Sometimes brand new technological developments come from age-old ideas. James J. Gibson and Laurence E. Crooks already envisioned a concept for safe travel in 1938 that is materializing only today. They formulated the concept of a safe-field-of-travel that should consist, “…at any given moment, of the field of possible paths which the car may take unimpeded.” This safe-field-of-travel would incorporate natural boundaries, such as physical road limits and other road users, physical limits of the own vehicle, neuro-physiological limits of the driver and ultimately it would also take into account the safe-field-of-travel of the surrounding vehicles.

Regardless of how far-fetched these ideas must have sounded in the 1930’s, today many of these features are either already on the market or are being developed. We have lane-departure warning systems keeping us informed of the road boundaries; there is vehicle dynamics control to improve vehicle handling; driver drowsiness detection systems to tell us we should take a break when getting tired; collision avoidance systems that help us avoid or minimize collision damage; adaptive cruise control to keep our distance to a leading vehicle automatically; rain sensors that turn on the windshield wipers when it starts raining; adaptive lighting systems that turn the headlights into a corner when steering – the list is endless.

However, a major factor is still lacking. Despite all these systems, we need another developmental step in realizing Gibson and Crooks’s vision of a safe-field-of-travel. That step is harmonizing this cacophony of separate safety systems into an integrated driver-vehicle interface through which all this information is communicated clearly such that it becomes a seamless part of the driving task.

At the Control & Simulation division of the faculty of Aerospace Engineering we have been working on this problem for almost eight years now (Mulder, 2007), in close cooperation with the Biomechanical Engineering division of the Faculty of Mechanical, Maritime and Materials Engineering (MME). This work has been sponsored by Nissan Motor Company, Ltd. Our philosophy to tackle this problem of combining several driver support system functionalities into an integrated interface is based on haptic feedback.

WHAT IS HAPTIC FEEDBACK?

Haptic feedback can be defined as the combination of tactile and proprioceptive neuromuscular feedback we get when we physically interact with our environment. Whenever we interact with an object or device we exert forces on it and subsequently, in accordance with Newton’s third law, we are exposed to reaction forces, which we sense through our tactile and proprioceptive senses. We are continuously exposed to this kind of sensory feedback and we process it without having to think about it, but it is full of information about the things we interact with, also in driving. Take, for example, the subtle changes in resistance you feel on the steering wheel when you are driving on a slippery road, or when you are manoeuvring in and out of the tracks in the asphalt formed by continuous heavy loading by trucks. These conditions can change the ‘feel’ of the steering wheel in a split second and our neuromuscular system adapts to these changes just as fast. It is this capability of sensing subtle haptic information and being able to adapt to it quickly that we try to exploit in our haptic guidance interfaces for supporting drivers in their driving tasks.

On both the steering wheel and the gas pedal we have to exert forces to command a control action. The key factor for haptic feedback is, that we are influenced in our control actions by the reaction forces we experience when we exert forces on a
control device. So, we asked ourselves, can we introduce additional forces to the gas pedal and steering wheel that actively influence the control actions of the driver, while not automating the control of the vehicle? In other words, can we provide forces prominent enough to enable drivers to act upon them, but small enough not to provoke automatic control of the vehicle by the system?

MAKING HAPTIC FEEDBACK WORK
In our first project with Nissan, we worked on the design of a haptic gas pedal. The haptic gas pedal interface is an in-vehicle device that informs the driver about the state of the vehicle in relation to another vehicle in front during car-following. To help drivers form a mental image of their longitudinal safe-field-of-travel (situation awareness), haptic information of the field boundaries provides them with a complementary channel, besides vision, to determine these boundaries. This allows them to keep updating their mental image even when visually distracted. Second, if the haptic information is presented continuously, the field boundaries can be perceived continuously. Third, when the haptic information is presented through the longitudinal control channel, that is, the gas pedal, the consequences of control actions can be felt too, as they will induce changes in the safe-field-of-travel. Furthermore, the stimulus-response compatibility of this feedback is high as a force from the gas pedal is already suggesting the correct control action required to improve the current safe-field-of-travel boundaries – reducing speed.

The challenge with designing haptic interfaces is to create a system that provides meaningful haptic information. For the haptic gas pedal a relation had to be created between the car-following situation and the forces on the gas pedal. However, no naturally occurring connections between haptic information and car-following exist. Nevertheless, similarities between the characteristics of the interpretation of forces and car-following information can be identified. First, an increase in force is readily associated with an object moving towards the observer and vice versa. Relative movement of the vehicle in front of the own vehicle is the most important environmental information during car following. Hence, the force should increase with a decrease in inter-vehicle separation and vice versa. Second, the change in force and the change in vehicle separation should be correlated such that the magnitude of the required control action can be estimated by the driver. Too much force might result in too much control action and too little force might result in too little control action.

APPLICATION DURING CAR FOLLOWING
From these design requirements we developed an algorithm that used relative distance and relative velocity between the own vehicle and the followed vehicle as the main parameters for the generation of the haptic feedback. This haptic feedback is presented to the driver as additional force in combination with a change in stiffness of the gas pedal. The relative distance and velocity parameters are combined in such a manner that the haptic feedback is scaled depending on the urgency for the need to take action. Thus, when there is a stable following situation, little to no haptic feedback is presented to the driver. In normal following situations, the haptic feedback gently increases when the distance between the lead vehicle and the own vehicle is decreased. And in a close following situation a change in separation distance between the two vehicles results in a fast increase of the haptic feedback on the gas pedal. The resulting haptic feedback system allows drivers to position their vehicle at any desirable range behind another while the sense of urgency to slow down is communicated stronger when the distance between the lead vehicle is smaller or growing smaller faster (Figure 2).

In experimental investigations in our fixed-base driving simulator, we consistently found that drivers could almost instantly use the haptic gas pedal feedback and had no problems interpreting the information they were receiving. The main effect of this additional information during car-following situations was that drivers could maintain similar following behaviour and performance, with strongly reduced control activity. With the haptic gas pedal, drivers had much faster feedback on the effects of their longitudinal control actions than their visual feedback could provide. Thus, drivers could more easily avoid unnecessary control actions (accelerating too fast, then needing to brake more) since it was much more apparent to them that many of the control inputs they generated without the haptic feedback did not have a significant effect in maintaining distance with the lead vehicle. The haptic gas pedal feedback gave drivers an extra information channel on which they could base their control actions. This made them less dependent on visual information alone. This can help in situations where the visual information is degraded, for example during adverse weather conditions or at night. It also gives drivers information when they temporarily have their visual attention elsewhere, for example when scanning road signs, rear-view mirrors or navigation systems. Additionally, neuromuscular studies confirmed that drivers did not resist the feedback forces, but gave way to them, indicating that they trusted the feedback and found it useful to cooperate with
it. Moreover, we could confirm that the feedback forces allowed drivers to also respond on a neuromuscular level to changing lead vehicle separation, by using much faster reflexes (Abbink, 2006).

FROM LAB TO PRODUCT
In December 2007, Nissan announced the introduction of their Distance Control Assist system—a haptic gas pedal feedback system to help drivers maintain distance during car following in a variety of driving situations, from “…congested urban roads to high-speed expressways” (NISSAN, 2007). The success of this work and our philosophy that haptic feedback could be used to integrate multiple driver support system functions in the driver controls has led to more cooperation with Nissan. Current work focuses on investigating haptic steering wheel guidance, where we integrate environmental information in the lateral control task with haptic feedback. Numerous driving tasks can be supported with this kind of interface, such as lane keeping, curve negotiation, lane-changing and evasive manoeuvres.

ONGOING WORK
The applicability of our haptic feedback philosophy extends to other manual control tasks as well. Other studies in our research group (Aerospace Engineering/3M) investigate haptic feedback for assisting control of unmanned aerial vehicles (Lam, 2009), for supporting pilots in demanding manual control tasks, and even for tele-operated maintenance of nuclear plants. Several months ago a VENI grant (3M) was awarded to stimulate our research into these areas for the next four years.

By using a single unifying concept—haptic feedback—to make environmental constraints tangible we believe we’re taking the final step towards materializing Gibson and Crooks’s safe-field-of-travel.>

References


