Stony Brook University

SUNY

MagTrack: Enabling Safe Driving Monitoring Based on Wearable Magnetic Sensing

Hua Huang, Hongkai Chen, and Shan Lin

Annual Distracted Driving Statistics

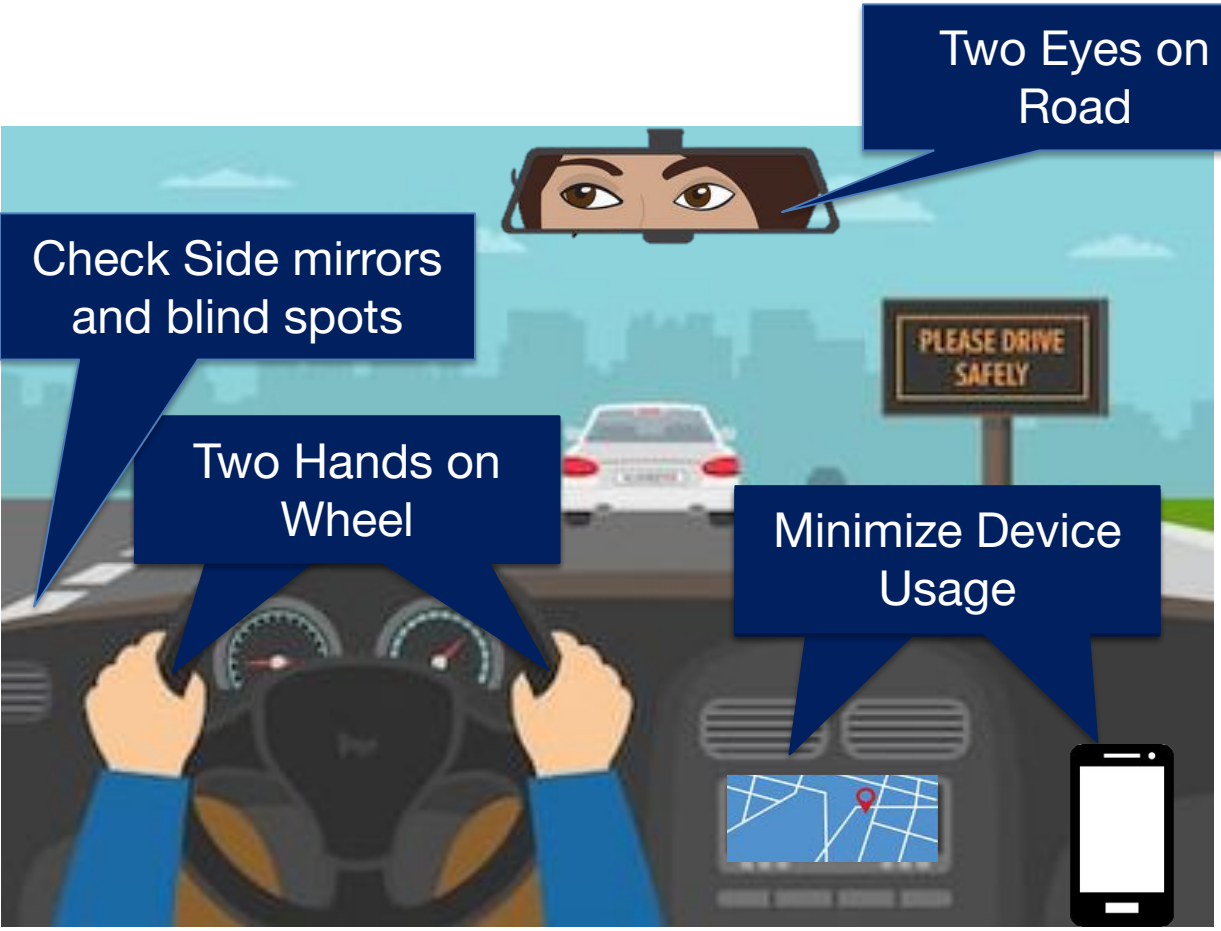
Texting while driving: 6X danger than drunk driving

1.5M crashes

3K+ deaths

$129B financial loss

Safe Driving Guidelines



Avoid:
Manual Distraction
Visual Distraction
Safe Steering

Existing Solutions

Car Motion Monitor*

- Can’t detect dangerous driver gestures

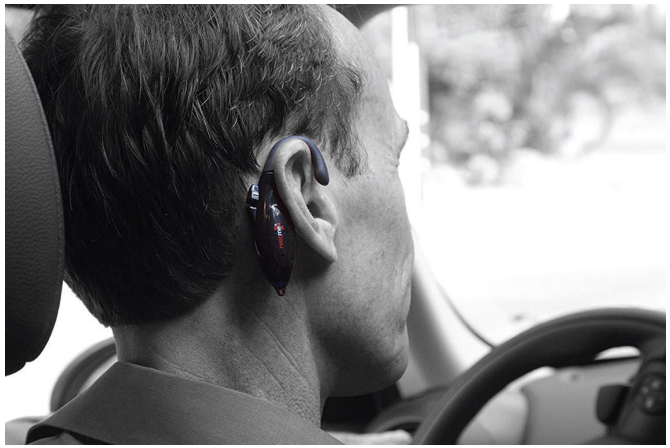
Snapshot from progressive auto insurance

*Chen. et.al “Invisible Sensing of Vehicle Steering with Smartphones”

Existing Solutions

Wearable IMU Systems*

- multiple active sensors needed



Driver Alert System

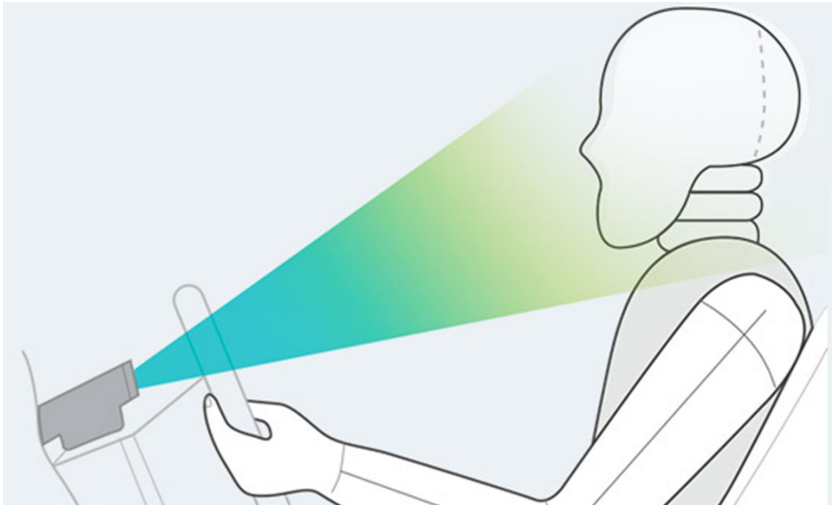
Smartwatches

*Bi et. al. “SafeWatch: A Wearable Hand Motion Tracking System for Improving Driving Safety”
*Karatas et al. “Leveraging wearables for steering and driver tracking”

Existing Solutions

Camera Systems*

- Influenced by ambient lighting conditions



*You et al. “Carsafe app: Alerting drowsy and distracted drivers using dual cameras on smartphones”

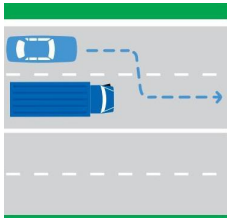
Challenges

- Monitor multiple targets with single device
  - Solution: Magnetic sensing
  - ❖ Magnetic tags to provide additional signals
  - ❖ Simultaneous tracking and classification for multiple tags

- Additional challenges
  - Posture variations
  - Environmental magnetic field
  - Energy constraints

MagTrack Overview

Safe Driving Apps



Safe Lane Change/Turn

Manual Distraction

Visual Distraction

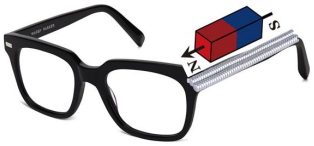
Bimanual Steering

Smartwatch

Simultaneous Hands and Head Tracking and Classification

Magnetic Wearables

One hand wearable



One head wearable

Wearable Magnetics Design

- Low-cost, battery-free and compatible with existing accessories
- Works at night. Line-of-sight not needed.
- Precise tracking, handles orientation changes

Hand and Head Tracking with Wearable Magnetics

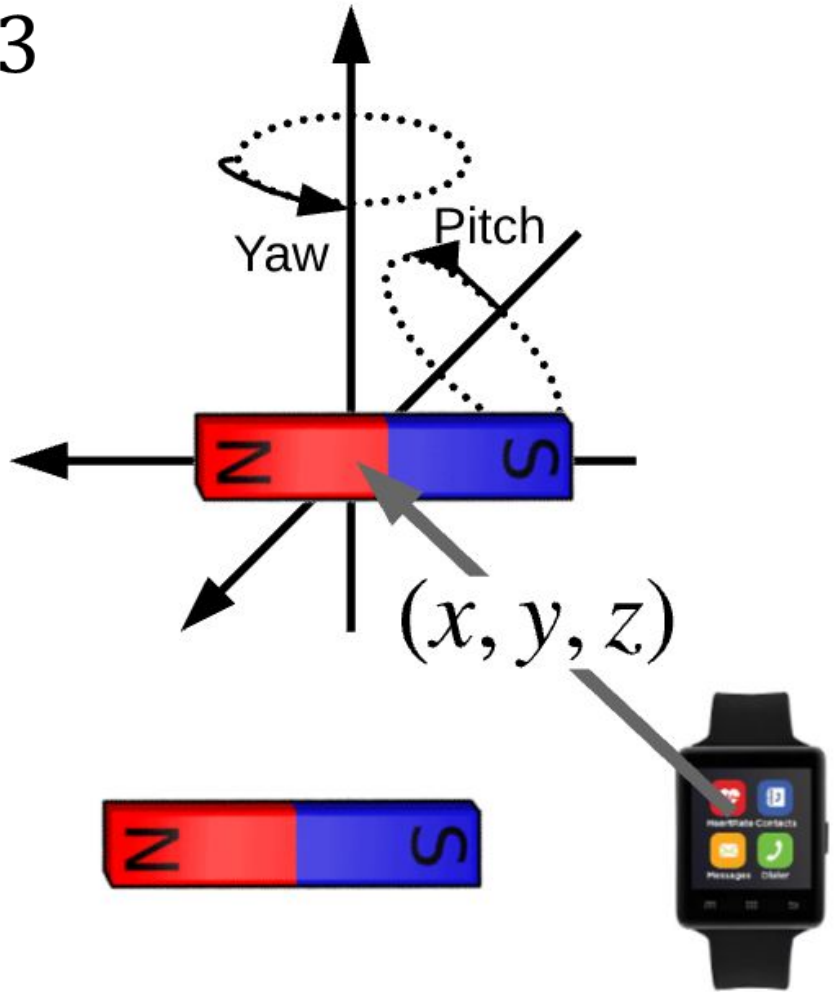
Challenge: Insufficient Sensing Channels

of measurements: $n = 3$

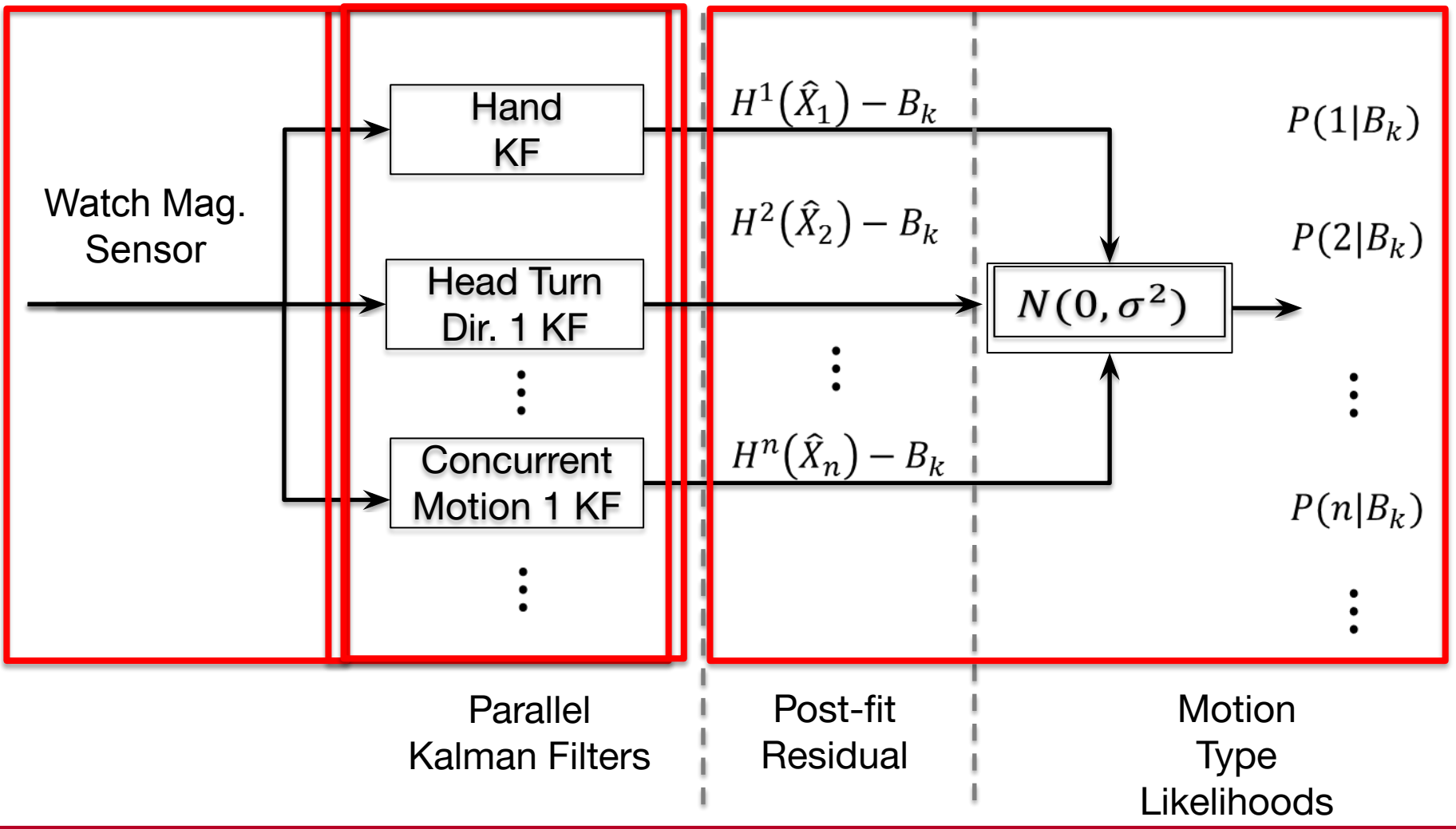
# of variables: $m = 5 \times 2$

Underdetermined system

Observation:
Motion constraints while following guidelines



Simultaneous Tracking and Classification (STC) Algorithm



Kalman Filter Model

State Transition Model:

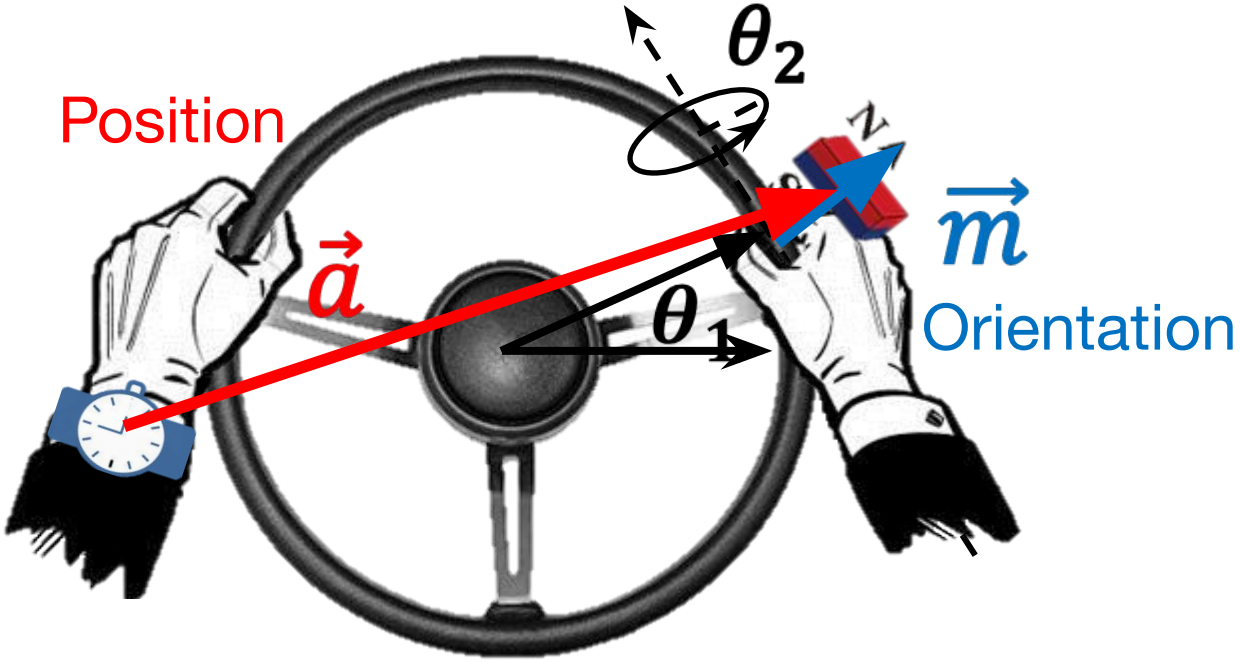
$$\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} \qquad X_{k+1} = F \cdot X_k$$

State Transition Matrix

Sensor Measurement Model:

$$\begin{bmatrix} b_x \\ b_y \\ b_z \end{bmatrix} \qquad B_k = H(X_k)$$

Hand Motion Kalman Filter

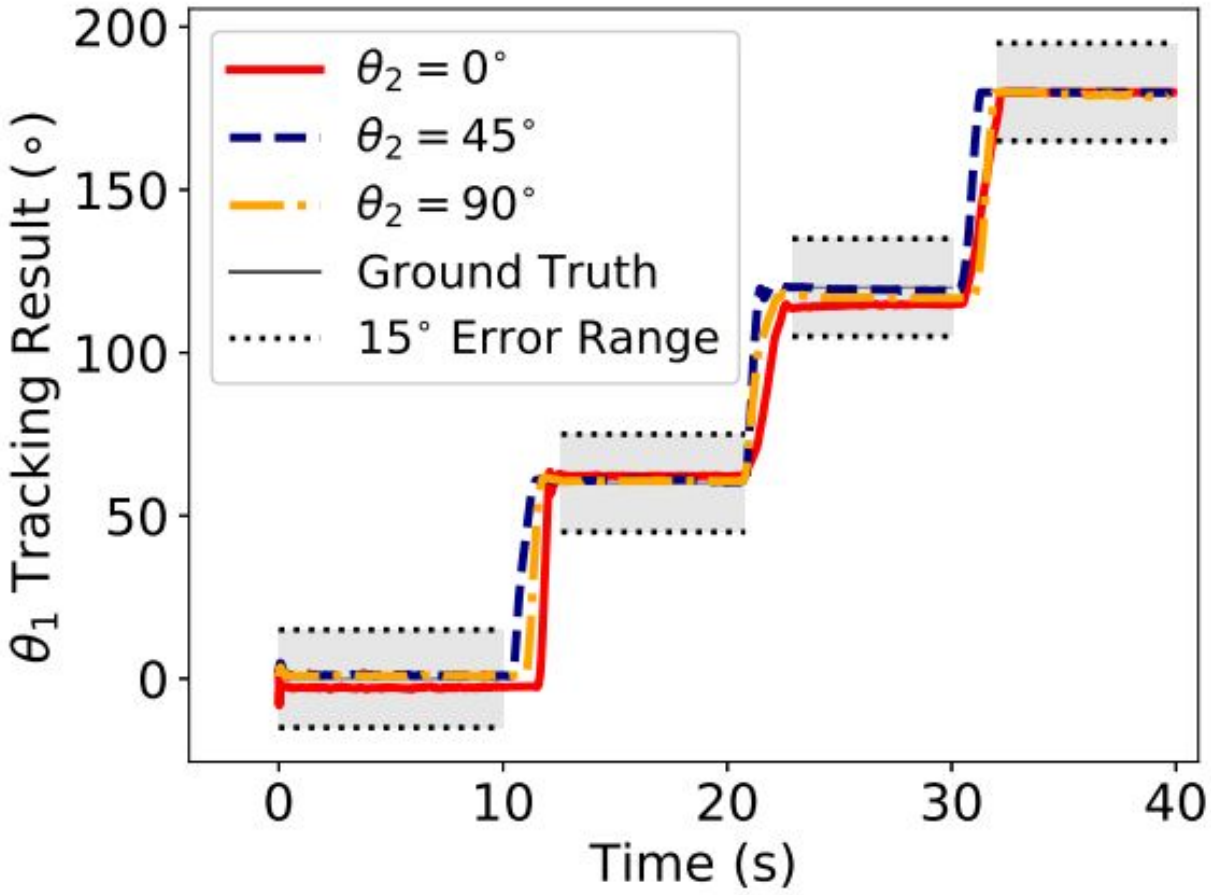


KF^s:

$$X^s{}_{k+1} = F^s \cdot X^s{}_k$$

$$B_k = H^s(\theta_1, \theta_2) = \frac{\mu}{4\pi|\vec{a}|^3}\left[\frac{3\vec{a}\cdot\vec{a}^T}{|\vec{a}|^2} - \boldsymbol{I}\right]\vec{m}$$

Hand Tracking Results



Head Turn Motion
Kalman Filters

Divide into left, right and down turns

- Head turn angle γ_k in the state variable
- Linear approximation for measurement model

KF^l:

$$X^l{}_{k+1} = F^l \cdot X^l{}_k$$

$$B_k \approx H^l(\gamma_k) = \vec{a}_0 + \vec{a}_1 * \gamma_k$$

Linear approximation

State Transition Model:

- Include both hand and head angles
- Limit the state variables to large values

Measurement Model:

- Sum of hand and head measurement models

Hand Measurement

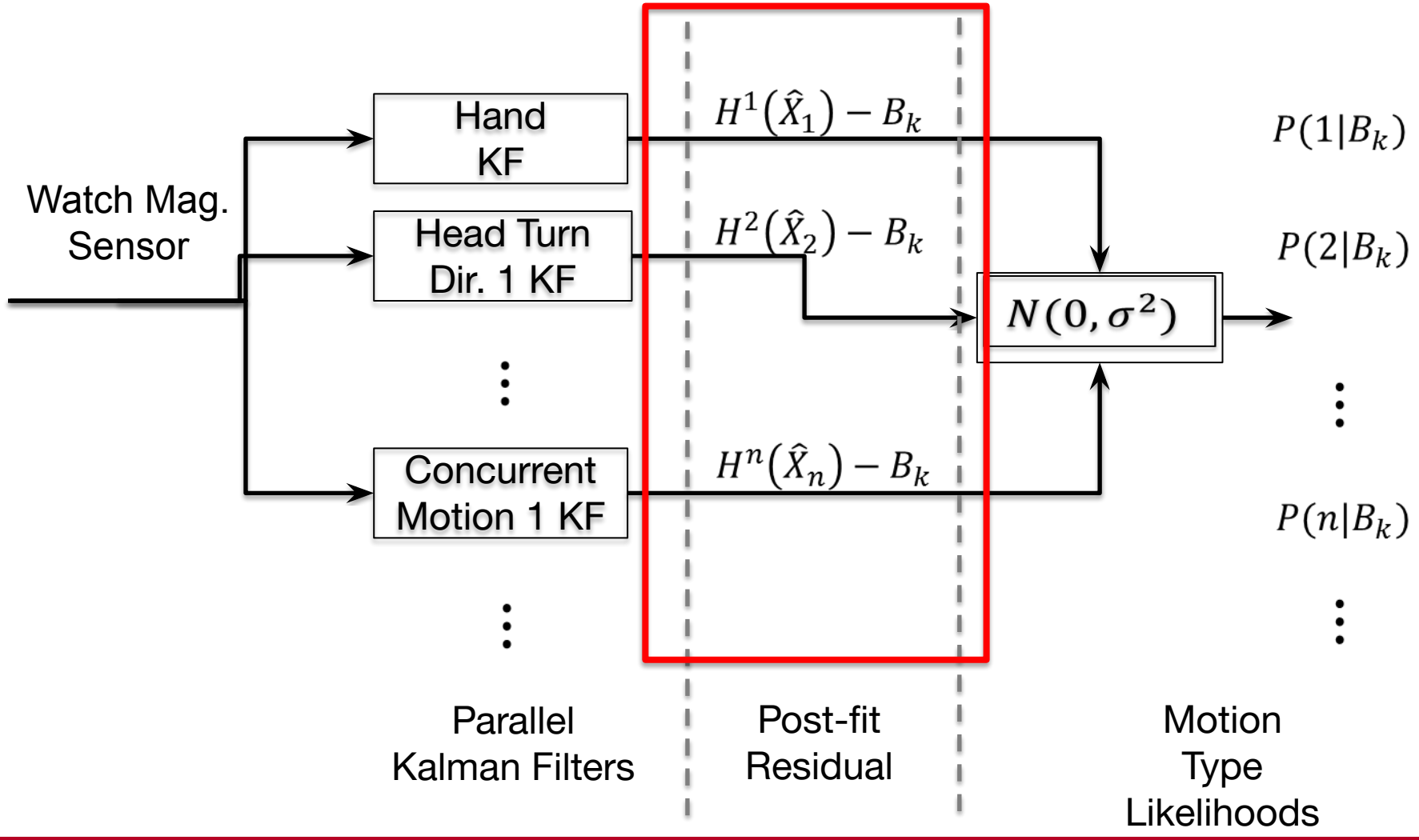
Head Measurement

$$KF^{sl}: \quad X^{sl}{}_{k+1} = F^{sl} \cdot X^{sl}{}_{k}$$

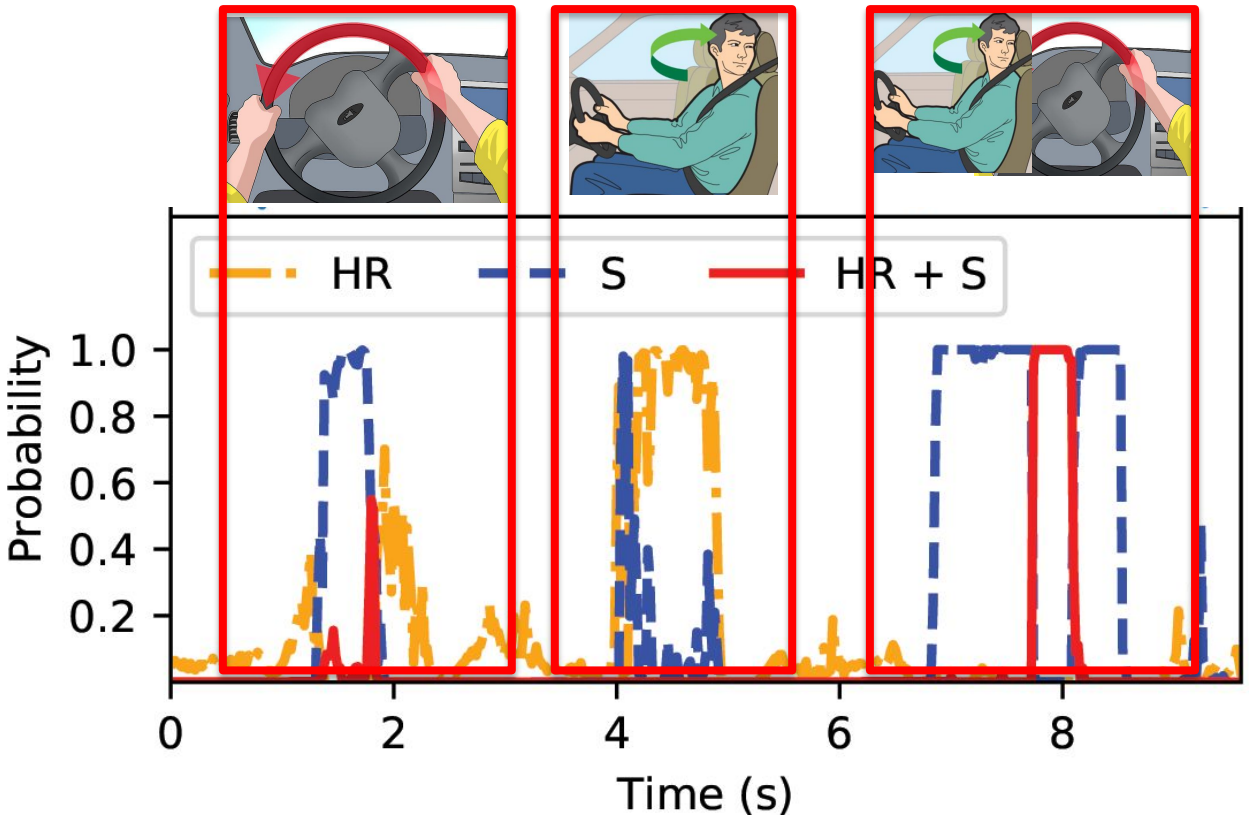
$$B_k = H^{sl}(\theta_{1k}, \theta_{2k}, \gamma_k)$$

$$= H^{s}(\theta_{1k}, \theta_{2k}) + H^{l}(\gamma_k)$$

Simultaneous Tracking and Classification (STC) Algorithm



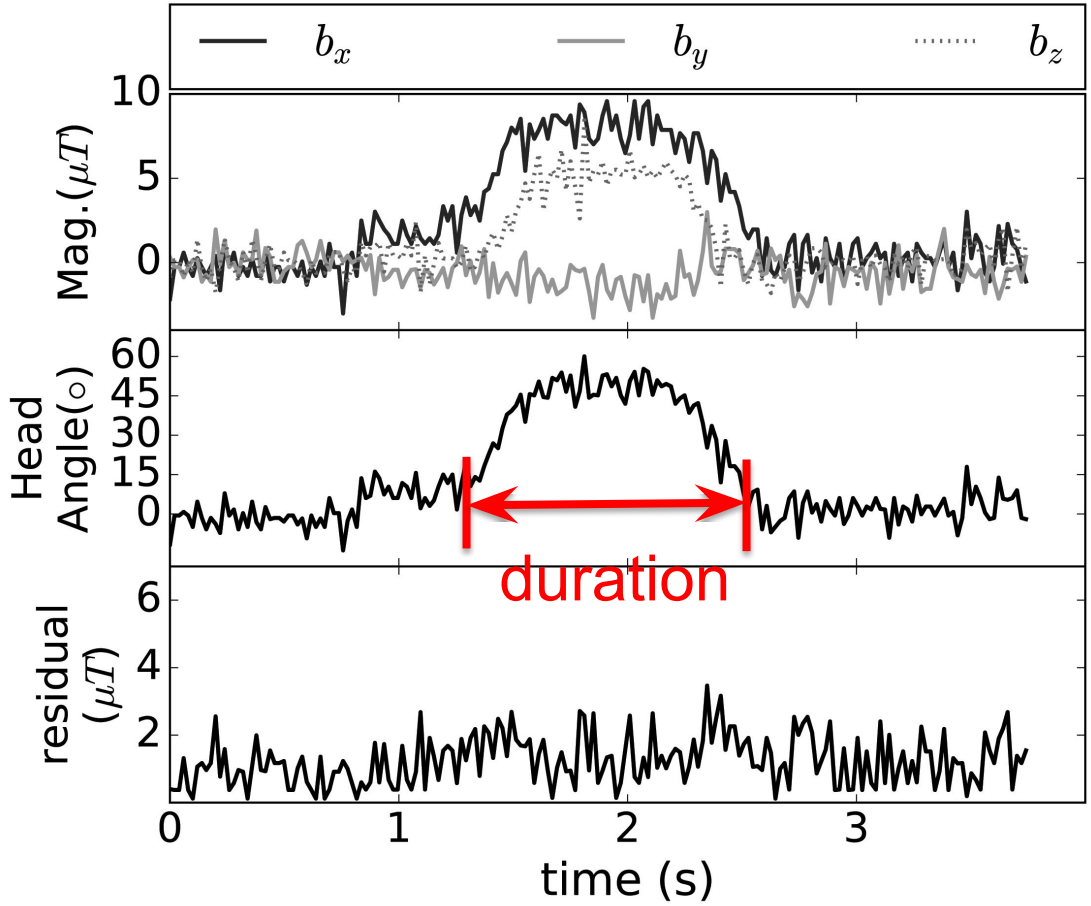
Motion Type Recognition



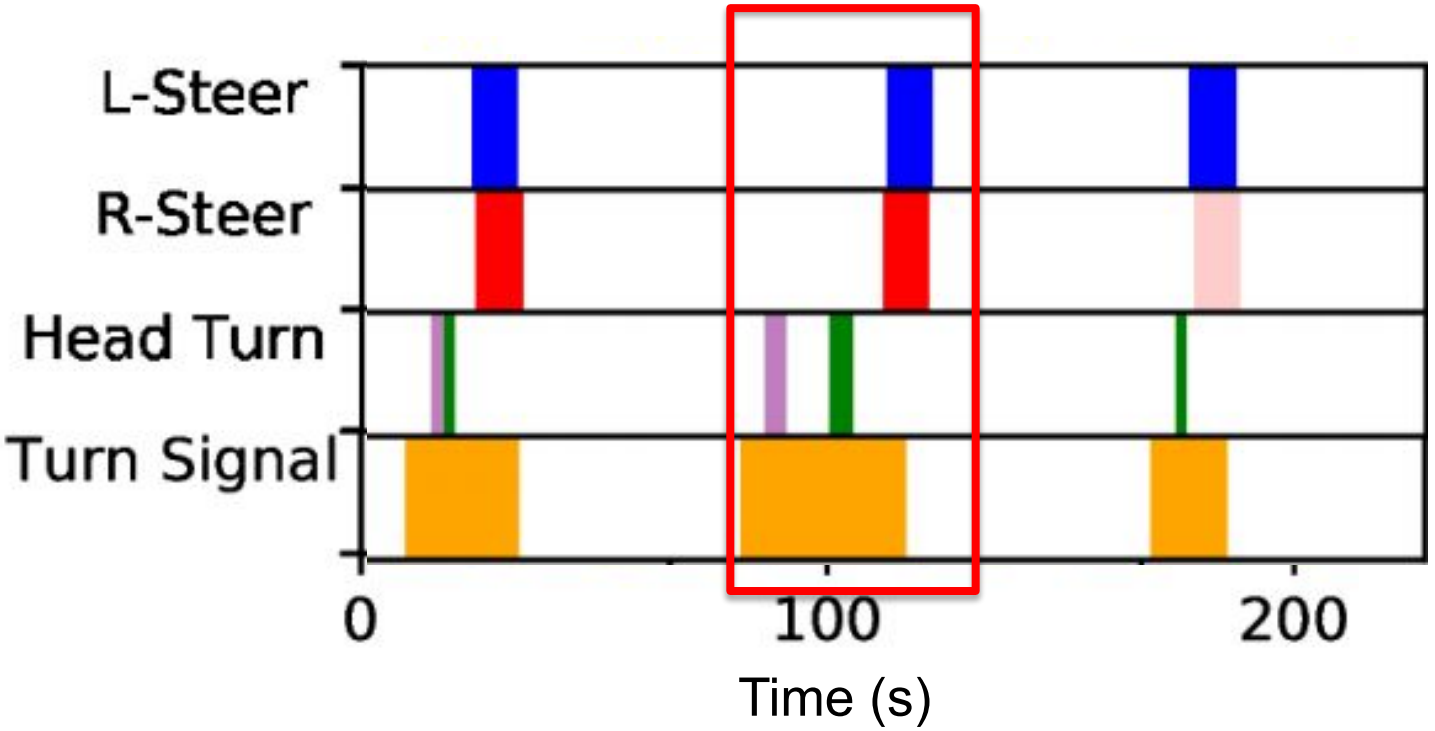
S: Steering
HR: Head Right turn
HR+S: concurrent motion

Safe Driving Monitoring

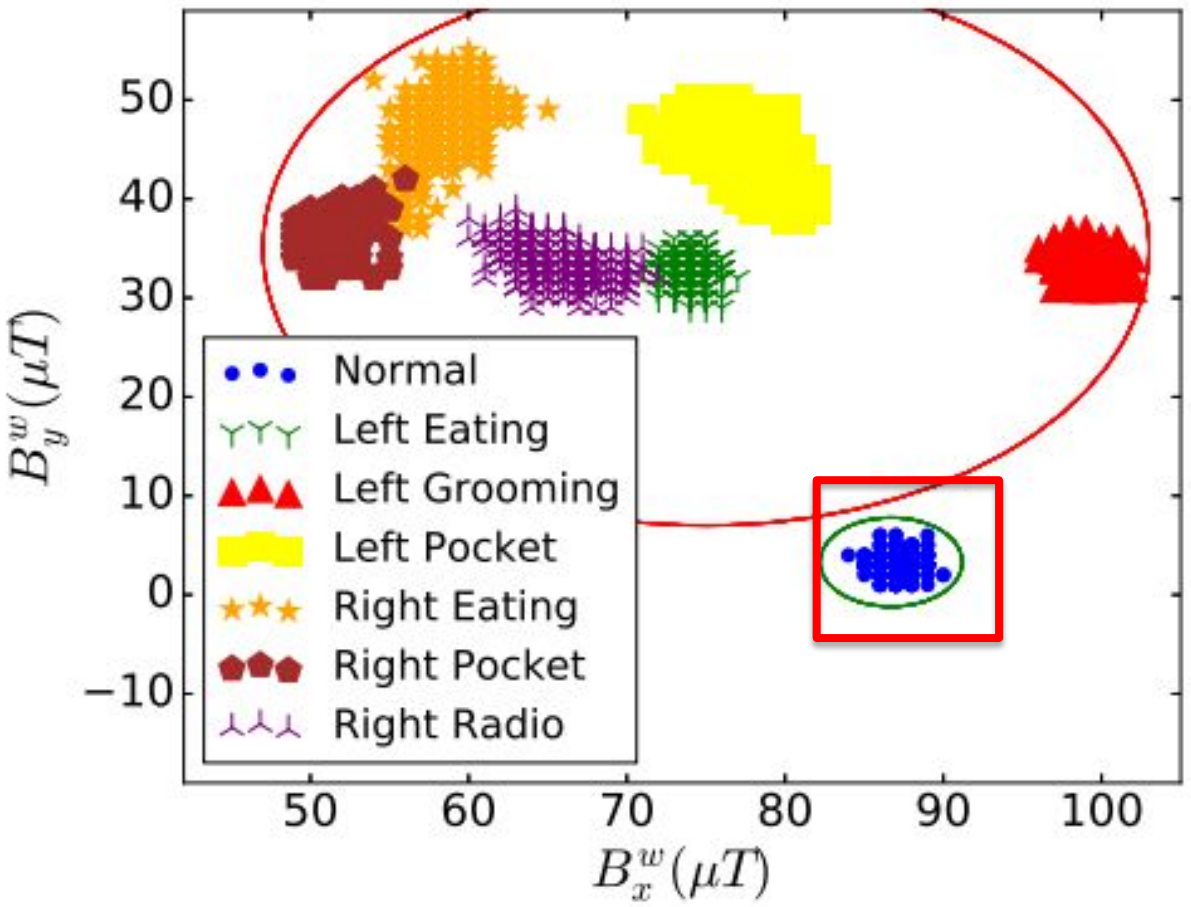
Visual Distraction Detection



Safe Steering Monitoring



Manual Distraction Detection



Evaluation

Evaluation: Motion Type Classification

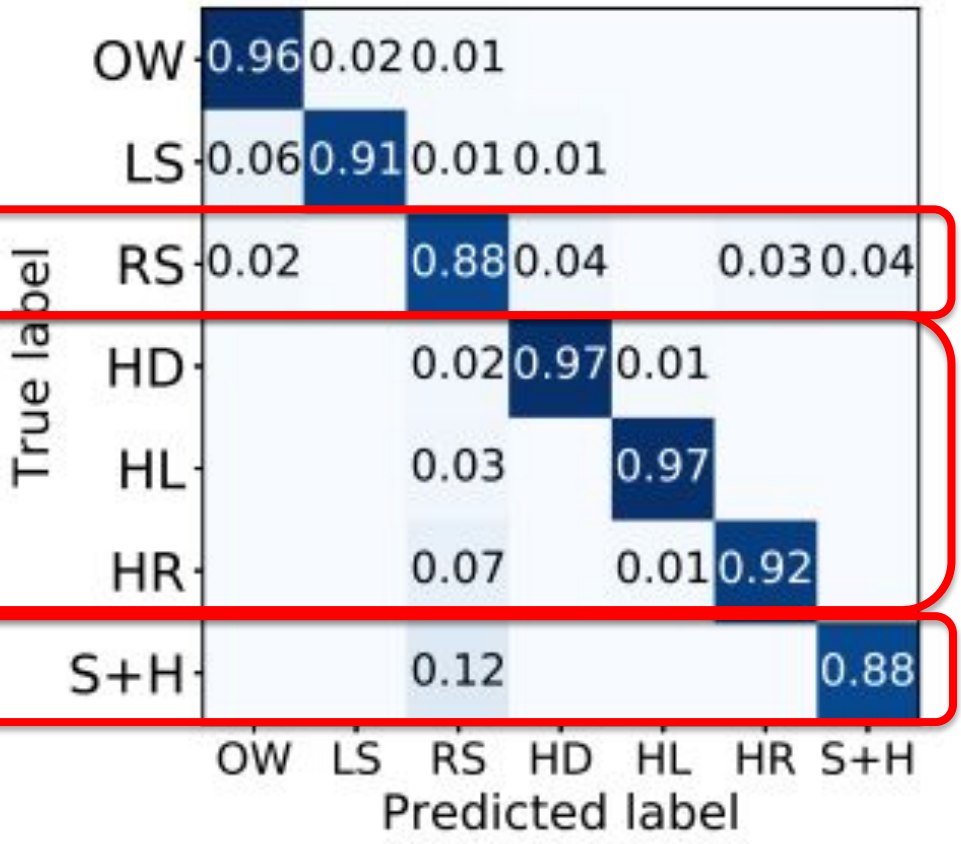
Right hand Steer (RS)

Head Down turn (HD)

Head Left turn (HL)

Head Right turn (HR)

concurrent motion (S+H)



Driving Motion Type Confusion Matrix

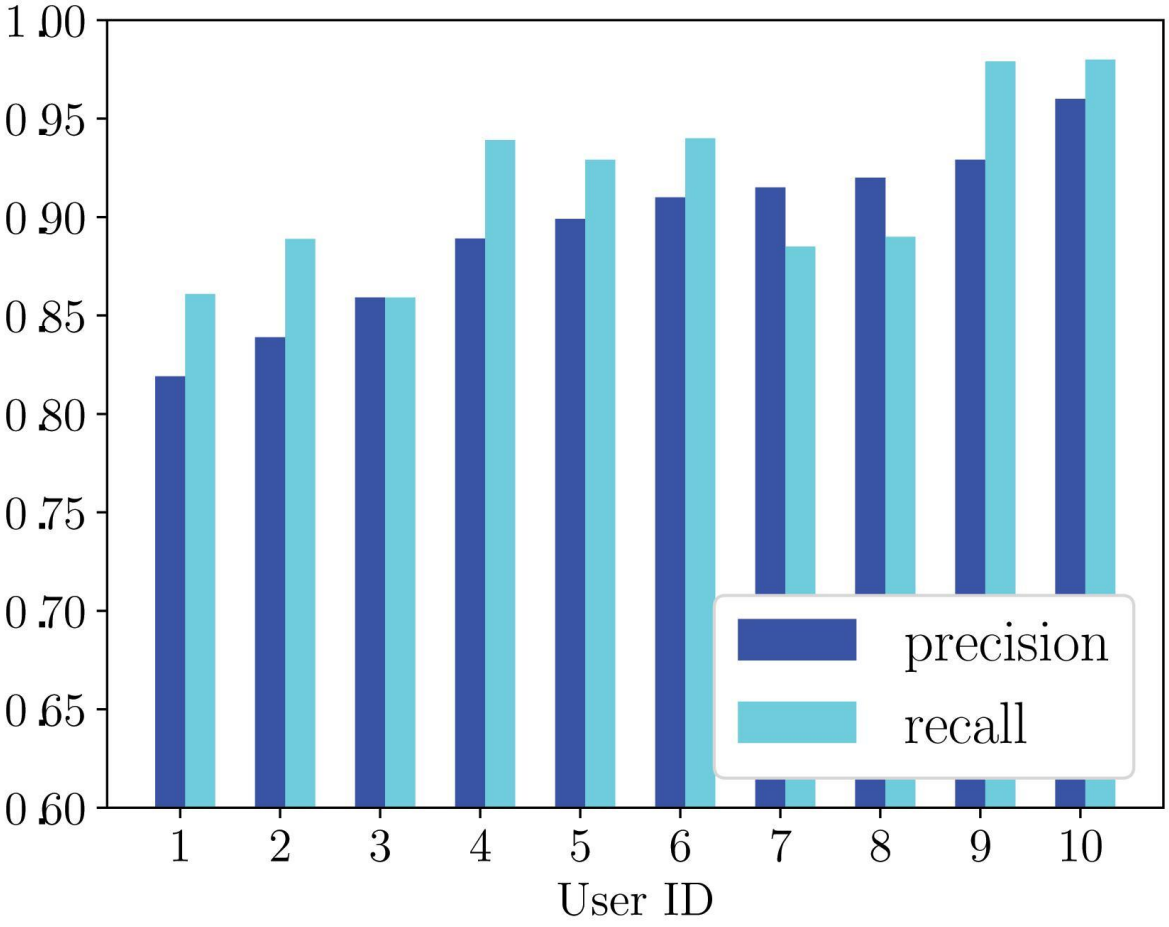
Road Test Data Collection

- 10 drivers, 500+ minutes road test
- IRB approved
- Co-pilot records ground truth
- 547 driving events, including distraction, steering, and head turn motions.
- User survey for experience

Unsafe Driving Detection

Events	Precision	Recall
Unsafe Turning	87%	84%
Manual Distraction	92%	89%
Visual Distraction	85%	91%
Overall	87%	90%

Unsafe Driving Detection

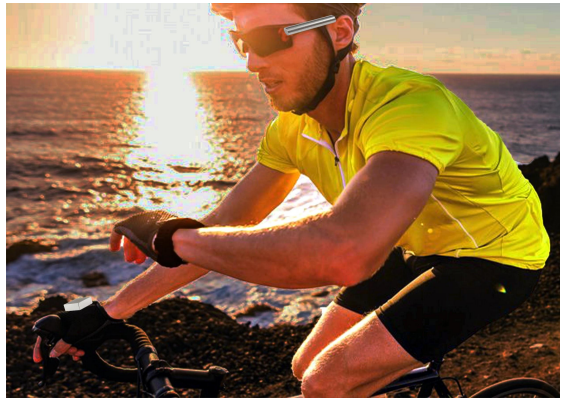


Future Work

Eating

Hand Washing

Hand Head Coordination Exercise



Cycling

Summary

- MagTrack: A system that monitors two-hand and head motions for many driving activities
- Use magnetic tags to track constrained motions with high accuracy
- A novel algorithm that tracks two magnets with a single sensor
- Achieves 88.5% of unsafe driving detection accuracy in road tests with 10 users, with 500+ events

Q&A for MagTrack

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