Preventing Driving Accidents via Detection of Driver-induced Steering Oscillations

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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.
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.
Also, we may try to detect the underlying causes of such an overload — e.g., via eye tracking, or analyzing bio-medical data (heart 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.)
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.
Considering the human driver as a **controller** of a controlled **system** (car) with a **(negative) feedback**.
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.
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.
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.
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.
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 SETUP (3)
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
Effect of DoR on steering behavior: Steering behaviour is manifested in the pattern of \textit{lateral acceleration} of the car.

Case #3: Exit of corner

\textbf{PRESENCE OF OSCILLATIONS: EXPERIMENTAL RESULTS} (2)
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.

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**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)
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 \( t_{\text{initial}} + 2s \).

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

Typical dynamics of values of PS on straight (left) and curved (right) section of the road
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
Prototype implemented on full-scale Driving Simulator

Video

(Also available online: https://www.youtube.com/watch?v=tOuvPr2KTS0 )
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.
• 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.