Driver and Pilot Identification and Model Parameter Estimation; Modelling the Visual, Vestibular, and Neuromuscular Control Loops Describing Driver and Pilot Behaviour

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Summary

Driver and pilot modelling has been successfully applied to unravel driver and pilot behaviour, and to design systems optimally matching driver and pilot capacities. Modelling has been applied in particular for continuous manual control tasks such as steering where drivers apply continuous steering actions to control vehicle heading and lateral position. In such models the visuomotor loop describes steering wheel rotation as a function of visual information regarding the road and the vehicle state. Some pilot models include a vestibular component which describes how vestibularly perceived motion contributes to pilot behaviour. Interfaces such as steering wheels in cars provide drivers with haptic (force) feedback regarding the vehicle state, and to optimally design such interfaces neuromuscular models have been developed describing how operators use reflexes to control limb position, force or stiffness.

This paper describes state of the art driver and pilot models and shows how the visual, vestibular, and neuromuscular control loops have been tested and modelled. In particular it describes how multiple stimuli have been applied simultaneously to identify operator behaviour in relatively short experiments eliciting steady state behaviour. Human control behaviour is shown to adapt effectively and systematically to the dynamics of the system being controlled as well as to task instructions and applied stimuli.

Methods

Driver and pilot (or operator) model identification enables the estimation of operator model parameters based on measured operator responses to certain stimuli. Operator model identification has been successfully applied to capture human control behaviour in continuous closed-loop tasks such as aircraft control, car following and steering. Human control actions could be described as (linear, time-invariant) function of task-related stimuli and perceivable responses of the controlled vehicle. Such models describe how operators dynamically control the acceleration, velocity and position of vehicles to follow a desired path and to correct for possible disturbances. Complex operator models have been derived simply fitting available data and/or hypothesizing plausible control loops [9]. This paper focusses on operator models which can be uniquely identified from dedicated experiments on individual drivers. Here unique identification refers to the possibility to uniquely derive a set of operator parameters with good experimental reproducibility [16]. Unique identification makes operator model identification a sensitive design tool. For proposed vehicles and user interfaces, operator behaviour can be identified using driving or flight simulators. Comparing operator model parameters for different vehicle designs, we can measure whether and how operators adapt their control behaviour. Effects of proposed vehicle modifications have shown to provide valuable insight in operator behaviour, and have shown significant and relevant changes in cases where traditional performance measures reflecting task accuracy were not significantly changed as a result of effective adaptation by the operator

Operator models have been identified using data collected in real vehicles and in simulators (see Figure 1). To uniquely identify the various control loops dedicated stimuli have been designed aiming to create realistic task conditions as well as enabling unique identification. In general such stimuli are designed to be random appearing such that operator behaviour is elicited for an unknown task rather than testing “pre-programmed” behaviour.

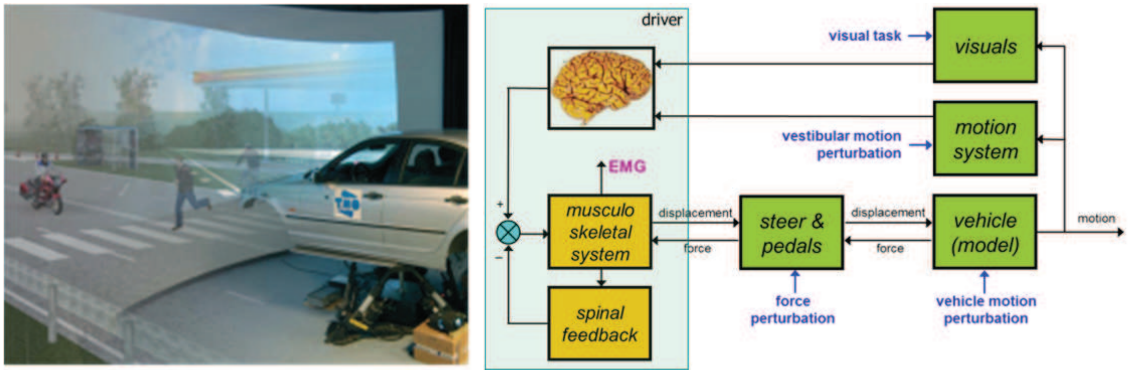

Figure 1. Driving Simulator; a human operator interacts with a virtual vehicle in a virtual driving environment. The driver receives visual task stimuli and various perturbations and driver actions and vehicle responses are recorded.

Visual stimuli primarily represent task related information, and can include desired states, actual states and errors between desired and actual states. Simple visual stimuli such as desired heading, speed, and position can be presented on dashboard or cockpit displays. Complex visual stimuli such as road geometry and other vehicles are naturally available in real vehicle testing, and can be presented virtually in simulators. Obviously in mathematical models such complex stimuli require derivation of simple variables assumed to be perceived by the operator from the available visual information field. Such variables represent perceived ego-vehicle motion: e.g. longitudinal and lateral position, heading and their derivatives in time, observed road geometry, and (relative) position, velocity and heading of other vehicles. Visual stimuli are primarily applied to identify the operators visuomotor control behaviour.

Vehicle motion stimuli can represent perturbations of the vehicle motion for instance related to wind or other physical disturbances. Vehicle motion stimuli can be used to jointly identify the visuomotor and vestibular control loops. As illustrated in Figure 1 a vehicle motion perturbation will be perceived visually as well vestibularly, and hence such stimuli are not suitable to separate these two components.

Vestibular motion stimuli can be applied in simulators only. Where in actual vehicles the visual and vestibular information regarding vehicle motion are mechanically linked, in a simulator additional perturbations can be applied on the simulator motion without affecting the visually perceived vehicle motion. In principle this enables separate identification of the vestibular control loop, but humans easily notice a mismatch between vestibular and visual information, and discard apparently incongruent vestibular information.

Neuromuscular stimuli can include disturbance forces applied to steer, pedals and other interfaces. Measuring the resulting displacement and muscular activity (EMG) we can model the human stiffness or compliance, and estimate neuromuscular feedback delays and gains reflecting position control using muscle spindles and force control using Golgi tendon organs [10]. Neuromuscular identification is valuable in particular for the development of haptic (force) feedback systems supporting the driver with guiding forces, where identification showed a systematic adaptation of neuromuscular control when haptic feedback is provided [1,3].

Results

Operator model identification methods have been used extensively to identify pilot models while controlling aircraft dynamics [5,13]. Neuromuscular control models were already identified in the 90ties [17,18]. The current state of the art allows us to simultaneously identify the separate contributions of the pilot's visual system, the vestibular system and the neuromuscular system [5,6,7]. System identification was also used successfully to observe changes in the estimated pilot model parameters due to changes in the motion cueing algorithm [19,20].

Neuromuscular feedback of the ankle joint while controlling a gas pedal was identified and used to design a prototype haptic gas pedal [1,4,11,12] that has led to the marketing of the Distance Control Assist (DCA) system available in the Nissan Infiniti in Japan and USA. With the haptic gas pedal, subjects were shown to adapt their neuromuscular feedback strategy controlling force rather than position. In these studies, a visual control loop was identified using the perceivable distance and relative velocity towards the lead vehicle. This visual feedback model for car following, was also used to evaluate a visual driver support system, and showed significant beneficial effects of a distance and acceleration display on the driver parameters [14,15].

Neuromuscular feedback of the upper extremities in car steering has been identified [2] and the use of visual information in car steering will be illustrated in a separate presentation at measuring behaviour [8].

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