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Full Body Haptic Display for Low-Cost Racing Car Driving Simulators

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Abstract

Motion platforms are advanced systems for driving simulators. Studies showed that these systems imitate the real driving behavior of cars very accurately. In low-cost driving simulators, most installations lack motion platforms and miss to simulate real motion forces. Their focus is on high-quality video and audio, or force feedback on steering wheels. We aim to substitute the real motion forces with low-cost actuators triggering the human extremities to create an extended immersion. By this, the quality of driving simulators without any motion platform can be increased. Our full body haptic display concept for low-cost racing car simulators is based on air cushion and pull mechanisms to support longitudinal and lateral forces addressing the human's mechanoreceptive and proprioceptive senses. The concept is analyzed within a user study covering twenty-two participants.

Keywords: Driving Simulation, Human Perception, Human-Machine Interface, Haptic Display, User Evaluation.

Index Terms: H.1 [MODELS AND PRINCIPLES]: User/Machine Systems – Human factors, Human information processing; H.5.2 [INFORMATION INTERFACES AND PRESENTATION]: User Interfaces – Evaluation/methodology, Haptic I/O, Prototyping, User-centered design

1 Introduction and Related Work

In the field of simulated driving, many systems were presented which try to reproduce reality by addressing the human senses. As shown by Latta and Oberg [1], virtual reality is a human-computer interface, simulating a realistic environment and allowing users to interact with it. Gibson [2] considered the human senses as perceptual system. He segregates them into the basic orienting, the auditory, the haptic, the taste-smell, and the visual system. Their significance is addressed by Kemeny and Panerai [3], who discuss the perception cues within a driving simulator. Gordon [4] presents a technique to isolate the operator's visual input. Sivak [5] states that although relevant information to a driver is likely to be predominantly visual, this fact still is lacking direct evidence.

An accurate reproduction of reality will cover multiple senses, as discussed by Driver and Spence [6]. Lindeman et al. [7] address directional cues to increase awareness in real and virtual environments. They present developments to offload work from the visual to the haptic channel. For driving tasks, motion platforms allow a good reproduction of a car's real behavior. The Iowa driving simulator [8] shows such possibilities: perception is addressed by visual, auditory, orienting, and haptic cues. Low-cost driving simulators lack a multi-channel stimulation of all these senses. Basic installations are restricted to visual and auditory cues, and some haptic feedback at the steering wheel ([9], [10]) or in the seat with vibrotactile feedback. Our goal is to develop a concept for simulating a racing car's behavior without any motion platform. Due to limitations of stationary simulators, the concept should provide multi-channel immersion. We analyzed the potential of mechanoreceptive and proprioceptive senses and the regions on the body for positioning the acting forces. Based on this, we developed a concept to display longitudinal and lateral accelerations and implemented it as a prototype to demonstrate the communication pipeline from the simulation software to the driver's perception.

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2 Full Body Haptic Display Concept

In a racing car, human perception is exposed to various gravitational, longitudinal, and lateral accelerations, being influenced by the car's velocity, its physical behavior, or the track's characteristics. This complexity can be simplified by distinguishing driving situations like accelerating, braking, cornering, oversteering, and understeering. Based on a racing car's telemetric data, we concentrate on longitudinal and lateral forces, neglecting the gravitational forces. For acceleration, the forces are acting in longitudinal direction and push the driver into the seat. The forces act at the back part of the head, the back, and at the hips. When braking, the body is pressed into the seat belts. The main pressure is on the shoulders, the chest and the hips. For cornering, longitudinal and lateral forces are superimposed. The lateral forces are centripetal with the highest pressure on elbows, lateral torso, hips, and knees. As we concentrate on adequate feedback of forces in low-cost driving simulators, a full body haptic display represents a promising approach.

3 User Study

In a user study, we determined locations on the human body that are adequate to trigger the mechanoreception with an air cushion system and the proprioception with a pull mechanism. The setup consisted of a discarded racing car. Its pedals and steering wheel were replaced by a game steering wheel and a pedal box. The race track was projected onto a screen in front of the racing car.

Figure 1. Left: Pull mechanism, Right: Air cushion system.

The proprioceptive feedback uses a *pull mechanism*. Each participant had bandages around torso, hips, and knees. The bandages could be pulled in lateral direction for torso, hips, and knees, and in longitudinal direction just for the torso. An operator handled the cords to simulate acceleration, braking, left, and right turns. Mechanoreceptive feedback was realized with an *air cushion system* using freezer bags fixed to the participants (see

Figure 1). Forces were applied at the back, at the car's belts to trigger pectoral regions, the lateral sides of the torso, each side of the hips, and the lateral part of the thighs. The bags were connected to an air pump and triggered by an operator.

Our study covered twenty-two male subjects between 23 and 62 years (median age of 29). They were divided into two groups. Group A started with the pull mechanism, followed by the air cushion system, Group B performed the study in an inverse order. All participants completed two laps without any force feedback to get accustomed to the track. These two laps were followed by one lap, which was divided into four sections. After each section, users answered questions concerning the immersion and the haptic feedback's quality. After the participants were prepared for the second test installing the new feedback system, they completed another lap with the same sections and procedural feedback.

The questionnaire evaluated air cushion and pull mechanisms. The participants rated the overall feedback of both systems after each section. The evaluation of the longitudinal and lateral forces is based on a 7-point Likert scale within a range of -3 (very disturbing), over 0 (neutral), up to +3 (highly supportive).

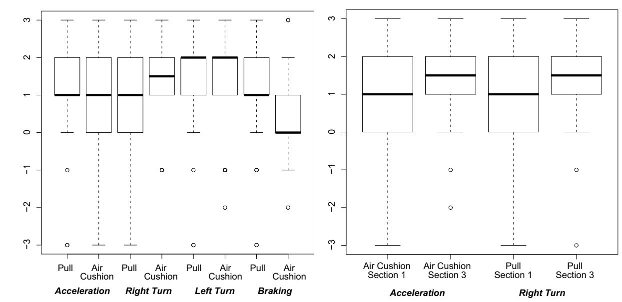

Figure 2. Left: Box plots for both systems, Right: Boxplots for the first and second driven section.

In Figure 2 (left), the results are divided into acceleration, right turn, left turn, braking; with the pull mechanism on the left, and the air cushion system on the right. All median values are positive (one neutral). Using Mann-Whitney tests at a 5% level of significance, there is a difference in medians only for braking. The reason for this difference is the air cushion system that was attached at a fixed position on the belt. This made it difficult to adjust it to the body size and to generate the mechanoreceptive feedback. Further, there are two exceptional results (air cushion system for acceleration and pull mechanism for right turns) with 25% negative ratings. As the procedure triggered every situation twice, we segregated the results for the first and the third section (Figure 2, right). This revealed a higher variance in the first section, which could be due to the need of getting used to the new impression. In the overall evaluation, the air cushion system for mechanoreception was preferred compared to the pull mechanism for proprioception. Group A stated a preference for the air cushion system, whereas group B had an even voting result. This leads to the interpretation that the air cushion system is widely accepted to trigger a force feedback, but the pull mechanism is needed to provide a higher immersion.

4 PROTOTYPICAL SETUP

Based on the results above, we prototypically implemented the whole communication pipeline, from the simulation software up to the perception. The triggering signals for the control electronics are collected in real-time from the simulation, using the motion-control software X-sim v2.0. This data is transferred to an Arduino Duemilanove µ-controller module, where the data packages are unpacked and interpreted by the controller code. For the pull mechanism, the prototype uses a servo-motor, which is connected to the µ-controller via an H-bridge to switch the rotational direction. The speed is controlled by the µ-controller. The µ-controller is also connected to a MOSFET-switch to address the magnetic valve of the air pressure system. The physical prototype consists of the power supply, the micro-controller, the pull mechanism with hex-inverter, H-bridge, servo-motor, pressure actuator system with the MOSFET-switch, the magnetic valve, the air pressure supply, the freezer bag, the sound absorber, and the open drain (see Figure 3).

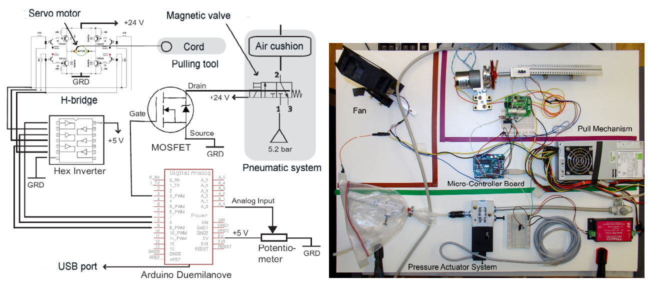

Figure 3. Left: System overview, Right: Physical setup.

5 CONCLUSION AND OUTLOOK

We presented a full body haptic display based on air cushion and pull mechanisms to support the feedback of longitudinal and lateral forces addressing mechanoreceptive and proprioceptive senses. The user study bases on a preliminary implementation of the final system. The results lead to a feedback concept combining the tested solutions for mechanoreception and proprioception.

In future, we will integrate the air cushions and the pull mechanism into the racing car. With this, we will evaluate a full body feedback. Next, we will analyze the differences between users with and without the full body haptic feedback.

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