"Monitoring Human Behavior"

Speech Communications, Driving Behavior and Safety: Can they Co-exist?

John H.L. Hansen

Center for Robust Speech Systems (CRSS)
Erik Jonsson School of Engineering & Computer Science
The University of Texas at Dallas
Richardson, Texas 75083-0688, U.S.A.
http://crss.utdallas.edu John.Hansen@utdallas.edu

CREST Symposium on Human-Harmonized Information Technology (Behavior, Interaction, Music, User-Generated Content)
Kyoto University (April 1-2, 2012)

Acknowledgements

- **Sincere thanks to many!**
  - **Our Students/Staff!**

Hynek Boril, Amardeep Sathyanarayana, Abhijeet Sangwan, Pinar Boyraz, Wooil Kim, Pongtep Angkititrakul, Xianxian Zhang, Ayako Ikeno, Umit Yapanel, Murat Akbacak, Nitish K. Murthy, Matt Leonard, Steven Gallant, Jay Plucienkowski, Tristan Kleinschmidt, Jamie Yang

  - **Our Sponsors!**

NEDO, USAF-RL, WRAIR/ DARPA, UTD, NSF (Project Emmitt, Fearless Engineering)

  - **Our Collaborators!**

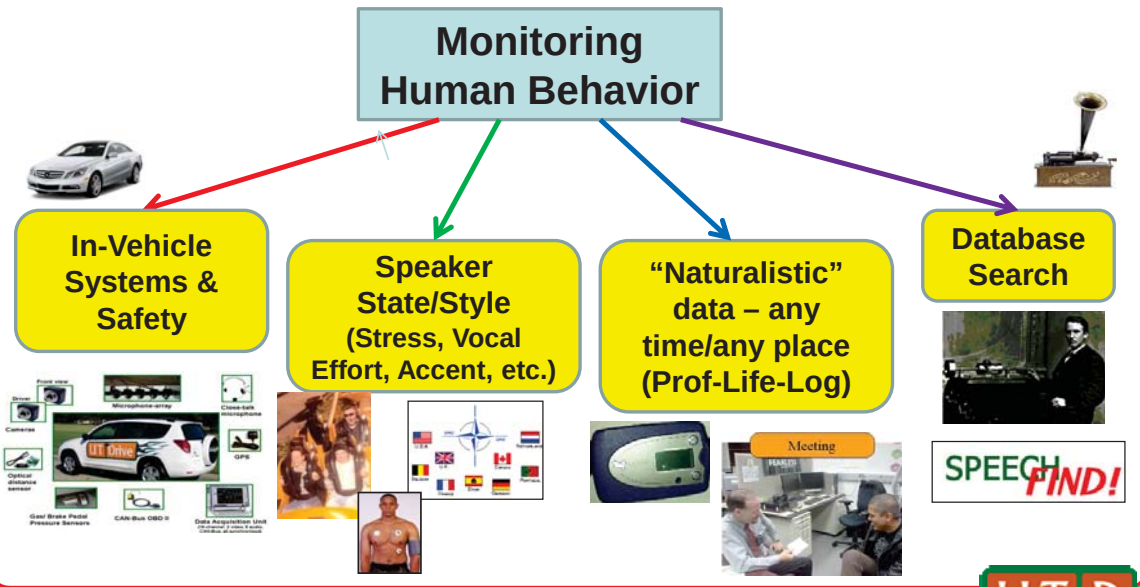
Kazuya Takeda, Huseyin Abut, Hakan Erdogan, Engin Erzin, Aytul Ercil, Abdul Wahab, J.C. De Martin, F. Itakura, Gerhardt Schmidt, Hanseok Ko, M. Hasagawa-Johnson, Bruce Magladry, Sridha Sridharan, John Hankey, and many others!

OUTLINE

- Monitoring Human Behavior – Overview
  - In-Vehicle Systems & Safety
  - Speaker State: Vocal Effort & Speech in Naturalistic Environments
  - Prof-Life-Log ("Naturalistic" data – any time/any place)
- Part 1: In-Vehicle Systems & Distraction
  - In-Vehicle Corpora; Driver Monitoring via CAN-bus & Speech
- Part 2: Speaker State Detection & Assessment
  - Stress, Vocal Effort/Whisper, Lombard Effect, etc.
- Part 3: Monitoring Movement & Database Search
  - Prof-Life-Log; SpeechFind® Applications
- Conclusions & Challenges

Overview

- Monitoring Human Behavior – Overview



OUTLINE

- Monitoring Human Behavior – Overview
  - In-Vehicle Systems & Safety
  - Prof-Life-Log ("Naturalistic" data – any time/any place)
  - Vocal Effort & Speech in Naturalistic Environments
- **Part 1: In-Vehicle Systems & Distraction**
  - **In-Vehicle Corpora; Driver Monitoring via CAN-bus & Speech**
- Part 2: Detecting Speaker State
  - Stress, Vocal Effort/Whisper, Lombard Effect, etc.
- Part 3: Monitoring Movement & Database Search
  - Prof-Life-Log; SpeechFind® Applications
- Conclusions & Challenges

Vehicle Technology

Present Day Vehicle & Driver

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

Previous Activities on DSP for In-Vehicle Environments

Biennial Workshop DSP for In-Vehicle & Mobile Systems

- Nagoya, Japan, March 2003
- Sesimbra, Portugal, Sept. 2005

- Istanbul, Turkey, June 2007
- Dallas, Texas, June 2009

Bruce Magladry, NTSB, USA

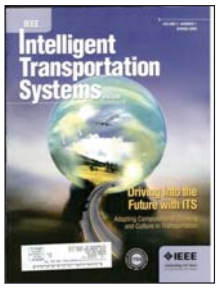
"Highway Safety, Where We Are and Where We Are Going"

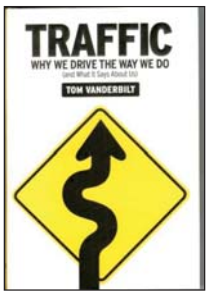
(Keynote talk at 4th Biennial DSP Workshop)

- Kiel, Germany, Sept. 2011

In-Vehicle Publications

IEEE Intelligent Transportation Systems Spring 2009

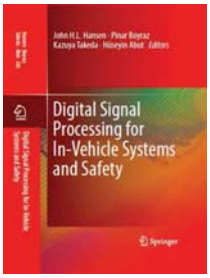


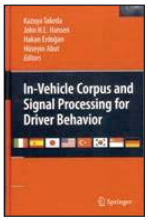


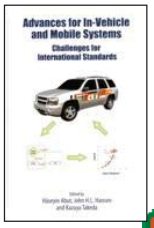
New York Times Best Seller List ('08)

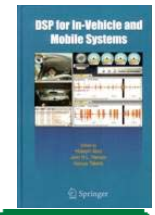
IEEE Signal Processing Magazine July 2009

Biennial DSP for In-Vehicle Systems
Springer: "In-Vehicle Systems & Safety"
[2011, '08, '06, '04]





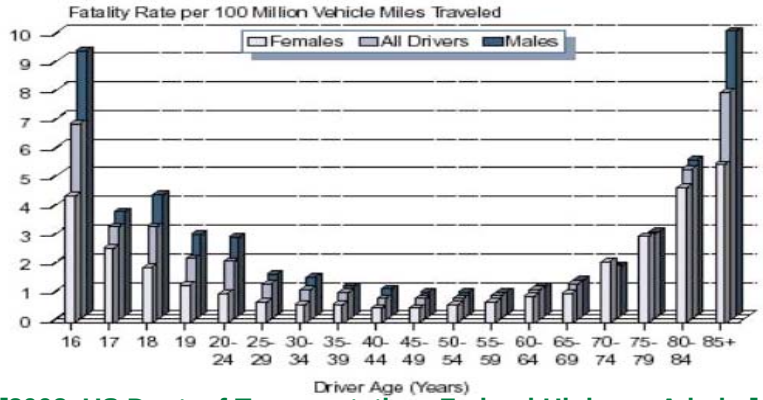




Drivers & In-Vehicle Technology

Not All Drivers are "The Same"

- Miles Driven & Fatalities ("Age, Experience, Gender" make the difference)



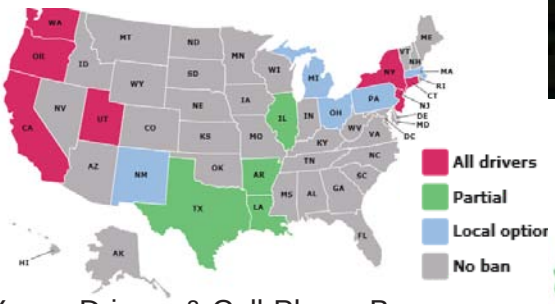
[2002, US Dept. of Transportation; Federal Highway Admin.]

[2010]: 6M accidents in USA / year; 3M injuries, 32k fatalities
NHTSA: 20-30% caused by distraction

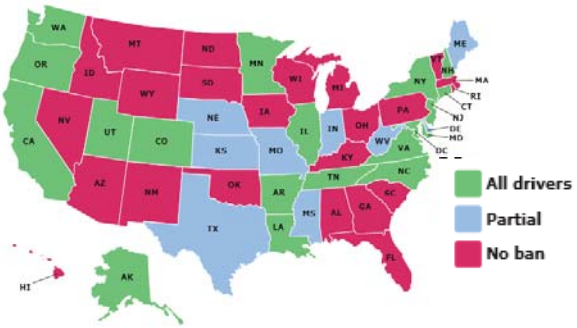
Cell phones & Laws …

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

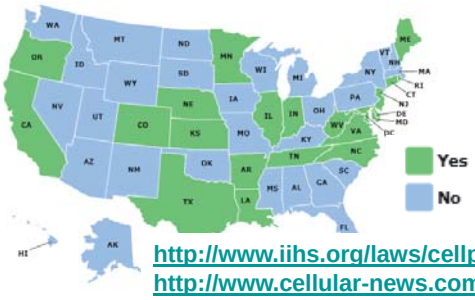
Drivers & Cell-Phone Restrictions



Drivers & Texting Bans



Young Drivers & Cell-Phone Bans



http://www.iihs.org/laws/cellphonelaws.aspx **[Cell Phone Laws in USA]**
http://www.cellular-news.com/car_bans/ **[Cell Phone Laws Worldwide]**

Driver Distraction: Who's Driving the Car? Who is Responsible?

- **Significant Increase in Technology migrating into the Car**
- **A "Vacuum" exists on who is responsible for ensuring safety**

Car Companies

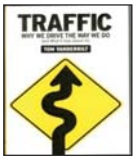
Government Regulators

Law Enforcement

Cell Phone Providers

After-Market Ad-Ons
(GPS, MP3/iPod, Navigation, internet, etc.)

- **Government Regulators & Law Enforcement**
  - **Seatbelts**
  - **Speed Limits**
  - **Cell Phone Use / Texting**



Tom Vanderbilt:
"Why we drive the way we do"

In-Vehicle Corpus Development

Corpus Development for In-Vehicle Systems

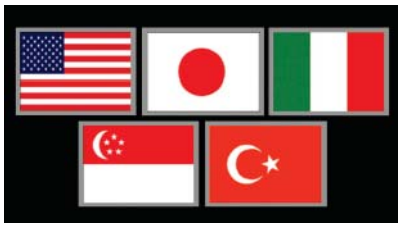
- CIAIR: Nagoya University
- CU-Move: RSPG / Univ. Colorado (UTDallas)
- UYANIK: Turkey
- UTDrive: CRSS-Univ. of Texas at Dallas

[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.

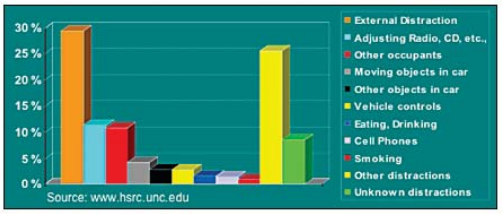
UTDrive

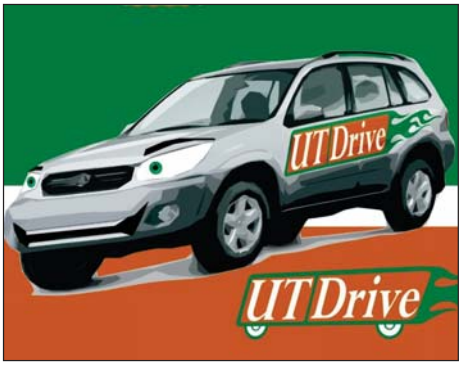
http://www.utdallas.edu/research/utdrive/UTDrive-Website.htm

“UTDrive: In-Vehicle Systems for Driving Behavior & Safety”

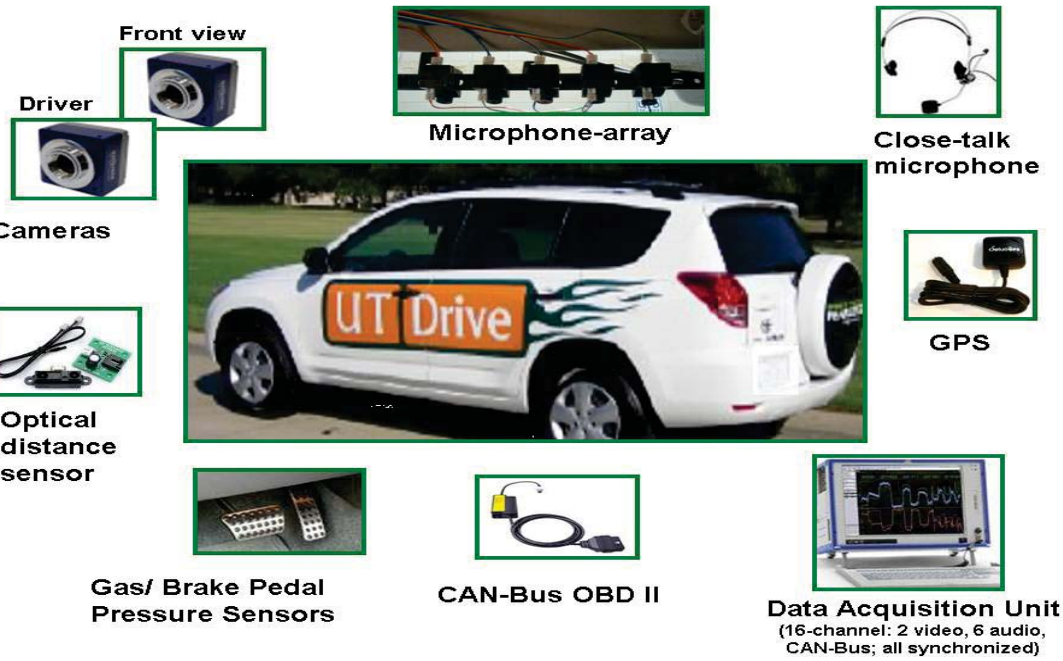


NEDO





UTDrive Vehicle and Sensors



UTDrive: Data Transcription

Speech

Driving Behavior

Route Info

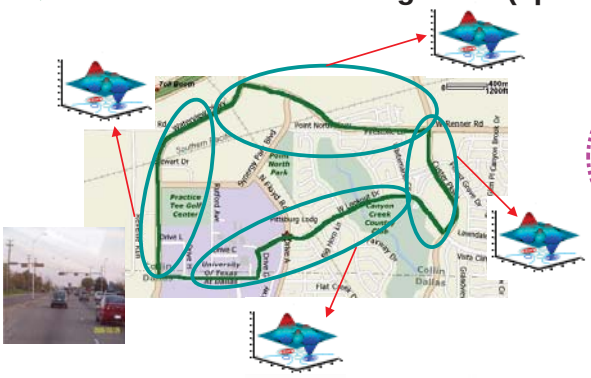
Distraction Tasks

- 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,..)

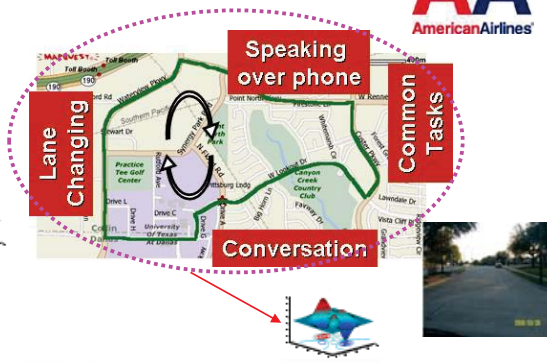
UTDrive: Distraction Detection

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

Environmental Sniffing

- **General System Architecture:**

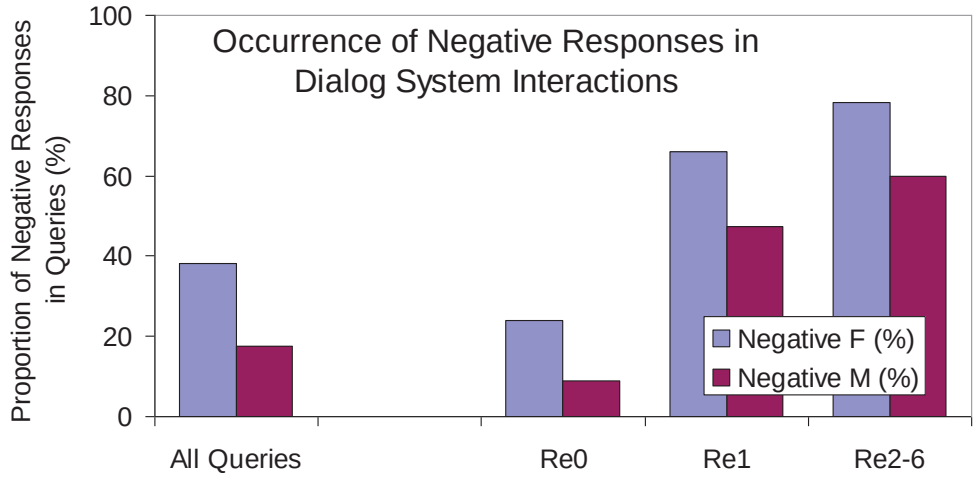
- **Goal:**
- Detect, classify and track acoustic conditions, extract acoustic knowledge.
- ***PASSIVE:*** Provide the acoustic knowledge.
- ***ACTIVE:*** Give smart decisions, direct subsequent speech systems.

[1] Akbacak, Hansen, "Environmental Sniffing: Noise Knowledge Estimation for Robust Speech Systems," *IEEE Trans. Audio, Speech & Lang. Proc.,* 15(2): 465-477, Feb. 2007

UTDrive: Detection of Driver's Emotions and Cognitive Load

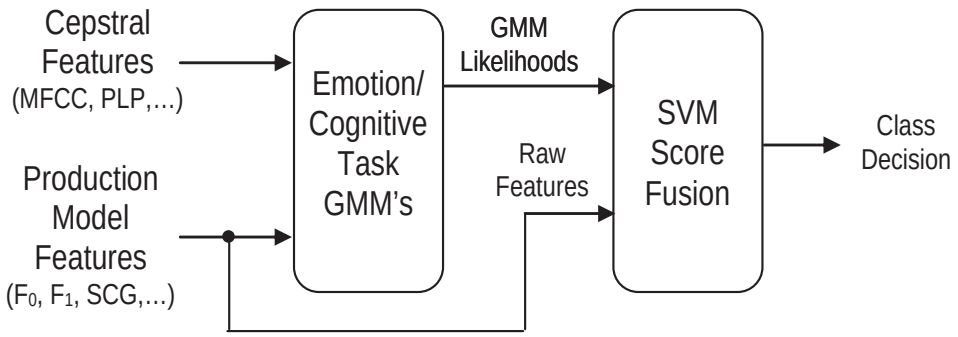
Proportion of negative driver responses in dialog system interactions

- Repeated requests by the system to re-enter the query (Re0 – initial query, Re1 – 1st repeat, Re2-6 – 2nd though 6th repeat) → negative emotions in drivers



UTDrive: Detection of Driver's Emotions and Cognitive Load

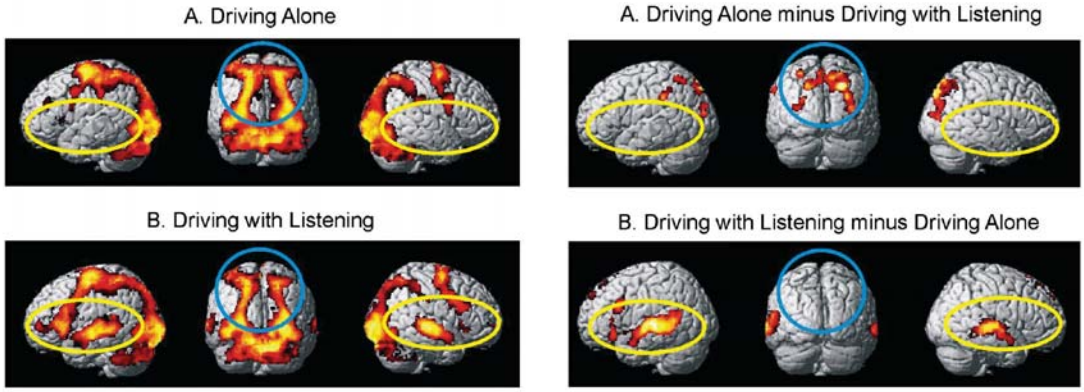
Automatic Detection of Negative Emotions and Increased Cognitive load



Performance

- Tested on drivers 'unseen' during the detector design
- Increased cognitive load – accuracy of **95.2%**
- Emotional state detection – accuracy of **79.0%**

Driving and Audio-Cognitive Load



Similar areas of activation are present in both conditions but with additional language-related activity in temporal and inferior frontal areas (yellow circles)

Top: parietal and superior extrastriate activation decreases with addition of listening task (blue).

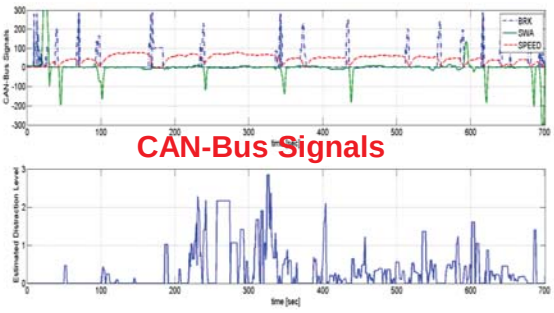
Bottom: Addition of listening task activates temporal and prefrontal language areas. (yellow)

[1] Just, M.A.,Keller, T.A., Cynkar, J.,'A decrease in brain activation associated with driving when listening to someone speak', *Brain Research*, vol. 1205, pp. 70-80, 2008.

Driver Distraction Assessment Methods

II- Driver Performance and Dynamics: CAN-Bus

CCDT: Color Coded Driving Time Line

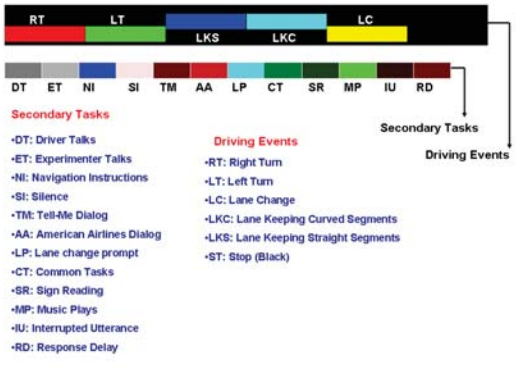


CAN-Bus Signals

Estimated distraction level

Black band: Driving events

White band: Secondary tasks

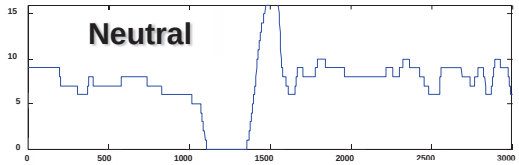


Simple concept, significant help in data analysis!

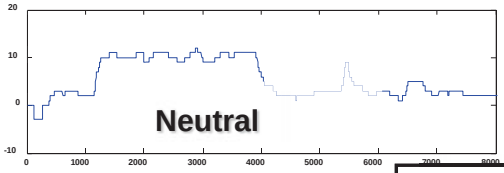
UTDrive: Distraction Detection

Steering Angle

Normalized Short-term variance = 1.21

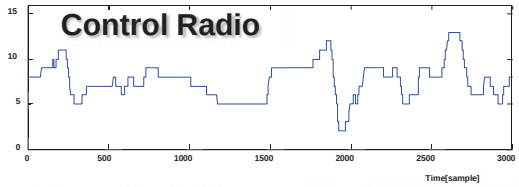


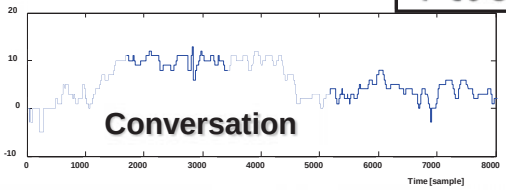
Normalized Short-term variance = 0.27



→ 30 sec

→ 80 sec





Normalized Short-term variance = 1.69

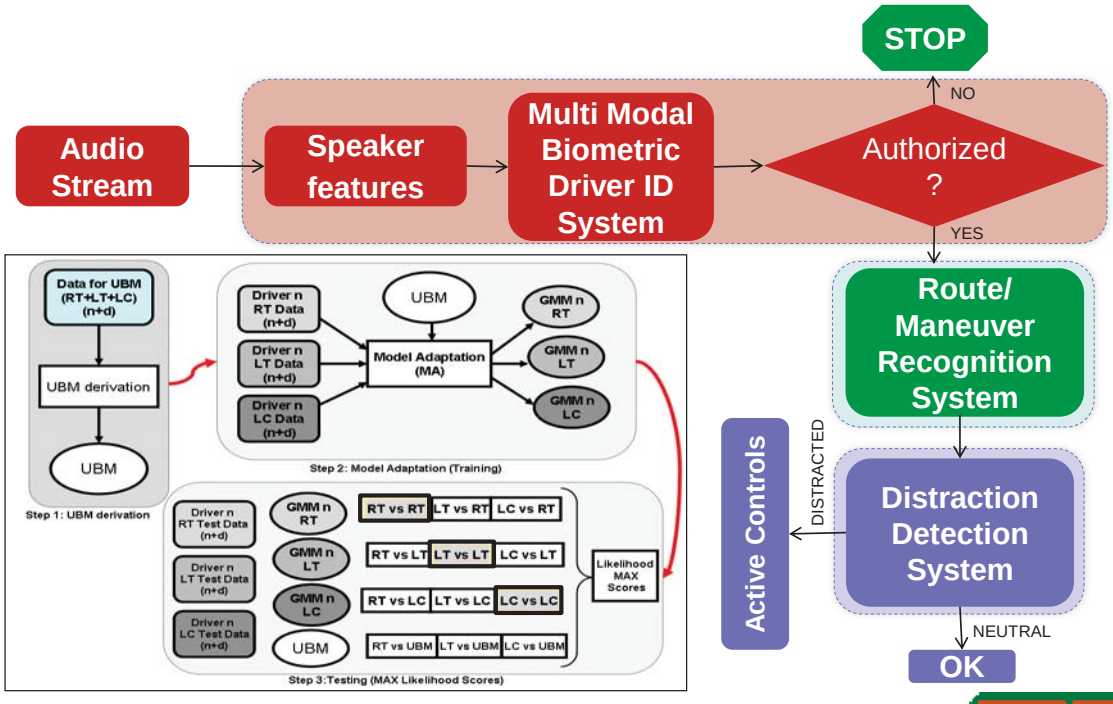
Increase 40% σ^2

Normalized Short-term variance = 0.82

Increase 203% σ^2

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

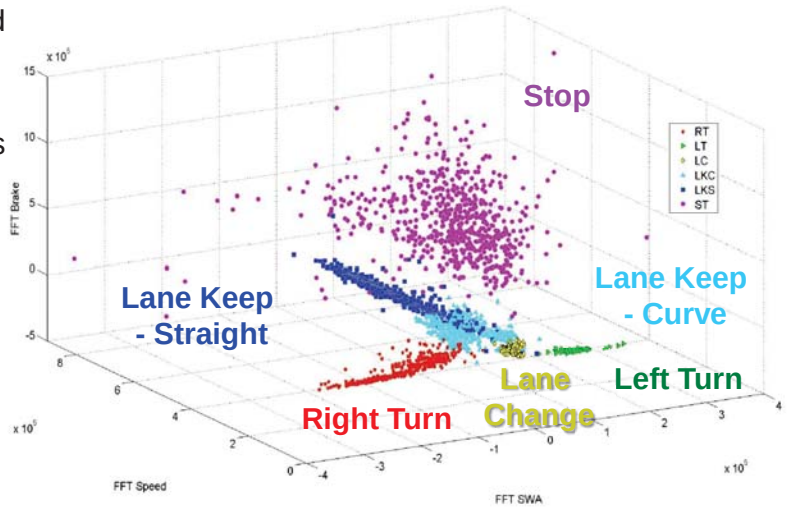
System: Route / Maneuver Recognition



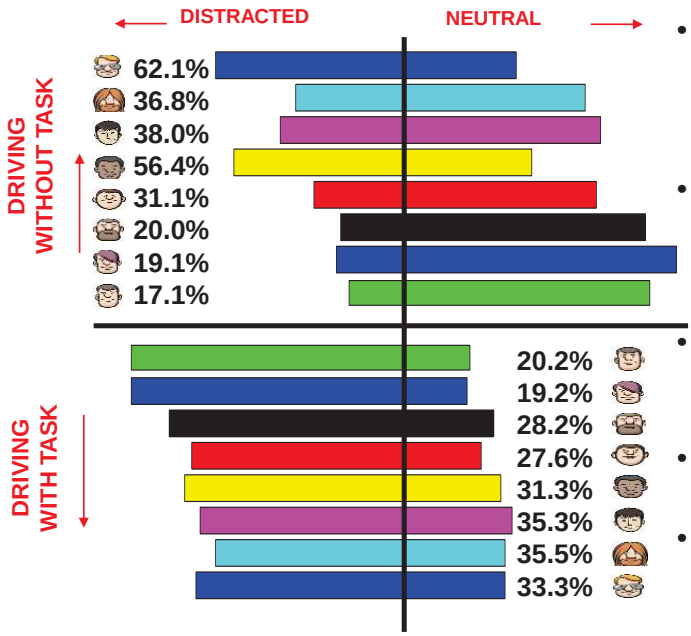
Proof of Concept: Maneuver Recognition
(simple & fast maneuver recognition)

Maneuver Recognition: Over 98% Accuracy

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



Task based Individual Driving Characteristics



- Most drivers are distracted to varying degrees while performing tasks.
- (D1 & D2) are comfortable driving the vehicle, but not comfortable driving and performing other tasks.
- (D5 & D8) are distracted both while performing and not performing secondary tasks.
- D5 – not comfortable with vehicle.
- D8 – 1 year of driving experience.

OUTLINE

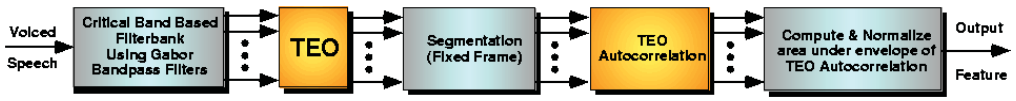
- Monitoring Human Behavior – Overview
  - In-Vehicle Systems & Safety
  - Prof-Life-Log ("Naturalistic" data – any time/any place)
  - Vocal Effort & Speech in Naturalistic Environments
- Part 1: In-Vehicle Systems & Distraction
  - In-Vehicle Corpora; Driver Monitoring via CAN-bus & Speech
- Part 2: Detecting Speaker State
  - **Stress, Vocal Effort/Whisper, Lombard Effect, etc.**
- Part 3: Monitoring Movement & Database Search
  - Prof-Life-Log; SpeechFind® Applications
- Conclusions & Challenges

Monitoring Speaker State

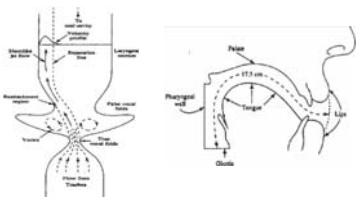
GOAL: (1) Identify, Model, and Classify Speech Under Stress in Military-Related Task Conditions, and (2) Improve Automatic Speech Coding under Stress

APPROACH:

- "Soldier of the Quarter Board" Paradigm
- Monitor and Track "Biometrics" of Stress: Heart rate, blood pressure, stress hormones, psychometrics.



- Engineering: Focus on NONLINEAR Air Turbulent Model – Teager Energy Operator; Identify Stress Dependent Performance across Speakers, phonemes



[1] Rahurkar, Hansen, Meyerhoff, Saviolakis, Koenig, "Frequency Distribution based Weighted Sub-Band Approach for Classification of Emotional/Stressful Content in Speech," Interspeech-03, Sept. 2003.
[2] G. Zhou, J.H.L. Hansen, and J.F. Kaiser, "Nonlinear Feature Based Classification of Speech under Stress," *IEEE Transactions on Speech & Audio Processing*, vol. 9, no. 2, pp. 201-216, March 2001

Monitoring Speaker State: Biometrics

Measure	AB -7 Day	C -20 min	D BOARD	E +20 min	FG +7 Day
HR	70.3	70.8	93.2	69.5	67.2
sBP	118	146	178	154	117
dBP	77.5	74.8	89.7	71.2	69.5

Change
+34.2%
+33.0%
+22.5%

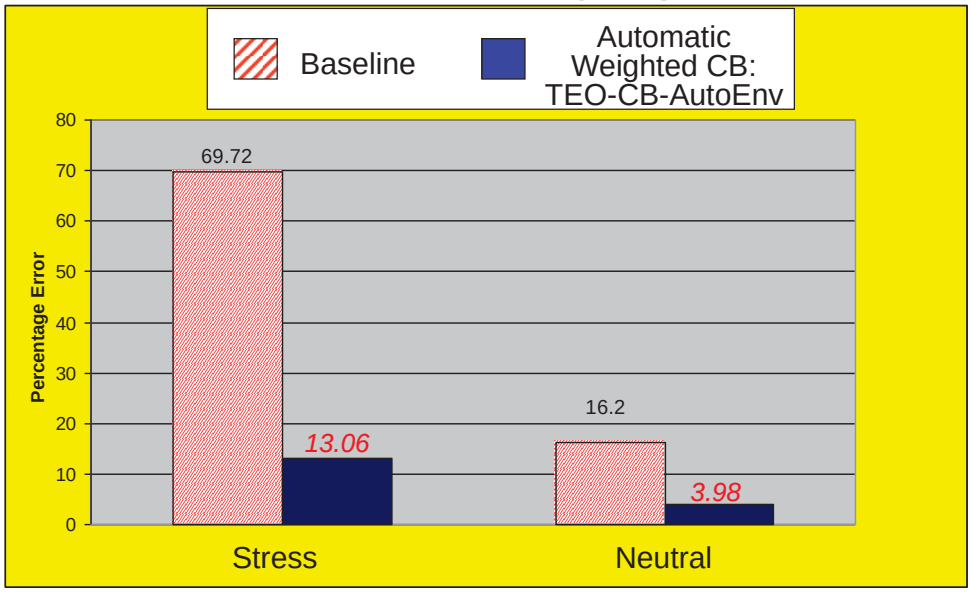
HR = Heart Rate (beats per minute).
sBP = Systolic Blood Pressure.
dBP = Dystolic Blood Pressure.

*** Chemical Analysis of Saliva & Blood Samples was also done**

Monitoring Speaker State:

(TEO-CB-AutoEnv vs. MFCC features)

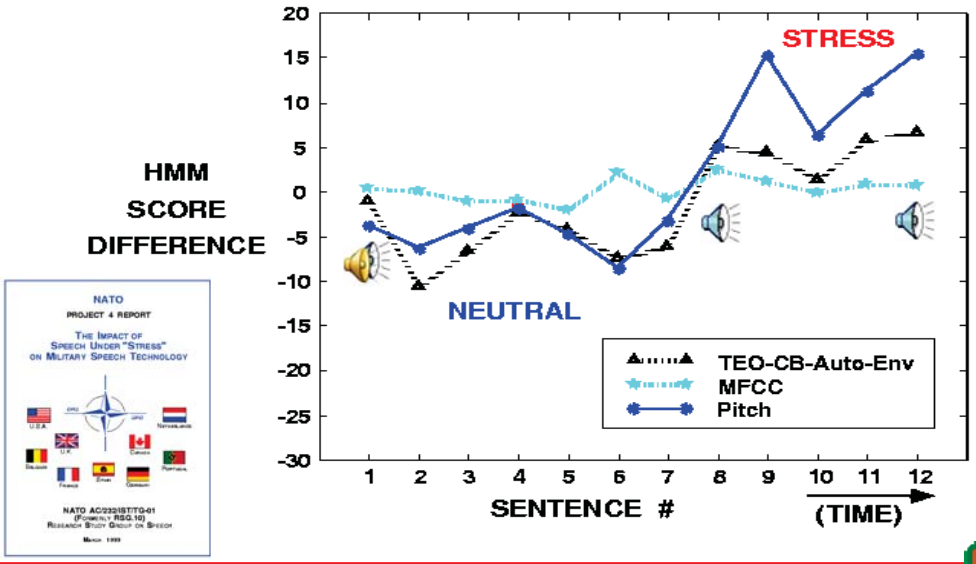
Classification Error Results for Open Speaker Set



[2] J.H.L. Hansen, W. Kim, M. Rahurkar, E. Ruzanski, J. Meyerhoff, "Robust Emotional Stressed Speech Detection using Weighted Frequency Subbands," EURASIP Journal on Advances in Signal Processing: Special Issue on Emotion and Mental State Recognition from Speech, April 2011

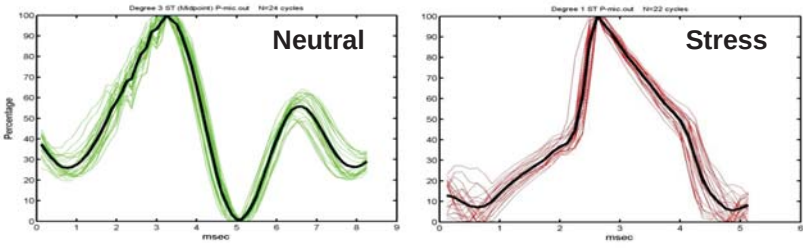
ASSESSMENT FOR NATO SUSC-0 Speech CORPUS

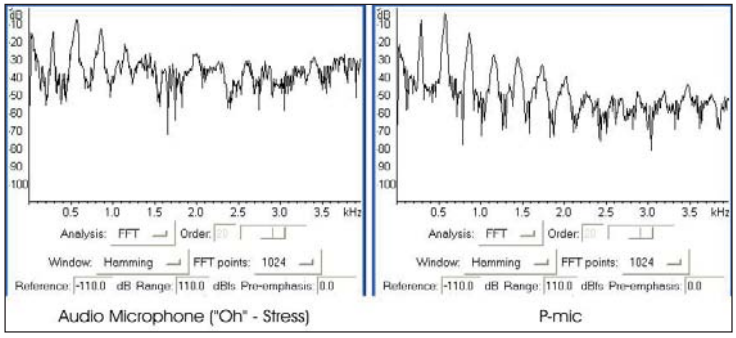
Neutral HMM Model vs. Stress trained HMM Model



P-Microphone: Speech Under Stress

P-Mic: "ee" Single Cycle



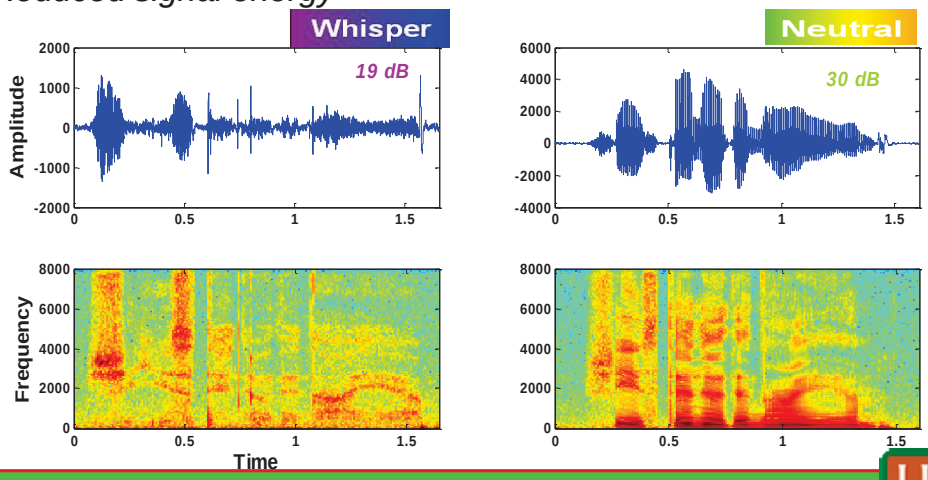


[1] D. Finan, J.H.L. Hansen, "Toward a Meaningful Model of Speech Under Stress," *Conference on Motor Speech: Motor Speech Disorders & Speech Motor Control*, March 2004.
[2] S. Patil, J.H.L. Hansen, "The physiological microphone (PMIC): A competitive alternative for speaker assessment in stress detection and speaker verification" *Speech Communication: Special Issue on Silent Speech Interfaces,* vol. 52, pp. 327-340, April 2010

Speaker State: Vocal Effort & Whisper

Normalization for Speech Systems

- Problem: Whisper is an alternative speech production which presents unique challenges to speaker ID systems
  - *The absence of periodic excitation (F0) and existence of formant shift*
  - *Reduced signal energy*

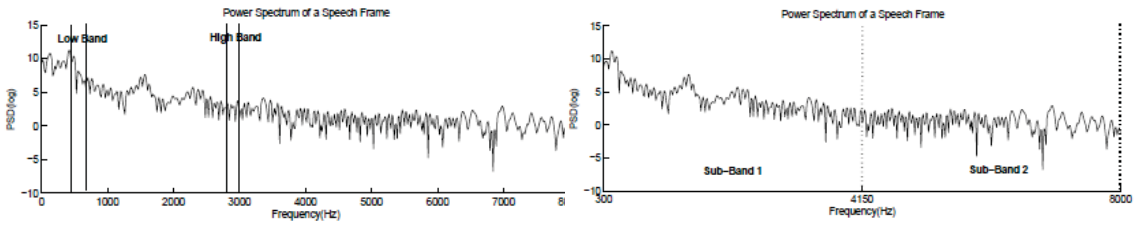


Whisper Island Detection

- Whisper-Island Detection(WhID) Feature:

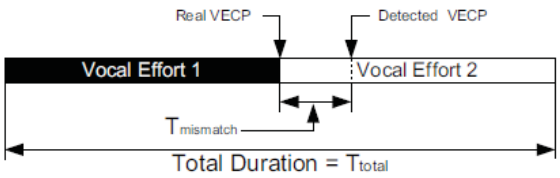
$$\text{WhID} = \begin{bmatrix} 1-D \text{ Spectral Informatio n Entropy Ratio(ER)}; \\ 2-D \text{ Spectral Informatio n Entropy(SI E)}; \\ 1-D \text{ Spectral Tilt(ST)} \end{bmatrix}$$

- Entropy Ratio(ER) between high and low frequency bands
- Two Sub-band for Spectral Information Entropy(SIE)



Whisper Island Detection

- Recall Multi-Error Score(MES):



MES = 1*False Alarm Rate(FAR)
+2*Mismatch Rate(MMR)
+3*Miss Detection Rate(MDR)

$$FAR = \frac{\text{False Alarm VECP \#}}{\text{Total VECP \# in Detection Result}} \times 100\%,$$

$$MMR = \frac{T_{mismatch}}{T_{total}} \times 100\%,$$

$$MDR = \frac{\text{Not Detected VECP \#}}{\text{Total Real VECP \#}} \times 100\%.$$

- Experimental results of segmentation using refined T^2-BIC (IEEE-ASLP, '05):
  - 59 subjects, 41 read TIMIT sentences, 1182 whisper-island in total

Feature Type	MDR(%)	FAR(%)	MMR(%)	MES
13-D MFCC	1.13	27.44	2.63	36.09
4-D WhID	0.00	8.13	1.69	11.51

68% reduction

Whisper Speech: Speaker Identification

Recognition Accuracy for closed-set speaker ID

Whisper	Feature vector	Accuracy	Accuracy (fixed *alpha*)	
read	MFCC	79.29%		
read	MFCC+LFCC	88.35%	87.30%	+43.75% Reduction Error Rate
read	MFCC+EFCC	88.14%	87.30%	
spontaneous	MFCC	73.54%		
spontaneous	MFCC+LFCC	83.23%	82.83%	+38.9% Reduction Error Rate
spontaneous	MFCC+EFCC	83.84%	83.23%	

[3] C. Zhang, J.H.L. Hansen, "Whisper-Island Detection Based on Unsupervised Segmentation with Entropy-Based Speech Feature Processing," *IEEE Trans. Audio, Speech and Language Processing,* vol. 19, no. 4, pp. 883-894, May 2011
[4] X. Fan, J.H.L. Hansen, "Speaker Identification within Whispered Speech Audio Streams," *IEEE Trans. Audio, Speech and Language Processing,* vol. 19, no. 5, pp. 1408-1421, July 2011

OUTLINE

- Monitoring Human Behavior – Overview
  - In-Vehicle Systems & Safety
  - Prof-Life-Log ("Naturalistic" data – any time/any place)
  - Vocal Effort & Speech in Naturalistic Environments
- Part 1: In-Vehicle Systems & Distraction
  - In-Vehicle Corpora; Driver Monitoring via CAN-bus & Speech
- Part 2: Detecting Speaker State
  - Stress, Vocal Effort/Whisper, Lombard Effect, etc.
- **Part 3: Monitoring Movement & Database Search**
  - **Prof-Life-Log; SpeechFind® Applications**
- Conclusions & Challenges

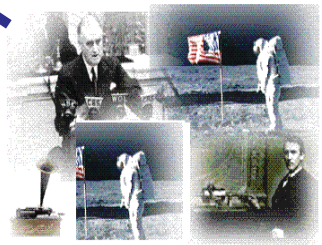
Audio Collection Examples

Telephone Data

Meeting Recordings

Broadcast News

Historical Archives



BN Transcription & Spoken Document Retrieval

Active Participants (Partial List)

- BBN Technology
- CU-HTK
- ICSI
- SRI
- LIMSI-CNRS
- IBM T.J. Watson Center
- HP Cambridge Research Lab
- ISL, Universität Karlsruhe(TH) & CMU
- Tokyo Institute of Technology
- CRSS, University of Texas at Dallas
- University of Washington

BN: Broadcast News
BN-E: English BN
CTS: Conversational Telephone Speech
MDE: MetaData Extraction
RT: Rich Transcription

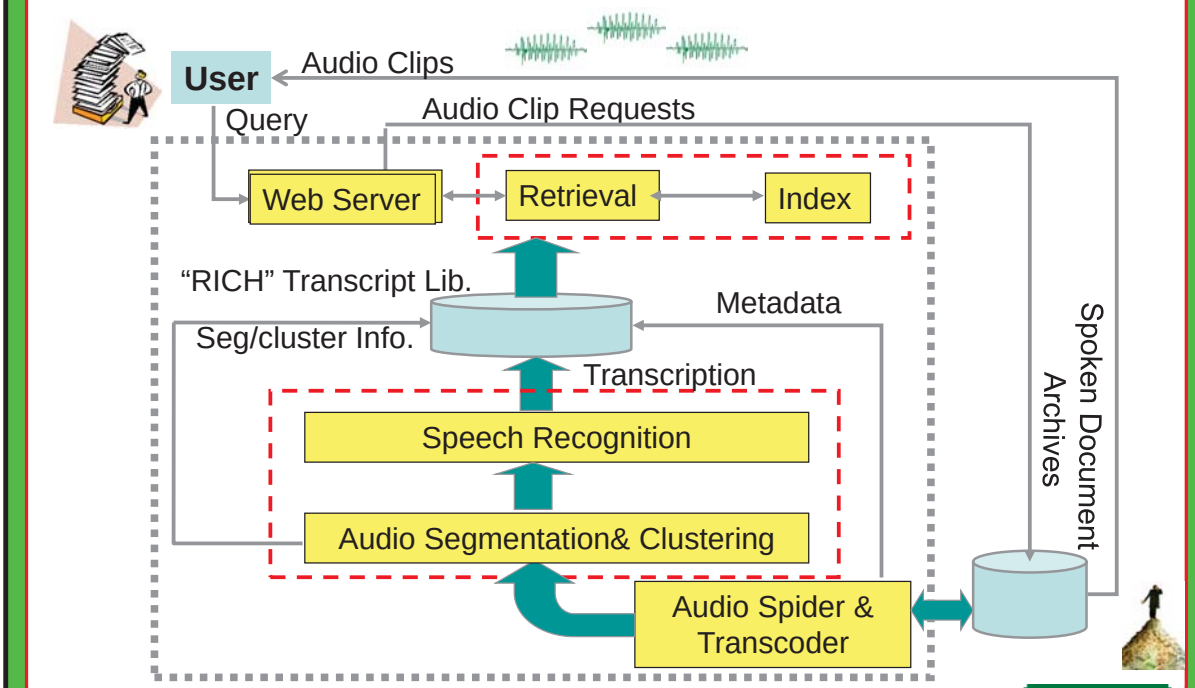
Audio Recordings of Historical Interest 20th Century

http://www.ngsw.org/

Vincent Voice Library

"I have a dream…"
"One small step for man…"
"Ich bin ein Berliner"
"A date which will live in infamy…"

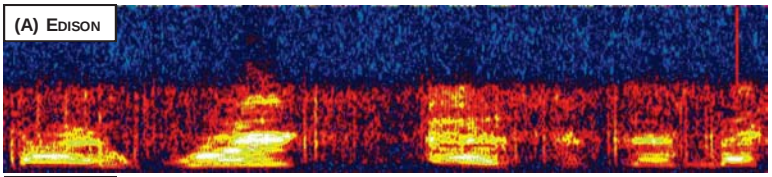
SDR Enrollment & Search Architecture



Audio Examples from NGSW

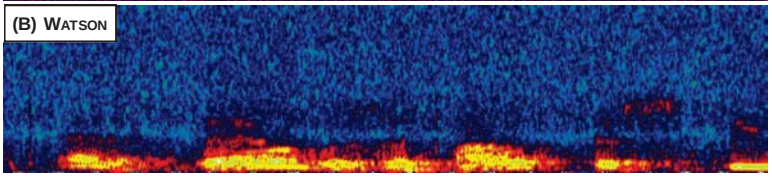
60,000 Hours of Recordings from past 110 Years

(A) EDISON



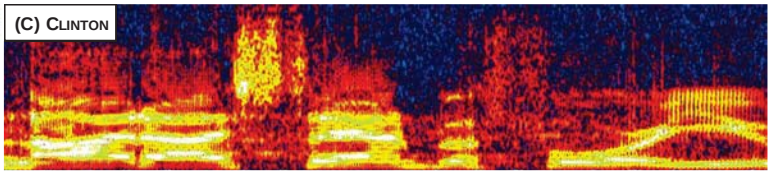
T. Edison
Cylinder Disk Recording 1908

(B) WATSON



T. Watson
discussion of A.G. Bell, recorded 1926

(C) CLINTON



W. Clinton
state of union address, Jan. 1999

Copyright Ownership of Audio Material

- Provide Audio Material Access via WWW
- Must Research Ownership of Audio File
- In U.S.A., public broadcasts prior to 1960's, are in th
Do not require copyright research
- If Audio is not in public domain, must obtain permissi
Audio Library
- Must Include Measures to Ensure Proof of Ownershi

Input Signal + Watermark ➡ **StegoSignal**

(released signal)

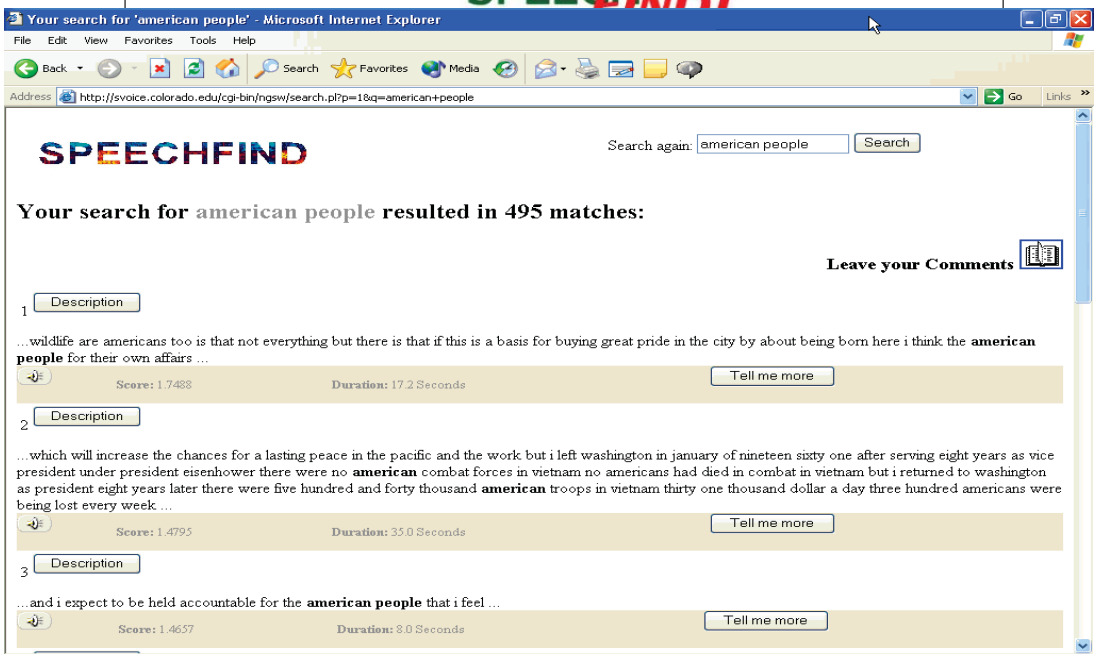

2D SUNDAY CAMERA

NEWS OF THE WEIRD

Lead stories

In June, after the British musical group the Planets introduced a 60-second piece of complete silence on its latest album, representatives of the estate of composer John Cage, who once wrote "4'33" " (273 seconds of silence), threatened to sue the group for ripping Cage off (but failed, said the group, to specify which 60 of the 273 seconds it thought had been pilfered). Said Mike Batt of the Planets: "Mine is a much better silent piece. I (am) able to say in one minute what (John Cage) four minutes and 33 seconds."

http://SpeechFind®.utdallas.edu



Monitoring Speaker & Environment:
Developing a "Complete" Profile of your Acoustic Life

- LENA stands for Language Environment Analysis; designed to capture child's language environment.

1 Data Capture

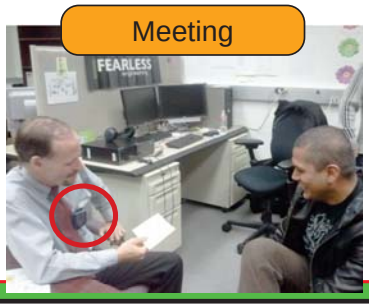
2 Data Transfer

3 Data Analysis

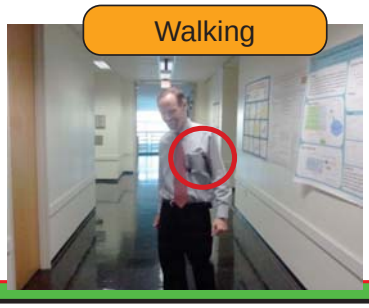
Prof-Life-Log Corpus

- We are using LENA to capture Hansen's daily interactions (his "Acoustic" profile/life)
- Multiple days (8-16 hours/day) (a total of 35 days so far ~400 hours of data)

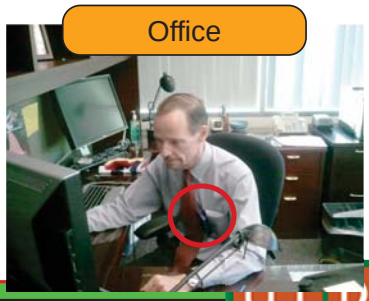
Meeting



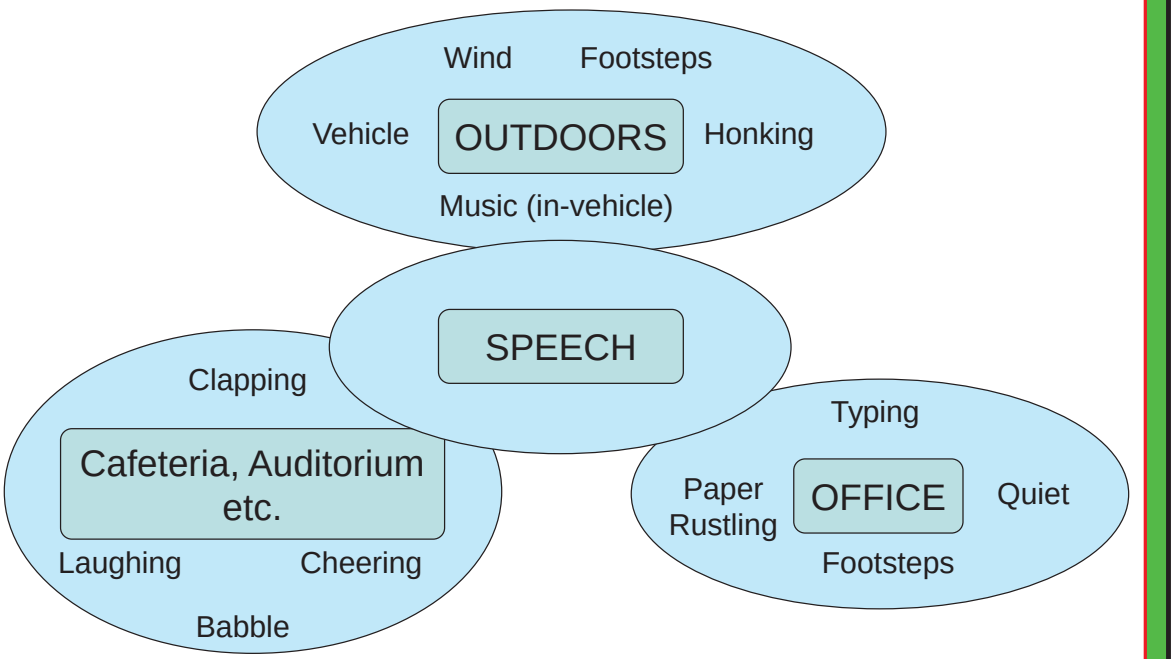
Walking



Office



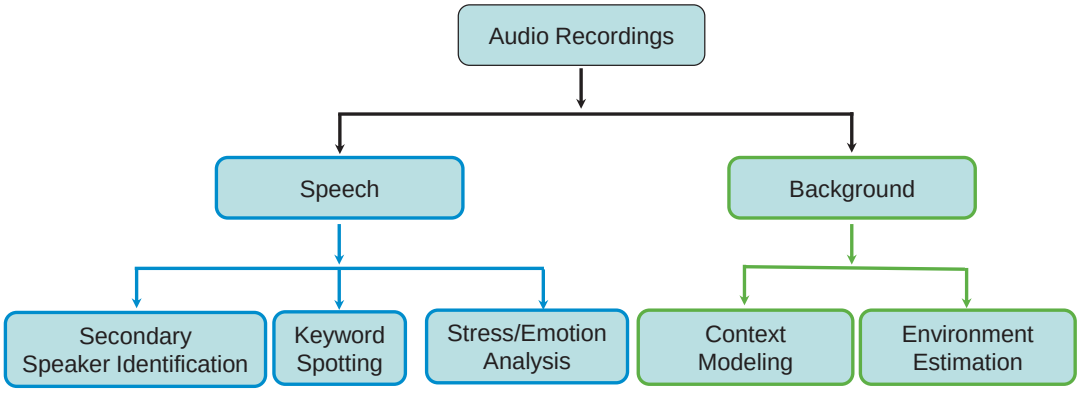
Monitoring Speaker & Environment:
Developing a "Complete" Profile of your Acoustic Life



Monitoring Speaker & Environment:

Developing a "Complete" Profile of your Acoustic Life

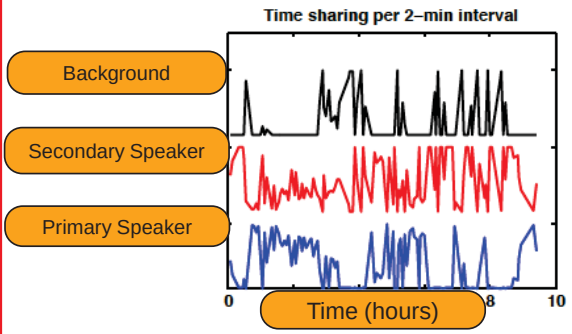
Scope and Range of Experiments

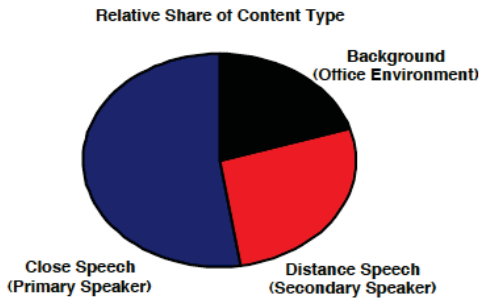


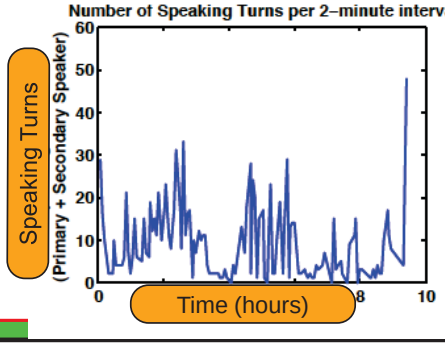
- Automatic Speech Recognition (ASR)
- Speaker Diarization
- Speaker Identification
- Environmental Sniffing
- Keyword Spotting
- Sentiment/Opinion Estimation
- Speaker Context Modeling
- Speech Background Separation

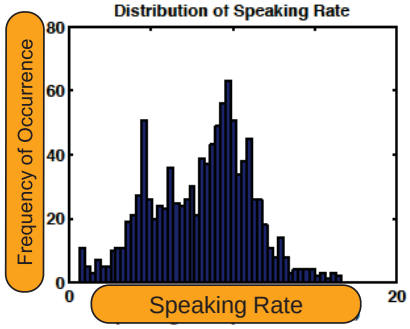
Monitoring Speaker & Environment:

Speaker Environment Analysis (SEA)



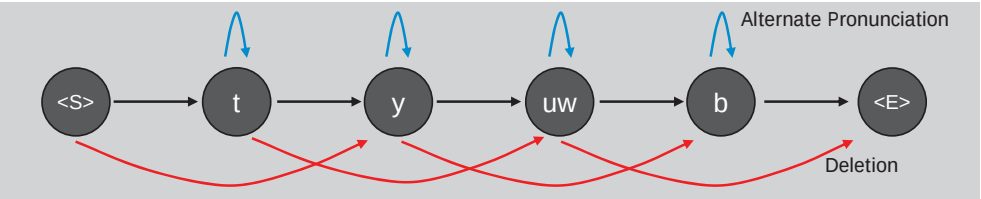






Monitoring Speaker & Environment:
Keyword Spotting (useful for search)

(A) Keyword Model

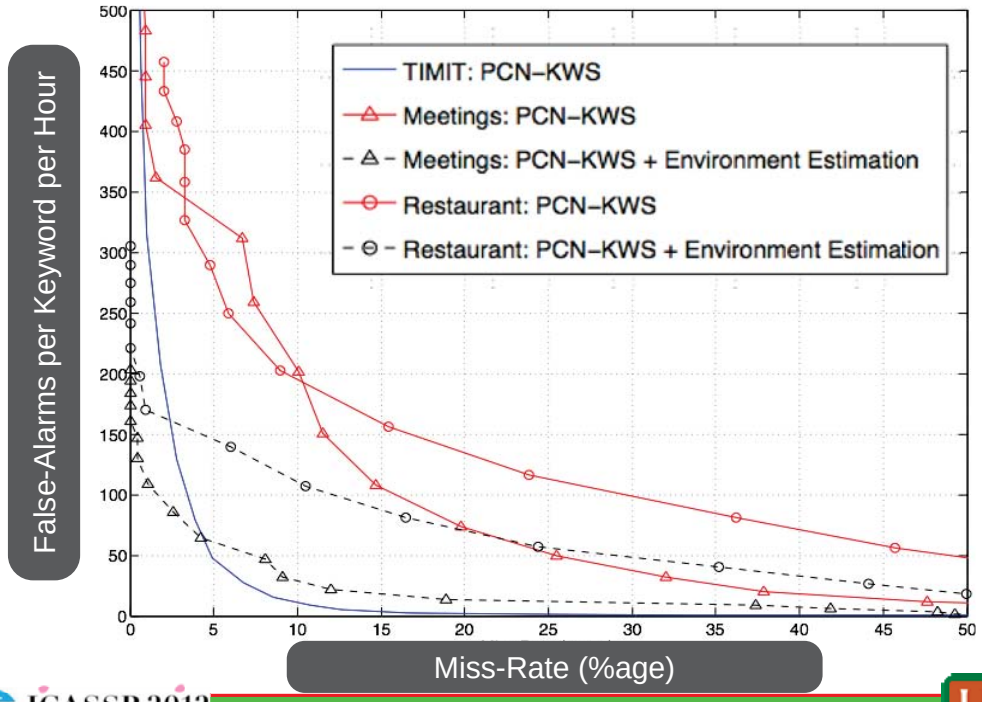


(B) Phone Confusion Network (PCN) : Search Space

- Problem: Search for keyword (A) in the phone confusion network (PCN)
- Strategy = Maximum Likelihood
- Parameters = (Likelihood of occurrence, Time-Location inside CN) [2]

[2] A. Sangwan, J.H.L. Hansen, "Keyword recognition with phone confusion networks and phonological features based key-word threshold detection," Asilomar Conference on Signals, Systems and Computers (ASILOMAR), pp. 711–715, Nov. 2010.

KWS Performance



Summary & Discussion

- **Monitoring Human Behavior – Overview**
  - In-Vehicle Systems & Safety
  - Prof-Life-Log ("Naturalistic" data – any time/any place)
  - Vocal Effort & Speech in Naturalistic Environments
- **Part 1: In-Vehicle Systems & Distraction**
  - In-Vehicle Corpora; Driver Monitoring via CAN-bus & Speech
- **Part 2: Speaker State Detection & Assessment**
  - Stress, Vocal Effort/Whisper, Lombard Effect, etc.
- **Part 3: Monitoring Movement & Database Search**
  - SpeechFind®, Prof-Life-Log Applications
- **Conclusions & Challenges**

Publications

[1] A. Sathyanarayana, P. Boyraz, J.H.L. Hansen, "Information Fusion for Robust 'Context and Driver Aware' Active Vehicle Safety Systems," *Information Fusion,* vol. 12, pp. 293-303, 2010
[2] P. Boyraz, J.H.L. Hansen, "Active Vehicle Safety System Design based on Driver Characteristics and Behavior," Inter. Journal of Vehicle Safety(IJVS), vol. 4, no. 4, pp. 330-364, 2009.
[3] K. Takeda, J.H.L. Hansen, P. Boyraz, L. Malta, C. Miyajima, H. Abut, "An International Large-Scale Vehicle Corpora for Research on Driver Behavior on the Road," *IEEE Trans. on Intelligent Transportation Systems*, vol. 12, no. 4, pp. 1609-1623, Dec. 2011.
[4] J.H.L. Hansen, W. Kim, M. Rahurkar, E. Ruzanski, J. Meyerhoff, "Robust Emotional Stressed Speech Detection using Weighted Frequency Subbands," EURASIP Journal on Advances in Signal Processing: Special Issue on Emotion and Mental State Recognition from Speech, Article ID 906789, 10pages, April 2011.
[5] C. Zhang, J.H.L. Hansen, "Whisper-Island Detection Based on Unsupervised Segmentation with Entropy-Based Speech Feature Processing," *IEEE Trans. Audio, Speech and Language Processing,* vol. 19, no. 4, pp. 883-894, May 2011
[6] X. Fan, J.H.L. Hansen, "Speaker Identification within Whispered Speech Audio Streams," *IEEE Trans. Audio, Speech and Language Processing,* vol. 19, no. 5, pp. 1408-1421, July 2011
[7] S. Patil, J.H.L. Hansen, "The physiological microphone (PMIC): A competitive alternative for speaker assessment in stress detection and speaker verification" *Speech Communication: Special Issue on Silent Speech Interfaces,* vol. 52, pp. 327-340, April 2010
[8] J.H.L. Hansen, V.S.Varadarajan, "Analysis and Normalization of Lombard Speech under different types and levels of noise with application to In-Set/Out-of-Set Speaker Recognition, *IEEE Trans. Audio, Speech & Language Processing,* vol. 17, no. 2, pp. 366-378, Feb. 2009
[10] 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
[11] G. Zhou, J.H.L. Hansen, and J.F. Kaiser, "Nonlinear Feature Based Classification of Speech under Stress," *IEEE Transactions on Speech & Audio Processing*, vol. 9, no. 2, pp. 201-216, March 2001.
[12] J.H.L. Hansen, "Analysis and Compensation of Speech under Stress and Noise for Environmental Robustness in Speech Recognition," *Speech Communications*, vol. 20(2), pp. 151-170, November 1996
[13] J.H.L. Hansen, R. Huang, B. Zhou, M. Seadle, J.R. Deller, Jr., A.R. Gurijala, P. Angkititrakul, "SpeechFind: Advances in Spoken Document Retrieval for a National Gallery of the Spoken Word," *IEEE Trans. Speech & Audio Processing, Special Issue on Data Mining,* vol. 13, no. 5, pp. 712 - 730, Sept. 2005.

- Thank you for your attention

Questions?