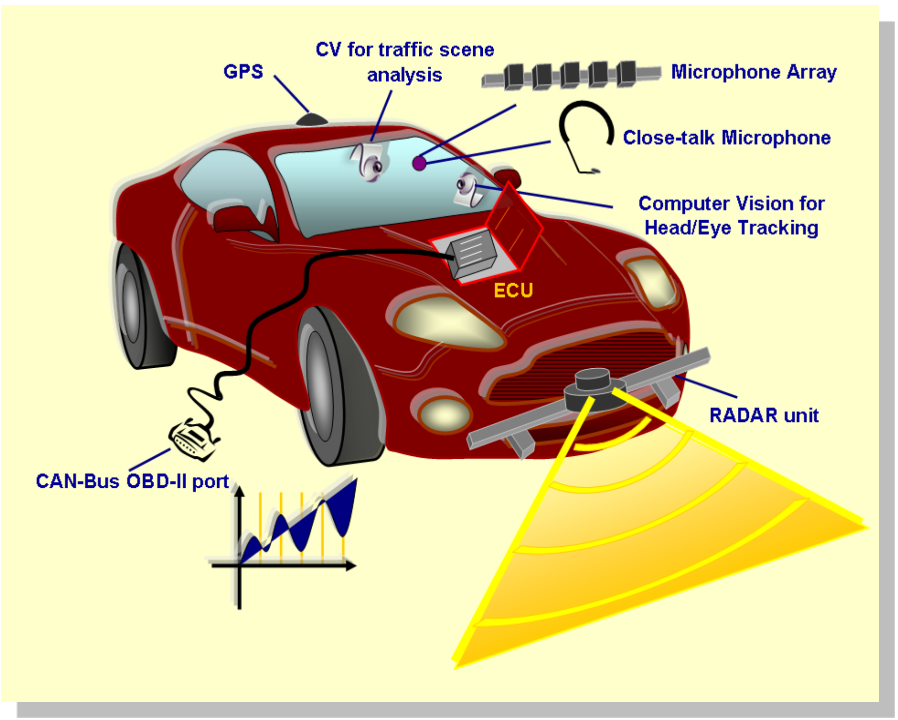
- Driver Specific/ Adaptive
- Context Aware



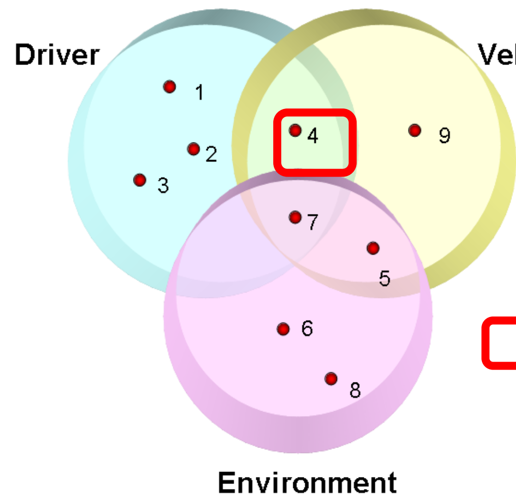
Based on Michon's Hierarchical Model (1985)

Driver Distraction Assessment Methods

II- Driver Performance and Dynamics: CAN-Bus



Potential: CAN-Bus signals include hidden states of driver and vehicle and can be exploited for active safety applications!

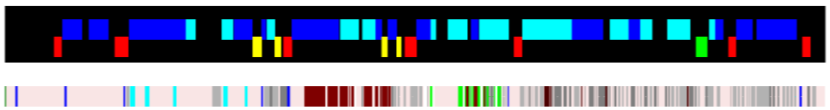


- 1: Head/ Eye Tracking
- 2: Speech Analyzer
- 3: Physiological/Bio Sensors
- 4: CAN-Bus Signals
- 5: GPS/ v2v communication
- 6:Road sign recognition
- 7:Lane/vehicle tracking
- 8: Pedestrian detection
- 9: Vehicle Diagnosis Unit

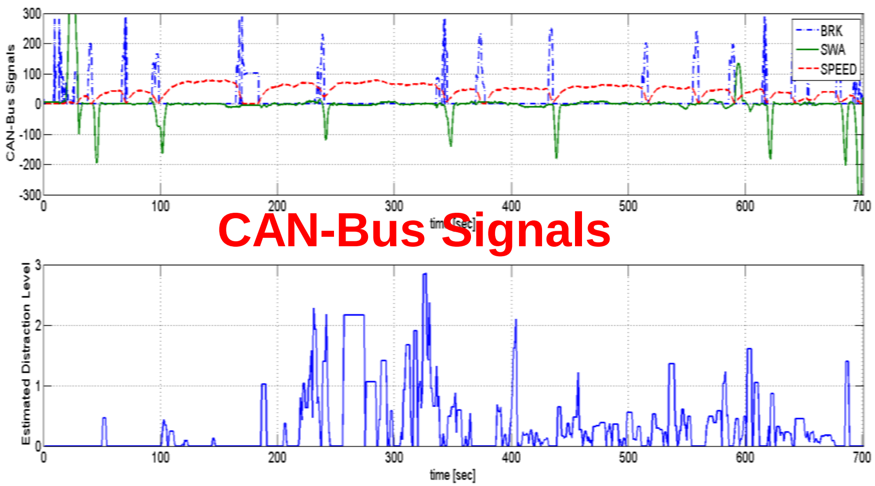
Merge: Signal processing, control theory, automotive engineering, cognitive science, human factors

Driver Distraction Assessment Methods

II- Driver Performance and Dynamics: CAN-Bus



CCDT: Color Coded Driving Time Line

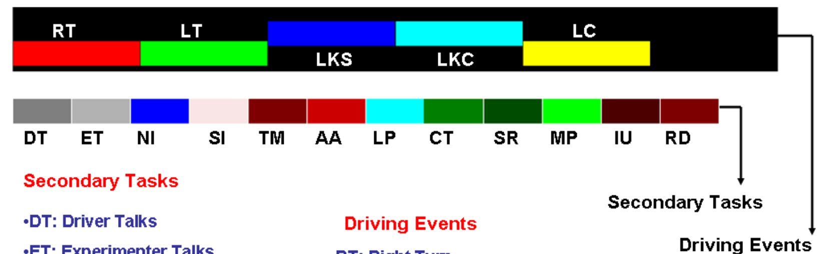


CAN-Bus Signals

Estimated distraction level

Black band: Driving events

White band: Secondary tasks



Secondary Tasks

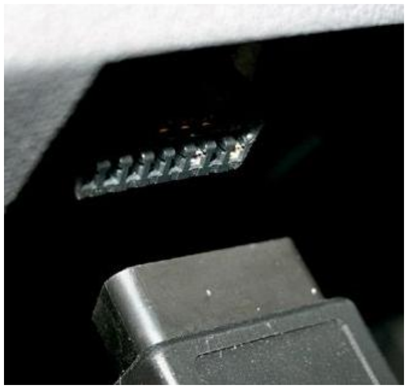
- DT: Driver Talks
- ET: Experimenter Talks
- NI: Navigation Instructions
- SI: Silence
- TM: Tell-Me Dialog
- AA: American Airlines Dialog
- LP: Lane change prompt
- CT: Common Tasks
- SR: Sign Reading
- MP: Music Plays
- IU: Interrupted Utterance
- RD: Response Delay

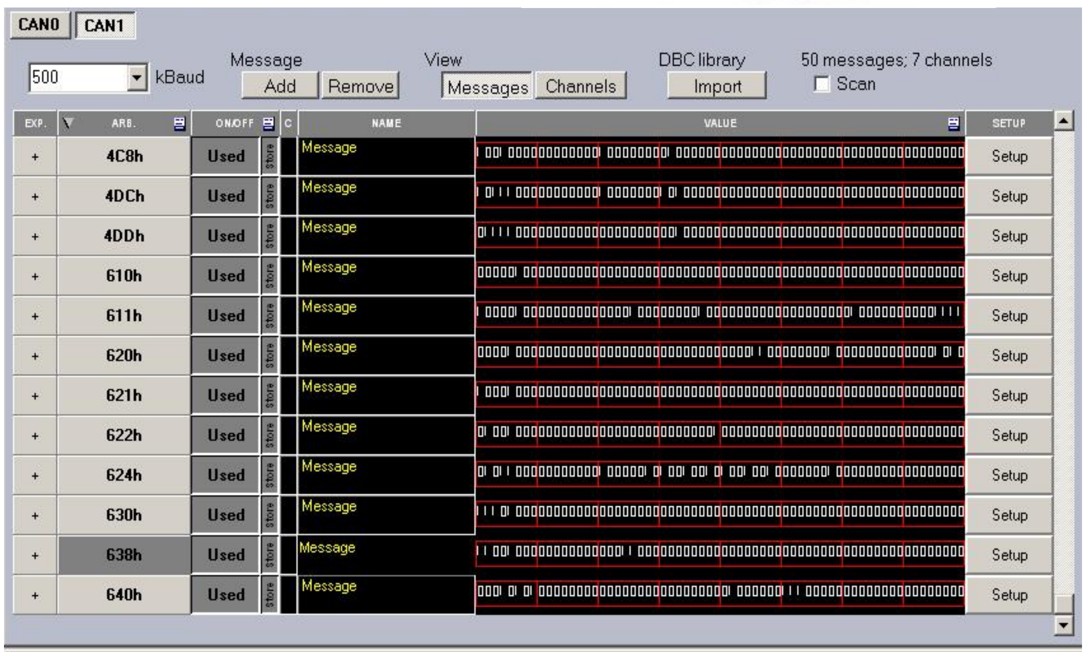
Driving Events

- RT: Right Turn
- LT: Left Turn
- LC: Lane Change
- LKC: Lane Keeping Curved Segments
- LKS: Lane Keeping Straight Segments
- ST: Stop (Black)

Simple concept, significant help in data analysis!

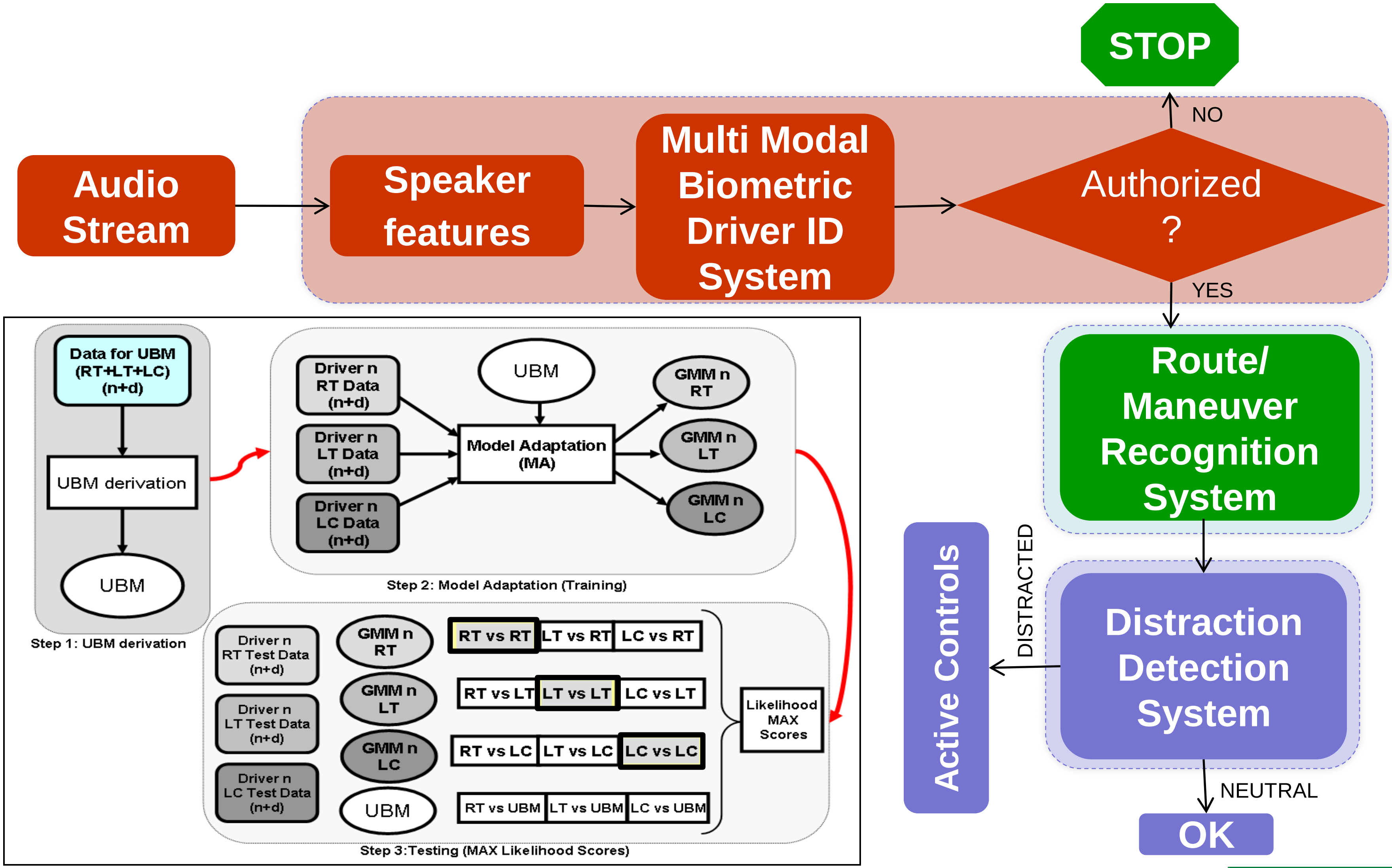
Driver Modeling: Why CAN Signals?





- CAN is used for communication between ECUs, sensors, actuators.
- So, most of the sensor information is already existing.
- Cost effective, no additional efforts/equipments.
- Any developed algorithm can be seamlessly integrated with existing system.

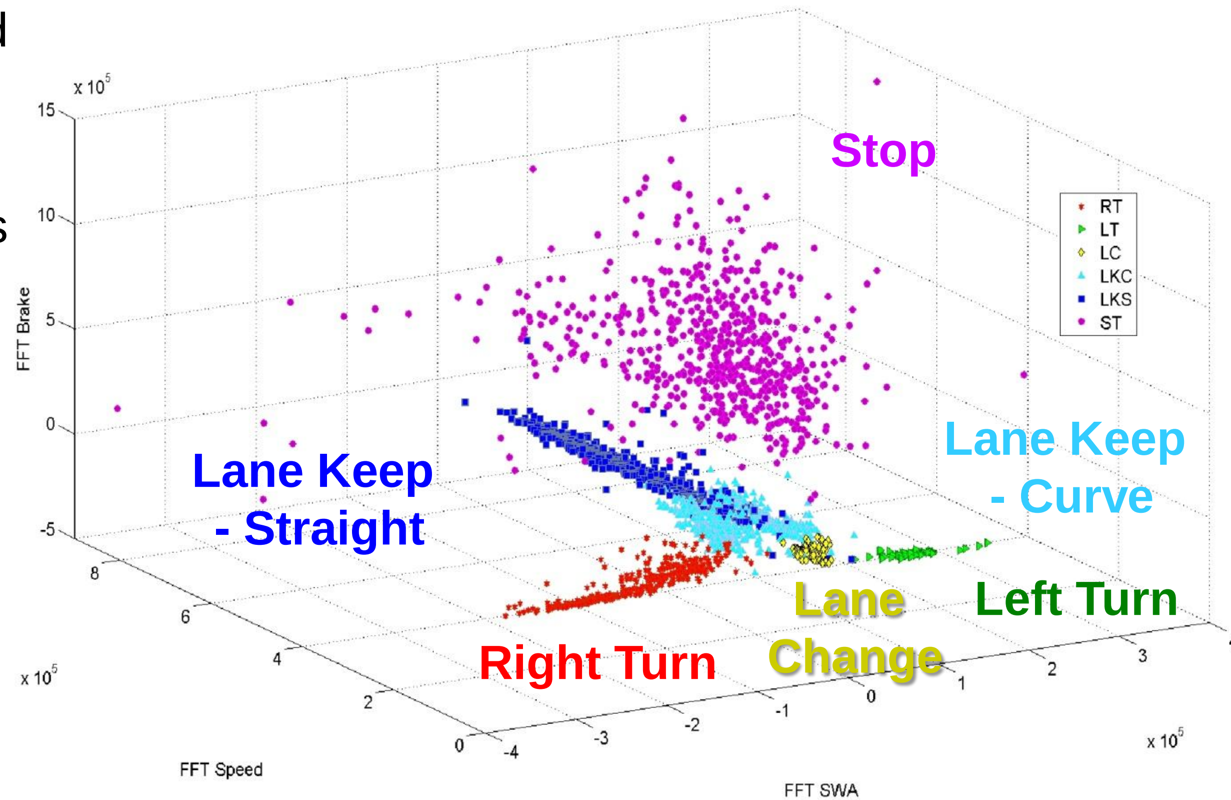
System: Route / Maneuver Recognition



Proof of Concept:
(simple & fast maneuver recognition)

Maneuver Recognition: Over 98% Accuracy

- Select feature set and feature space
- Cluster analysis
- Geometric constraints for clustering/ boundary selection.



SUMMARY

- **Part 1: In-Vehicle Technology, Distraction & Safety**
- **Part 2: In-Vehicle Interactive Systems & Distraction**
  - **In-Vehicle Corpora (speech, video, CAN-bus, etc)**
  - **Basic research: Driver distraction and cognitive load**
- **Part 3: Cognitive Load / Distraction Assessment**
  - **Driver Monitoring via CAN-bus & Speech Based Systems**
- **Summary & Conclusions**

➡ **Integration of Audio/Acoustics with CAN-Bus signal processing schemes can provide a low-cost, effective means of monitoring driver distraction**

References

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[1] K. Takeda, J.H.L. Hansen, H. Erdogan, H. Abut, *In-Vehicle Corpus and Signal Processing for Driver Behavior,* Springer Publishing, 2008

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Any Questions?