Preventing Driving Accidents via Detection of Driver-induced Steering Oscillations

Dipak Sharma, Ivan Tanev, and Katsunori Shimohara
Graduate School of Science and Engineering,
Department of Information and Computer Science,
Doshisha University, Kyoto, Japan

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INTRODUCTION

- With the ongoing evolution of automobile technology human error becomes the single most important factor contributing to traffic accidents.

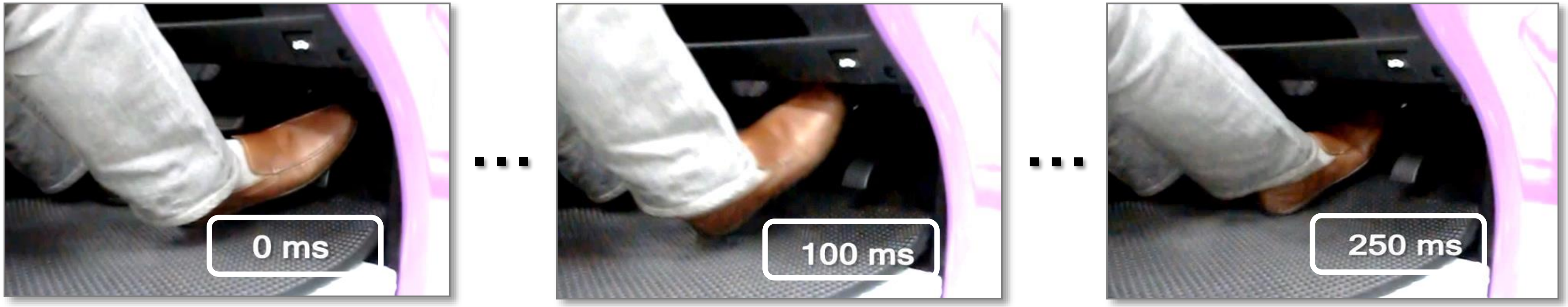
- Most of these driving errors: either an incorrect or a too late response of the driver.

- Most often, the primary reason for these errors is the inadequate cognitive engagement (or, cognitive load) of the driver.

- i.e., the amount of the attention, dedicated to driving is lower than the attention, required by the current traffic situation.

MOTIVATION (1)

- Inferring the cognitive overload - by measuring the delay of response (DoR) as an effect of cognitive overload. For example, when pressing the brake pedal.
- **Drawbacks:**
  - DoR is a subjective trait.
  - In emergency situations, it would be too late to measure it.
  - Therefore, could not be used for early warning.



MOTIVATION (2)

- Also, we may try to detect the underlying causes of such an overload – e.g., via eye tracking, or analyzing bio-medical data (hearth rate, GSR, etc.).

- Drawbacks - too subjective, and too vague:
  - Drivers may look away and still be able to control the car adequately if they perceive the current- and anticipate the future-state of the car (e.g., when looking at side mirrors, navigation map, or crossing traffic),
  - Conversely, drivers may look at the road, yet they might be unable to control the car adequately (e.g., due to daydreaming, fatigue, driving under influence of drugs or alcohol, etc.)

OBJECTIVE

- Therefore, there is a need of a different way of inferring the DoR that could facilitate early accident-preventing measures (from simple warning to the driver, to taking the control completely from the later)

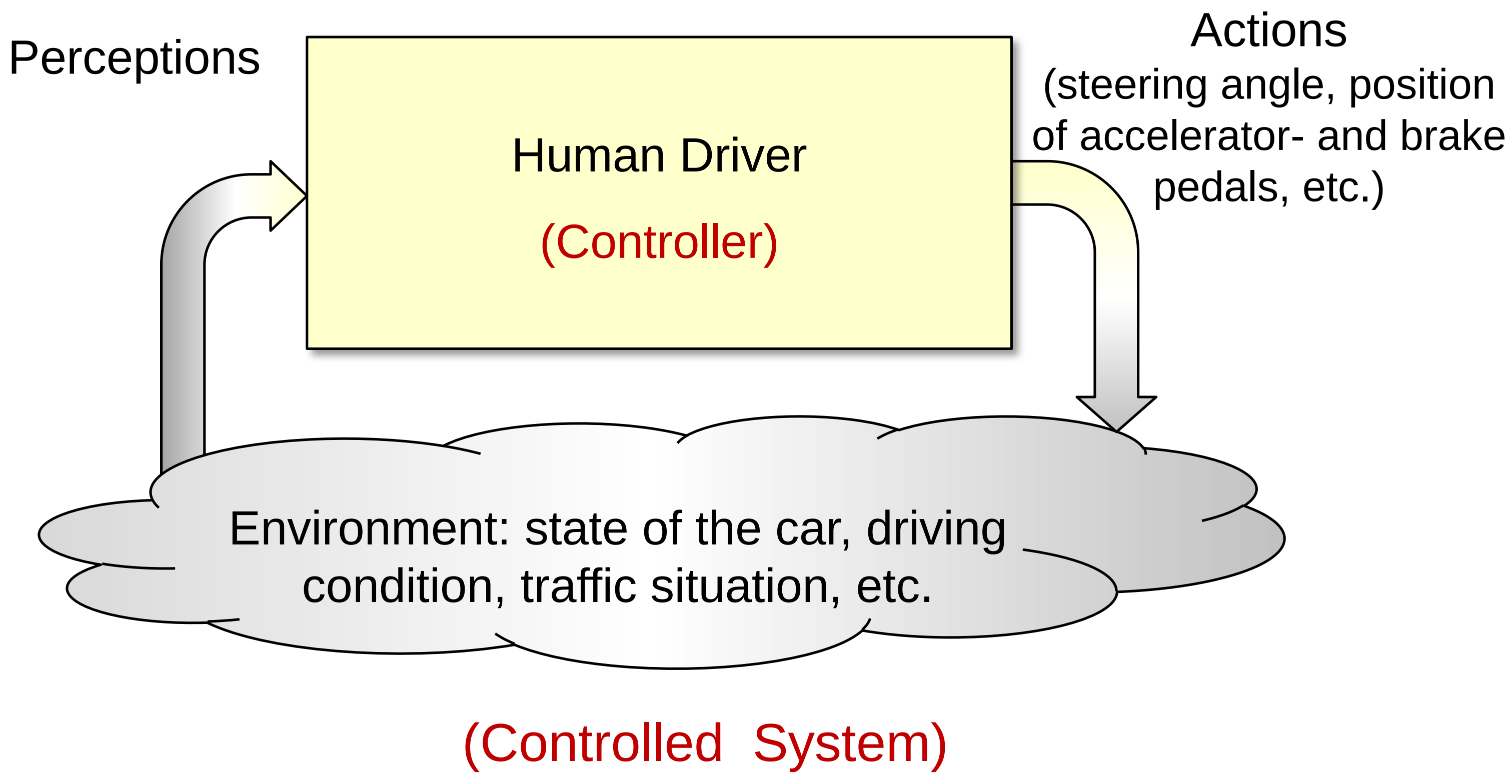
- Our objectives:

  - To propose a holistic symptom of DoR (as a result of inadequate cognitive load) in normal (rather than emergent) driving situations, and

  - To propose an approach to detect this symptom.

PROPOSED APPROACH (1)

Considering the human driver as a controller of a controlled system (car) with a (negative) feedback.



PROPOSED APPROACH (2)

- Any DoR (due to inadequate cognitive load of the driver) causes delay in the feedback (DiF) of control.
- By applying Nyquist Stability Criterion, we hypothesize that DiF would result in potentially unstable, oscillating system.
- Which parameters would oscillate? i.e., what is the symptom of DoR?
  - Dynamics of speed? Speed control is non-tracking behavior.
  - Dynamics of braking? Braking is non-tracking behavior.
  - Dynamics of steering? Steering is a tracking behavior.
- Oscillations in human-machine systems occur in tracking behaviors only.

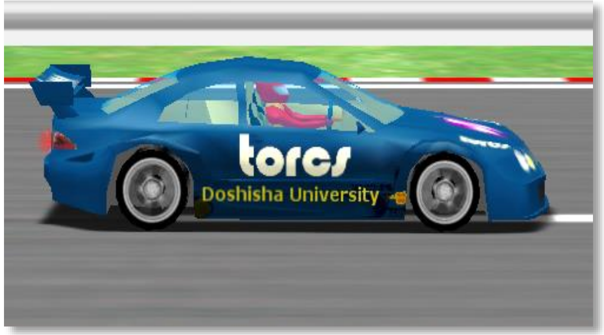
  Example: pilot-involved oscillations of pitch angle (and angle of attack) of airplanes occur due to delayed feedback (rate limits) during landing, mid-air refueling, etc.
- **Hypothesis:** Focusing on the control of the steering of the car, any DiF (caused by inadequate cognitive load of the driver) would result in detectable steering oscillations.

PROPOSED APPROACH (3)

- Our two objectives could be rephrased as:
  - To verify that steering oscillations are a well-manifested symptom of DoR in normal (rather than emergent) driving situations, and
  - To propose a mechanism to detect these steering oscillations.

PRESENCE OF OSCILLATIONS: EXPERIMENTAL SETUP (1)

- Verifying experimentally the hypothesis that steering oscillations are a symptom of DoR in normal driving situations:
  - Car and the track are simulated in The Open Source Racing Car Simulator (TORCS). Why TORCS:
    - Realistic simulation
    - TORCS is crash-safe,
    - Computationally efficient,
    - Open source and free of charge



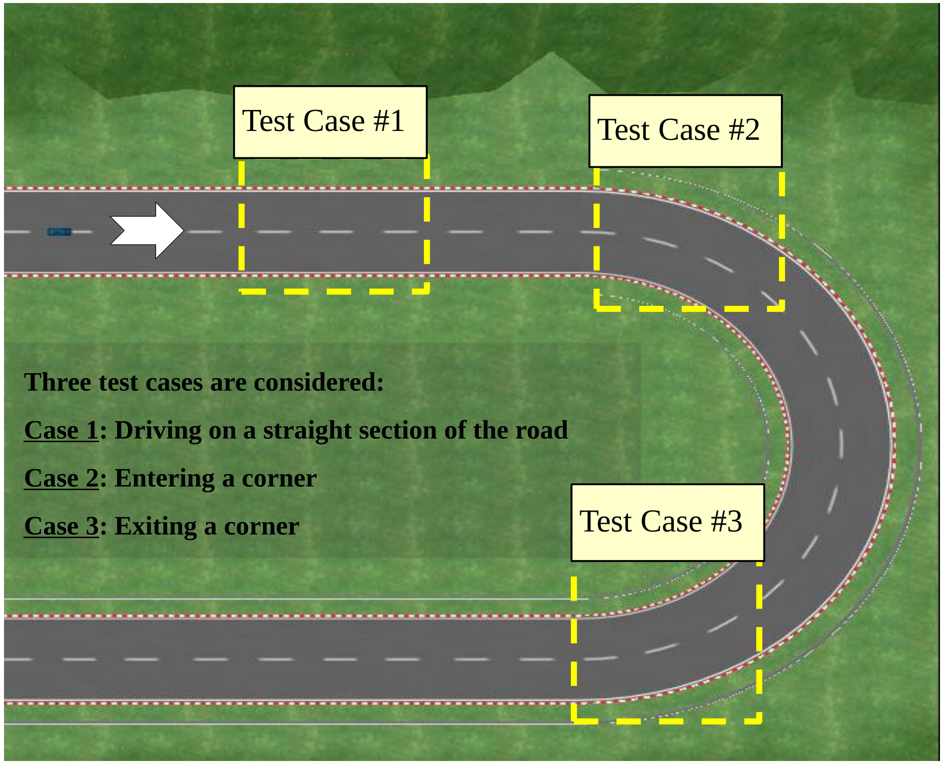
  - 10 human drivers, driving a car in TORCS in following two driving conditions:
    - Attentive (cognitively adequate) driving, and
    - Inattentive (cognitively impaired) driving caused by texting while driving.

PRESENCE OF OSCILLATIONS: EXPERIMENTAL SETUP (2)

- Experiments were conducted in three test cases (straight, corner entry, and corner exit) on a given test track.

- A simulated cruise control maintains a constant speed of 51km/h throughout the experiment.

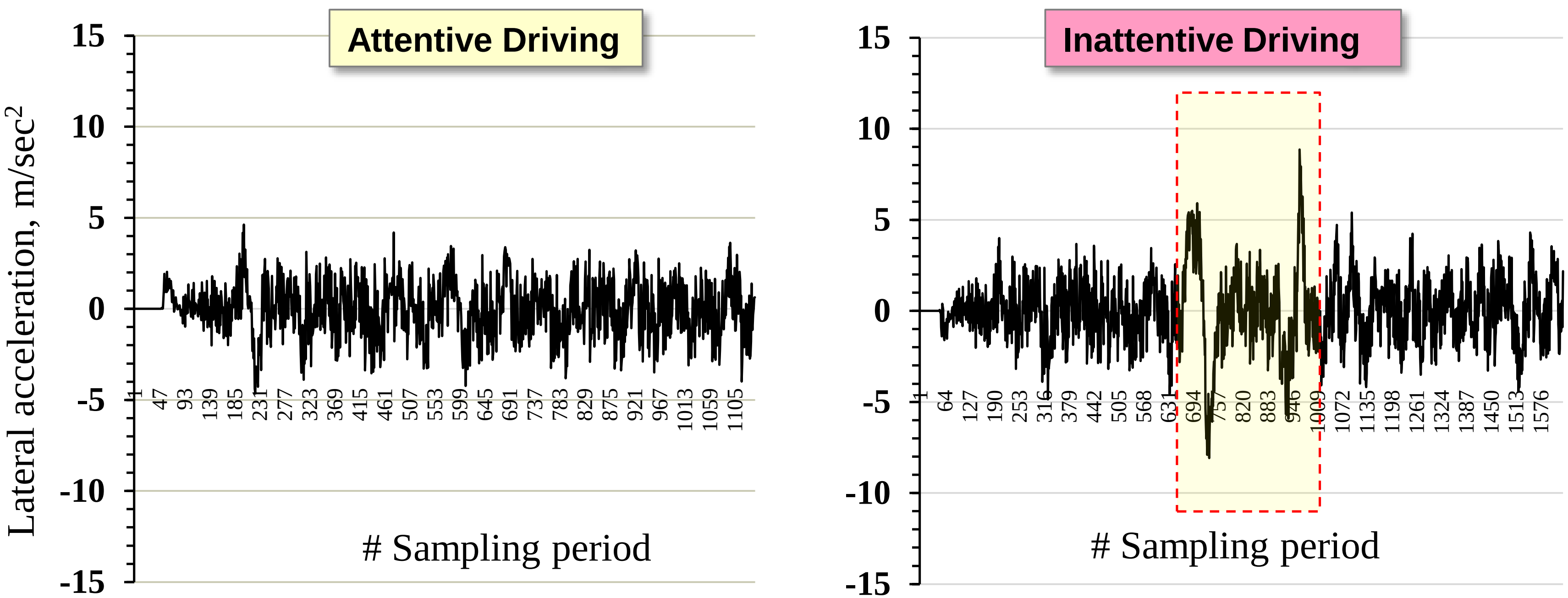
- This frees drivers from any unnecessary cognitive burden that would have been required to maintain the desired speed.



PRESENCE OF OSCILLATIONS: EXPERIMENTAL SETUP (3)

Effect of DoR on steering behavior: Steering behaviour is manifested in the pattern of lateral acceleration of the car.

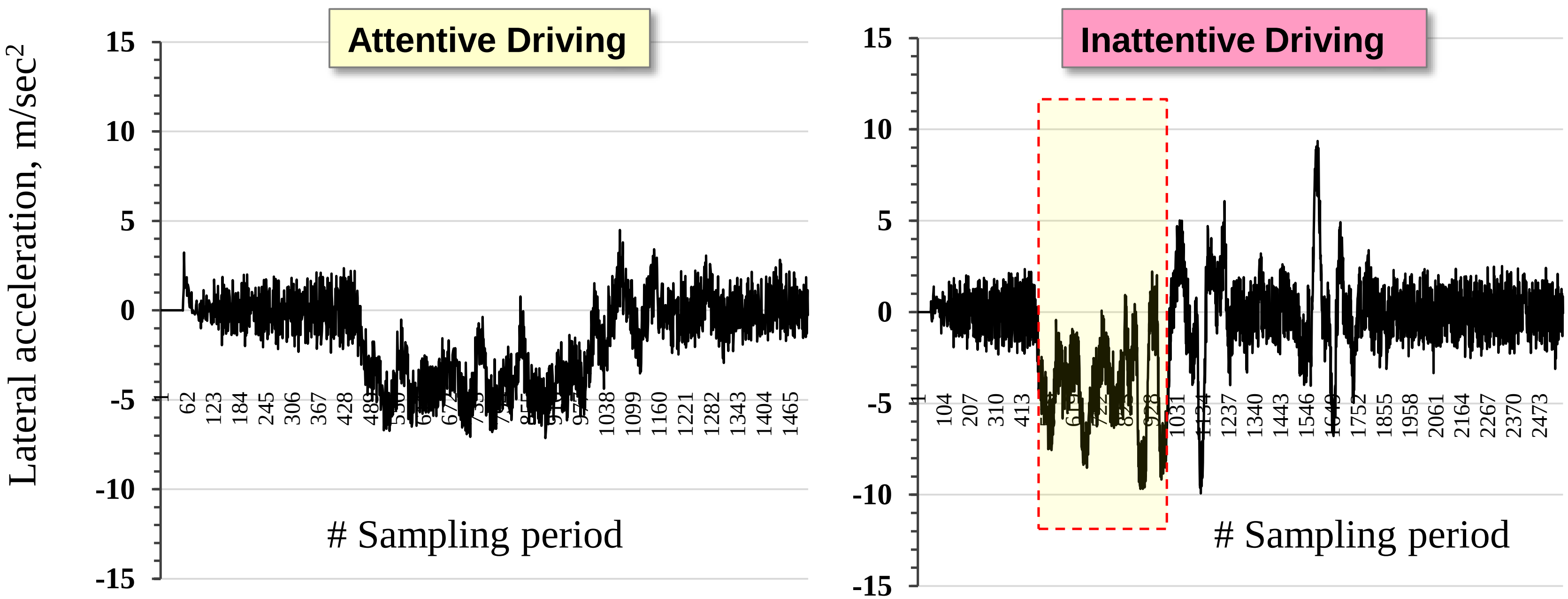
Case #1: Straight



PRESENCE OF OSCILLATIONS: EXPERIMENTAL RESULTS (1)

Effect of DoR on steering behavior: Steering behaviour is manifested in the pattern of lateral acceleration of the car.

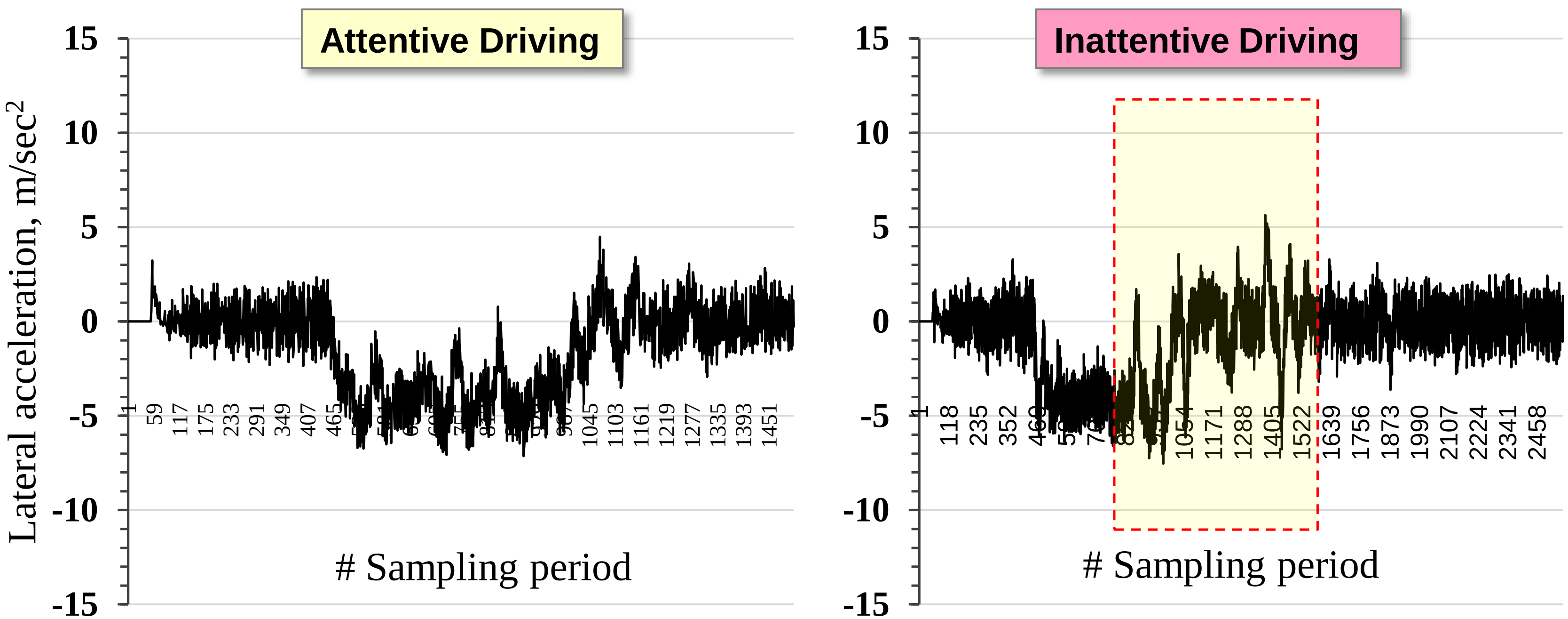
Case #2: Entry of corner



PRESENCE OF OSCILLATIONS: EXPERIMENTAL RESULTS (2)

Effect of DoR on steering behavior: Steering behaviour is manifested in the pattern of lateral acceleration of the car.

Case #3: Exit of corner



DETECTING OSCILLATIONS: STAGES (1)

- The proposed approach for detecting the steering oscillations from the pattern of lateral acceleration is realized in the following two stages:

Stage 1 Acquiring the raw signal (time series) of lateral acceleration.

Stage 2 Calculating the PS of Fourier-transformed signal of lateral acceleration

Stage 1 Acquiring the raw signal (time series) of lateral acceleration

- We acquired the raw signal (i.e. time series) of lateral acceleration of a simulated car, driven by *10* human drivers on the test track in the following two situations:
  - Cognitively unimpaired (attentive) driving, and
  - Cognitively impaired (inattentive) driving (Induced by texting while driving)

DETECTING OSCILLATIONS: STAGES (2)

Stage 2 Calculating the PS of Fourier-transformed signal of lateral acceleration

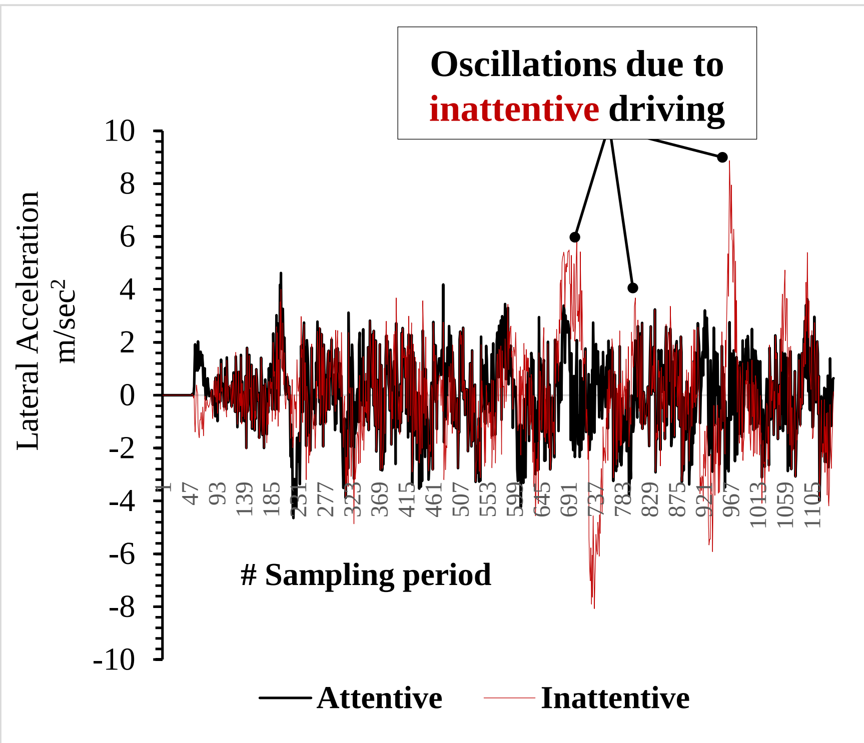
- In order to model an eventual real-time implementation of the proposed approach, we start with a window of the *initial 100* samples (corresponding to the first *2s* of data) of the acquired time series of lateral acceleration.

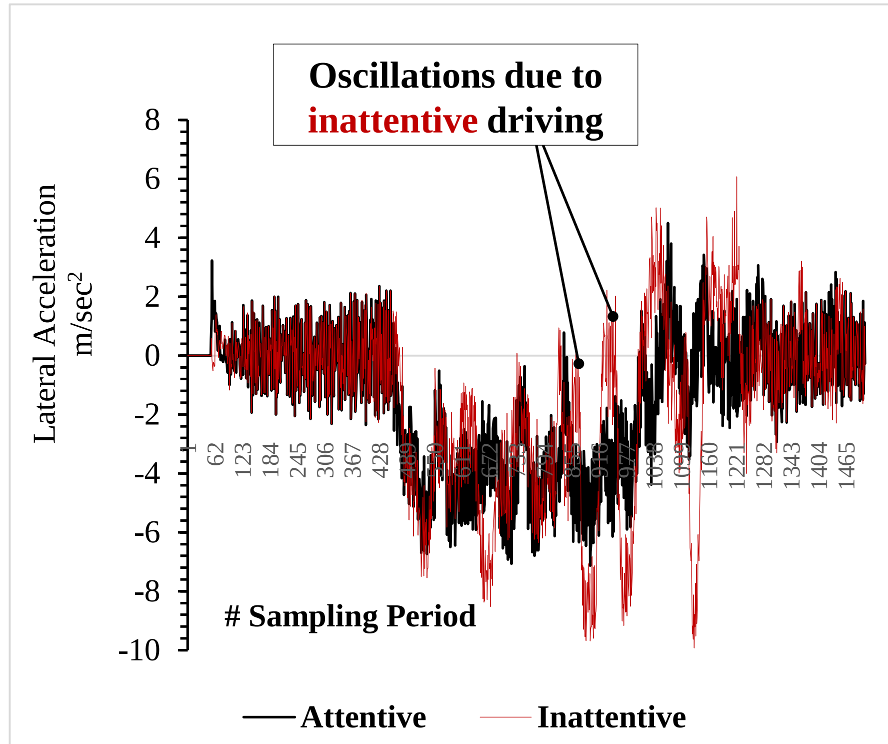
- Next, we perform the Fourier transformation and calculate the value of PS in frequency range *1Hz~50Hz* on the window of the initial *2s* of data samples and associate the calculated value of PS with the instant of time $t_{initial}+2s$.

- Then we proceed with repeatedly sliding the window of *100* samples by one frame (corresponding to a time shift by *20ms*) and performing both the Fourier transformation and calculation of PS, until we reach the final *100* samples of the acquired time series of lateral acceleration.

DETECTING OSCILLATIONS: EXPERIMENTAL RESULTS (1)

Stage 1 Acquiring the raw signal (time series) of lateral acceleration

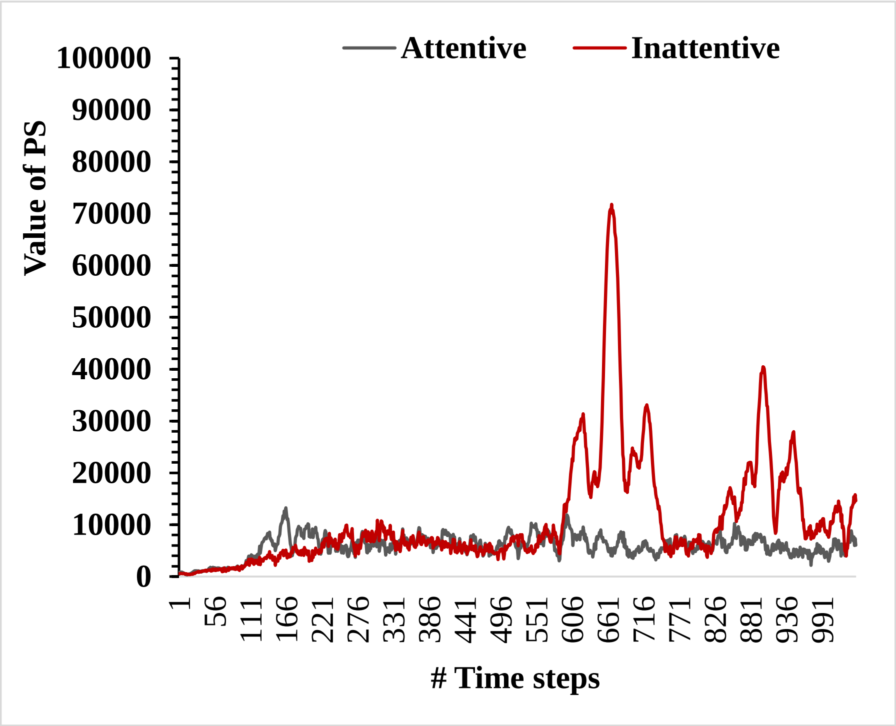


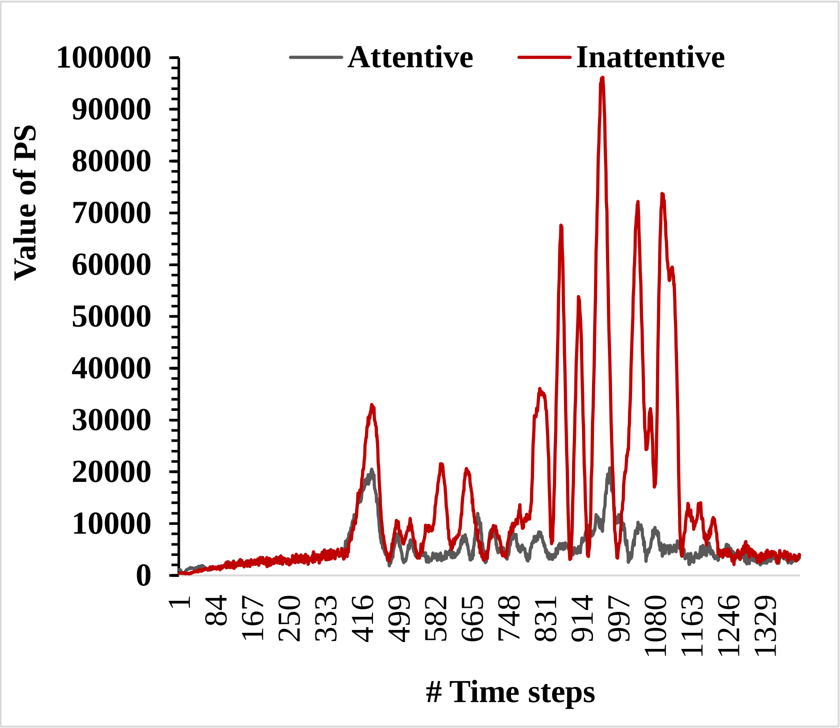


Typical dynamics of lateral acceleration on straight (left) and curved (right) section of the road

DETECTING OSCILLATIONS: EXPERIMENTAL RESULTS (2)

Stage 2 Calculating the PS of Fourier-transformed signal of lateral acceleration

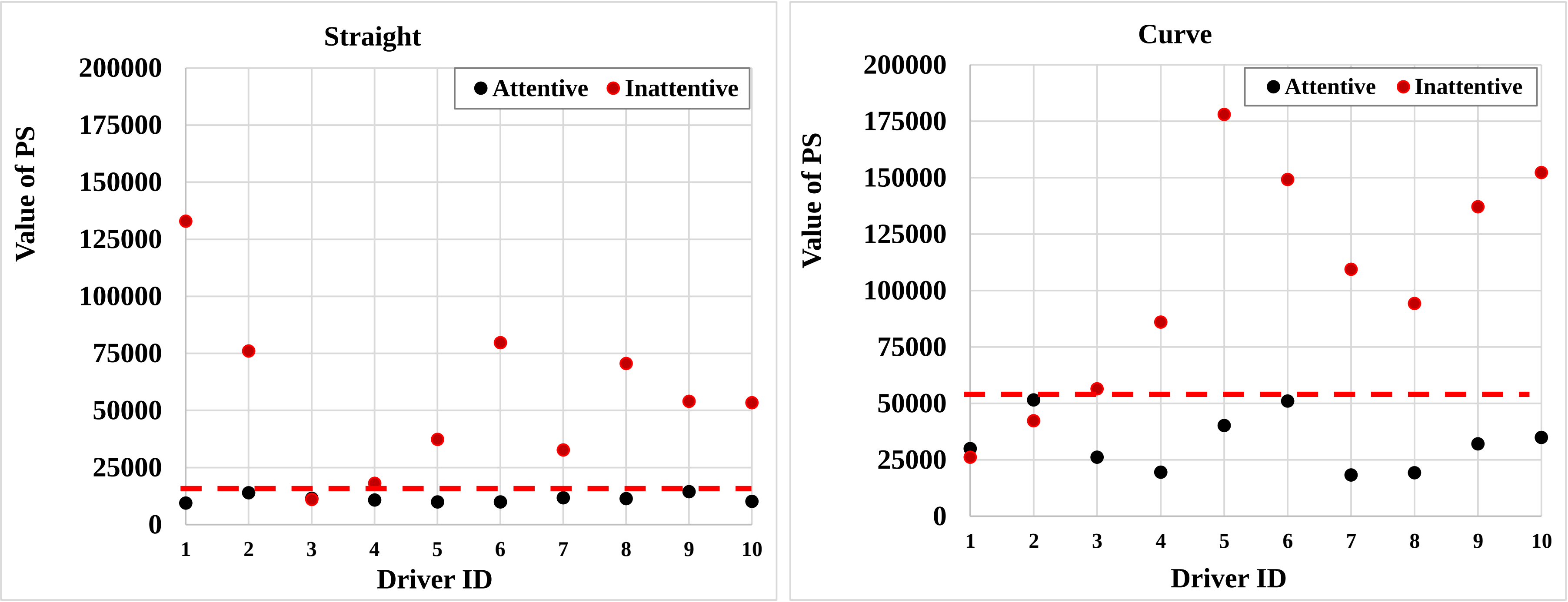




Typical dynamics of values o PS on straight (left) and curved (right) section of the road

DETECTING OSCILLATIONS: EXPERIMENTAL RESULTS (3)

Classification based on (static) thresholding of PS: Maximum value of PS of both attentive- and inattentive driving and on straight (left) and curved (right) sections of the road



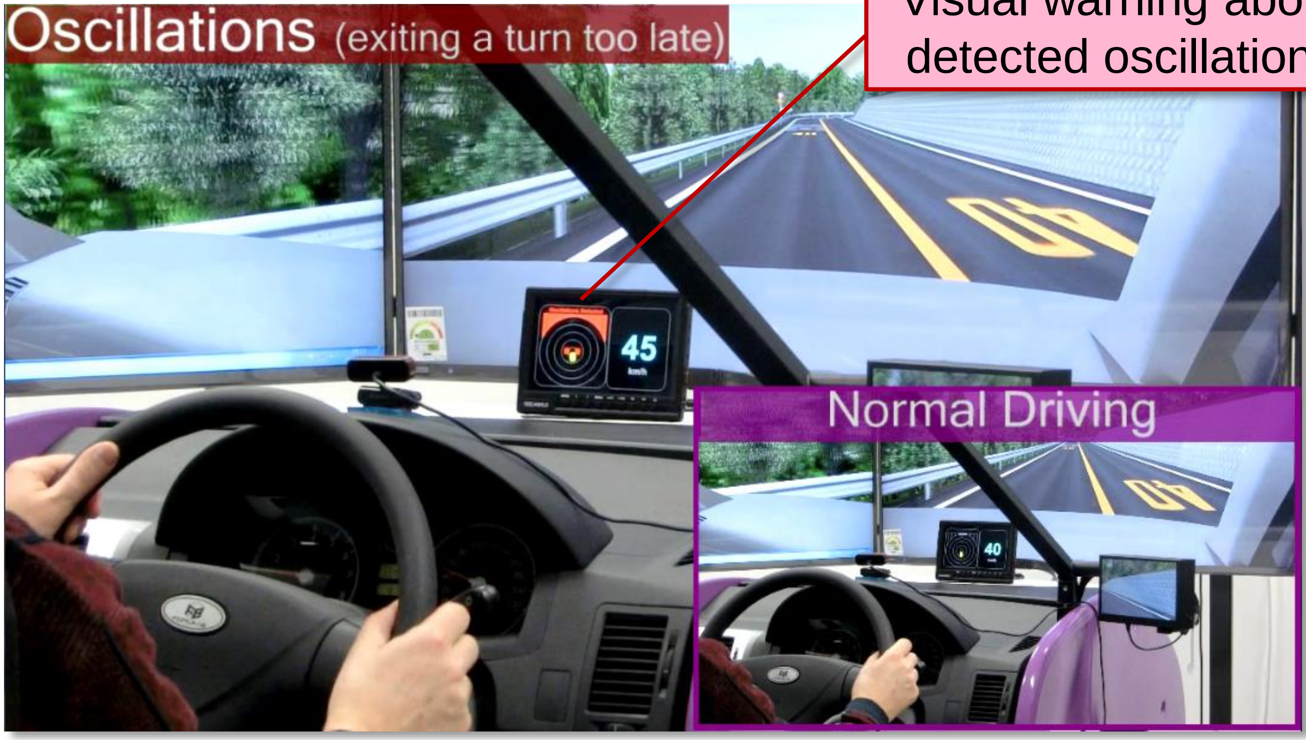
Correct classification in 9 (of 10) drivers

Correct classification in 8 (of 10) drivers

DETECTING OSCILLATIONS: EXPERIMENTAL RESULTS (4)

Prototype implemented on full-scale Driving Simulator

Visual warning about detected oscillations



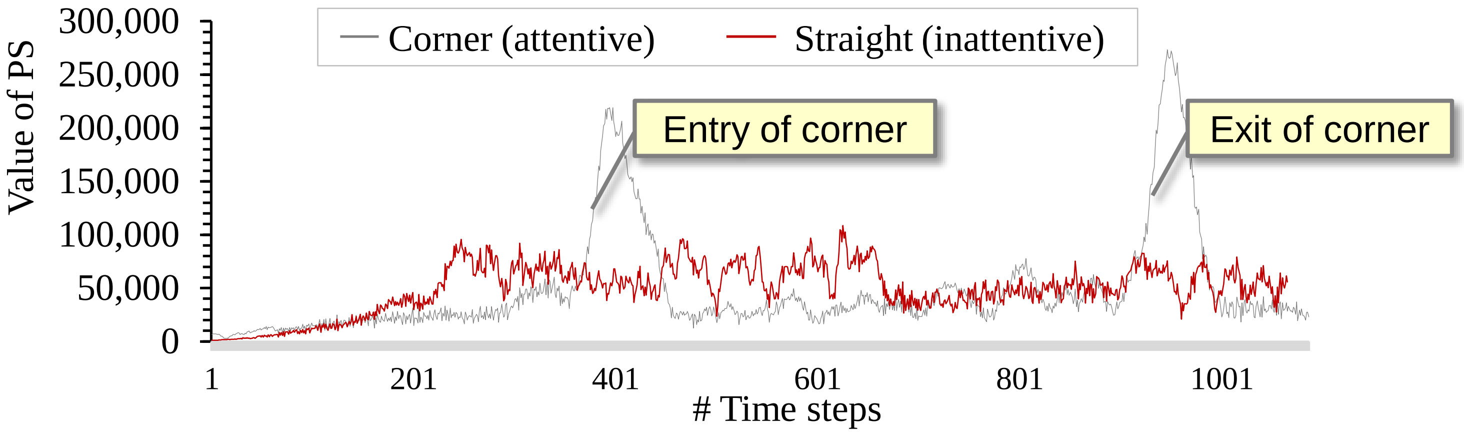
Video

(Also available online: https://www.youtube.com/watch?v=tOuvPr2KTSo)

DETECTING OSCILLATIONS: CHALLENGES AND FUTURE RESEARCH

Challenges of classifying steering oscillations via static thresholding of PS:

- PS for inattentive driving on straight could be anomalously *lower* than that of attentive driving in corners



Future Research:

- Adaptive thresholding of PS: threshold could be adjusted dynamically depending on driving style and current driving situation.
- Weighted PS: weight coefficients of amplitudes of spectral frequencies A_i could be introduced in the formula of PS (slide # 17) and their values could be optimized via genetic algorithms.

CONCLUSION

- Verified that cognitive overload of drivers results in well-manifested steering oscillations.
- Steering oscillations, pertinent to inattentive driving, could be detected by means of thresholding of the value of the power spectrum of Fourier-transformed signal of lateral acceleration of the car.
- By means of static thresholding of the value of the power spectrum, inattentive driving could be detected in at least 80% of the driving cases on both straight and curved sections of the road.