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Steering measurement decomposition for vehicle lane keeping – A study of driver behaviour

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ABSTRACT

Steering control for vehicle lane keeping has attracted significant attention from both automotive industries and researchers. To describe intermittent pulse-like qualities imparted by drivers that are seen in real-world steering measurements, a pulse control model (PCM) is presented for vehicle lane keeping. Inspired by the PCM, a steering angle measurement is decomposed into a combination of trend, integrated sine components (ISCs) and sine components (SCs), where trend corresponds to the path curvature, ISCs to the heading angles, and SCs to the lateral positions. Trends are extracted through the use of empirical mode decomposition (EMD) and principal component analysis (PCA), with singular spectral analysis (SSA) and Fourier curve-fitting (FCF) being employed to determine the ISCs and SCs in the main pulses. Through statistical pattern analysis on experimental measurements of drivers' steering performance, it is revealed that (1) the pulse steering behaviour from real drivers shows the benefit of the proposed PCM for steering control during lane keeping, and (2) classification of pulse steering characteristics can be used for normal driver state identification and highlight abnormal driving behaviour, leading to the prospect of identifying driving characteristics typical of impaired concentration, substance misuse or tiredness, for instance.

1. Introduction

Intelligent vehicle technologies have many different functions, all aimed at improving comfort, efficiency and safety. The systems, subsystems and algorithms that provide intelligent vehicle control are based on a range of disciplines: mathematics, computer science and engineering, which all contribute towards the goal of complementing or partially replacing the human driver in navigation and driving related behavioural tasks [1]. Of late, the intelligent vehicle concept has undergone a substantial increase in interest, as some of the required goals to achieve automated vehicles seem near accomplishment (examples include Volvo Steer Assist technologies, already successfully implemented, and the prototypical Mercedes self-driving trucks).

More recent information reveals that, with Volvo Pilot Assist, the driver can set a 'time gap' between their vehicle and the vehicle in front. The automation system can adjust the speed to maintain that 'time gap' according to the current speed. The system also helps the driver to maintain the vehicle inside the lane, but the driver can override the system by steering actively. Thus this is an example of shared control. Mercedes has an Adaptive Cruise Control system that performs a similar method for speed adjustment. The fact that, Level 5 automation – according to the SAE – does not seem to be happening soon due to technological constraints. Specifically, artificial intelligence does not seem to cope well in urban environments. On the other hand, shared control technologies seem to be more achievable. But in order to achieve effective transitions between the human and the vehicle, automated systems must be able to identify driver states. Drivers don't drive in the same mode at all times, e.g. sometimes more distracted or drowsy, and other times more alert, so an effective driver assistance technology should be able to identify these changes. In this paper, the attention is on identifying driver behaviour related to steering control.

Existing steering control models usually rely on two aspects: (i) a simplified models of visual information processing based on the numerical interpretation of perceived lane keeping error; (ii) a control law that models the manipulative control actions to keep the vehicle within the road boundaries and to track the road path. An example of such an approach is the well-known linear feedback law proposed by Salvucci and Gray [2,3]:

$$\dot{\delta} = k_1\theta_n + k_2\dot{\theta}_n + k_3\dot{\theta}_f \tag{1}$$

Abbreviations: PCM, Pulse Control Model; NDD, Naturalistic Driving Data; ISC, Integrated Sine Component; SC, Sine Component; EMD, Empirical Mode Decomposition; IMF, Intrinsic Mode Function; PCA, Principal Component Analysis; PC, Principal Component; SSA, Singular Spectral Analysis; RS, Reconstructed Subseries; FCF, Fourier Curve-Fitting; YRE, Yaw Rate Error; YAE, Yaw Angle Error; SVD, Singular Value Decomposition; CLK, Central Lane Keeping

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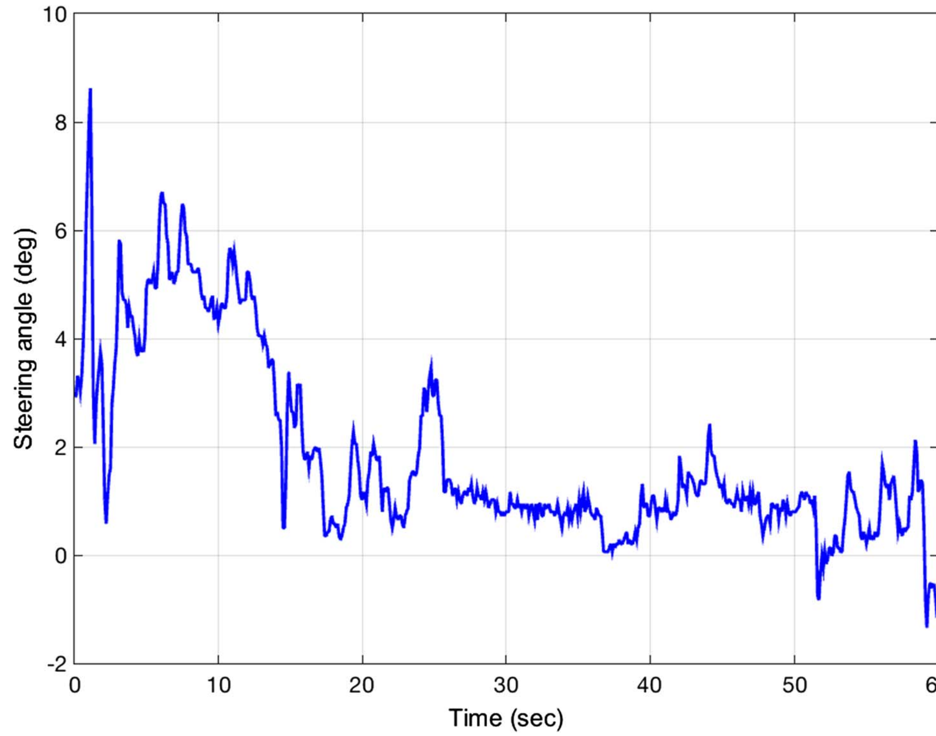

Fig. 1. Example steering angle measurement set.

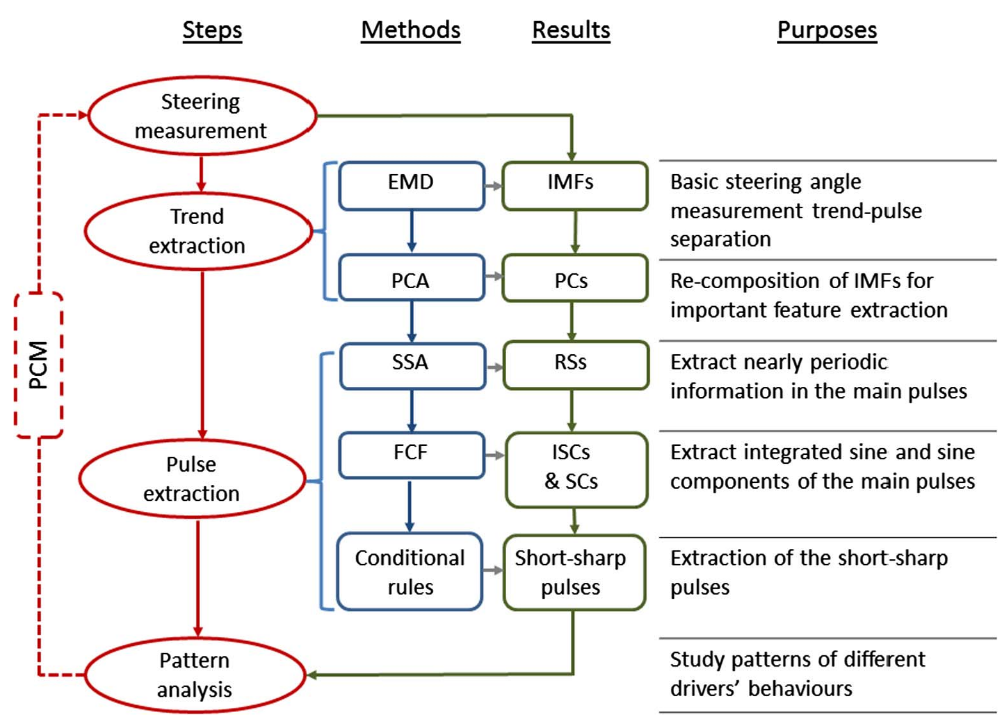

Fig. 2. Outline methodology.

where $\delta(t)$ is the steering angle, θ_n and $\dot{\theta}_n$ are the angle and angular rate to a near-point at a distance d_1 ahead of the vehicle (which a the lane centring abilities of the driver and the control of lateral velocity), and $\dot{\theta}_f$ defines the angular rate of the far-point at a distance $d_2 > d_1$ (which determines the path tracking abilities of the model). In [4], the adequacy of this model was tested with naturalistic driving data (NDD). It was seen that, although it is possible to fit the parameters of the control law (1) in a consistent manner, the fitted parameters lead to instability in closed-loop simulation. On the other hand, it has been verified experimentally that human drivers can achieve sufficient steering performance by using only the near and far information of the road [5]. Thus deficiencies in the Salvucci and Gray linear model to reproduce human steering behaviour arise from the control law itself. Although it is easy to optimize the parameters to produce high performance control, there is no evidence that the resulting control law is effective at representing human driving dynamics. Indeed, control law (1) is deficient in that it is purely reactive, there is no memory component in the model.