DEVELOPMENT ENVIRONMENT FOR HAPTIC FEEDBACK DEVICE ON MOBILE AGRICULTURAL EQUIPMENT

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Abstract The steering wheel equipped with a tactile feedback is a human machine interface (HMI), capable to present sophisticated feedback information for the operator. Haptic stimulation is superior in interpretation speed by humans compared to audio-visual information. In this paper we present the concept of haptic feedback on vehicle and the ongoing research activities at the Department of Mechatronics to develop flexible technology to retrofit production machines with steer-by-wire capability to collect data representing the interactions in different application context (road and field modes).

Keywords haptic feedback, steering wheel, off-road vehicles

1 INTRODUCTION

In the last decade numerous scientific results has been presented to the engineering community in the topic of Steer-by-Wire technology (SBW). Despite the fact that the more complex mechatronics providing the by-wire functionality raises several safety related questions, also open exciting new opportunities for off-road vehicles not existing before.

The topic SBW can be discussed in numerous aspects: For example the advanced sensor/actuator components, the administrative regulation of by-wire systems, the failure-tolerant communication to interconnect components and the redundant system design are all large topics alone [1], [2]. We would like to focus in this presentation on the new, exciting functions, which could be realized by the Human-Machine-Interfaces (HMI) of the SBW systems.

Driving speed of agricultural mobile machines have been increased in the recent years, raising serious questions about vehicle handling characteristics considering the high center-of-gravity, multi-mass configuration and rear-wheel-steering of these vehicles. The next generation of steering systems on off-road vehicles will incorporate a steering column mechatronic subsystem which will generate tactile feedback for operator.

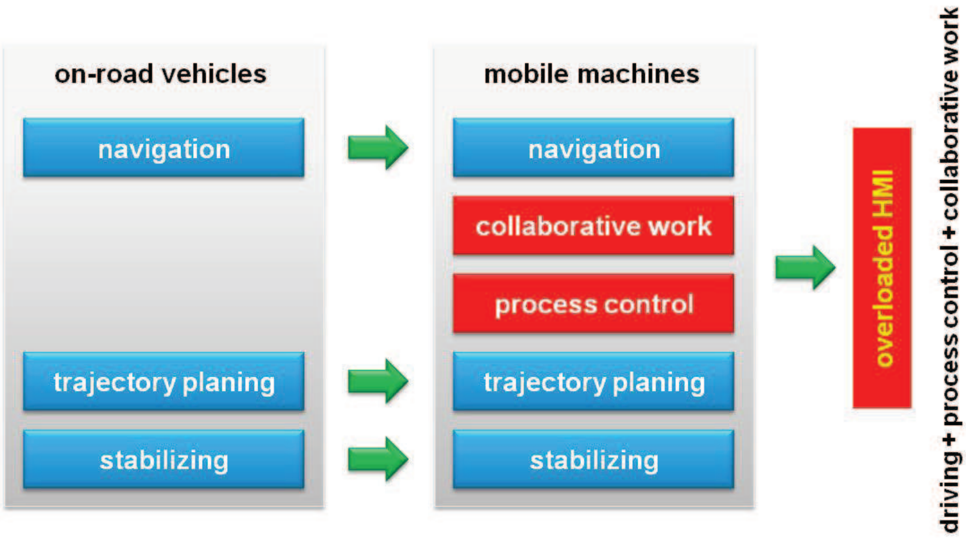

Figure 1. Operator’s Control Functions: the „5 level model”

The steering wheel and its force-feedback actuator should be recognized as a new operator interface which enables the representation of feedback information on a new way.

Considering the "operator – steering – vehicle" as a closed loop control system, quality of the control system performance significantly can be improved or degraded by the quality of the steering wheel feedback [5]. The force or pressure sensed by the human hand – to so called haptic stimulus - get a significantly faster interpretation in our brain compared to the acoustic or visual information.

The HMI's of today's agricultural equipment are based mostly on visual information and some acoustic warning signals. These channels are overloaded and a new signal representation could be very useful to unload these channels. There are several HMI devices in the cockpit, where an intelligent feedback signal could be used: hydraulic levers with force feedback, or speed handles with traction feedback, etc.

2 5 LEVEL MODEL OF OPERATOR ASSISTANCE SYSTEMS IN AGRICULTURAL EQUIPMENT

The haptic feedback signals of the vehicle steering should be analyzed as part of the 'big picture', as sub domain of the Operator Assistance System in agricultural mobile equipment. Analogy with passenger car exist, considering the Driver Assistance Systems (Fahrer Assistanz Systeme - FAS).

In passenger cars the functions of supporting electronics can be linked to hierarchy levels of driver's controlling functions: navigation, trajectory selection and vehicle stabilizing [3]. The navigation systems are on the topmost level, helping to locate the vehicle and selecting optimal route. Recent advance in automotive electronic systems provide support for the driver to keep vehicle inside the lane, and to keep safe distance in busy traffic. Stabilizing of the vehicle needs the shortest response time from the driver, and this is very well supported today by electronic systems in the car. (advertised with acronyms like ABS, ESP, ASR, etc.)

Using this analogy, similar hierarchy levels can be defined on agricultural mobile equipment also Figure 1. These levels should be extended with two more hierarchy levels compared to passenger car, which are unique on mobile equipment: Collaborative task execution and process control. Collaborative task execution is very common on field work, whereby operators must synchronize the motion and processes of several machines (e.g. Forage Harvester + Transport Equipment). In the collaborative field maneuvers safety is extremely critical to avoid equipment damage or serious injuries. As we know, there are no product features or electronic systems available to support operator in these functions.

The majority of the mobile agricultural equipments are "rolling factories", whereby the complex processes have to be controlled: settings must be changed according to changing field conditions, to achieve the requested product quality and equipment productivity. These processes are also supported some by electronic systems, mostly by visualizing process key figures or reloading preset values of machine settings. Navigation task on mobile equipment is supported by GPS based precision farming systems. The trajectory decision and speed control are also supported by GPS based automatic steering, which functions are state-of-the-art on today's production machines.

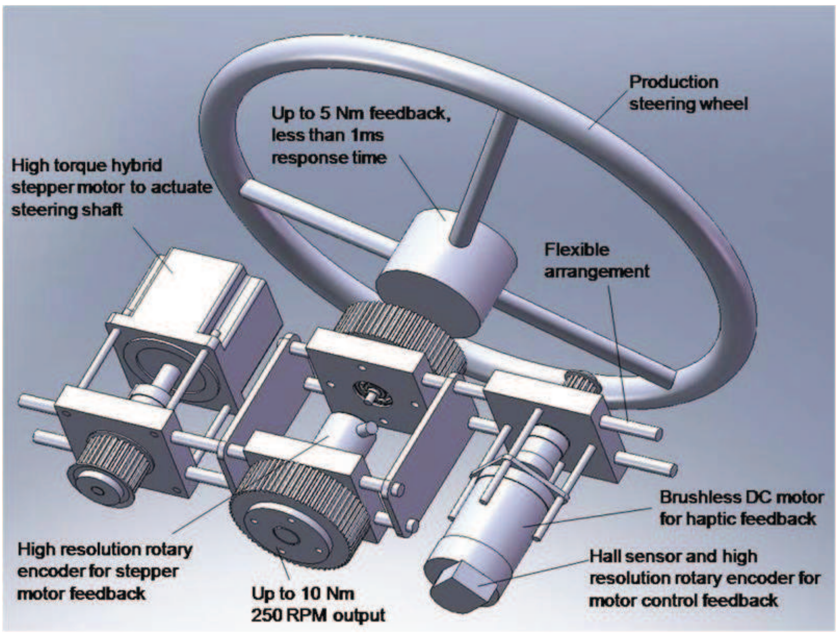

Figure 2. Haptic feedback signal testing equipment

The vehicle stability and controllability gets even more important. Increasing productivity means often higher transport speed and higher vehicle weight on public roads. We should consider the fact, that these vehicles will have higher center of gravity, low lateral stiffness of tires (terra) and no real suspension, even some have rear-wheel steering. This represents a rising risk, which can be significantly reduced by electronic systems, supporting the operator in stabilizing the vehicle. The numerous complex controlling task requires new information channels to be established, in order to provide safe way to feed information to the operator. Haptic feedback signals of the steering system regarded as one of this opportunities.

3 HAPTIC FEEDBACK RESEARCH METHODS AND TOOLS

Flexible research platform was designed to analyze the human-machine interaction and the vehicle dynamics, in accordance with the above mentioned physical and artificial feedback signals. The toolset can be placed on any kind of vehicle, with or without power steering.

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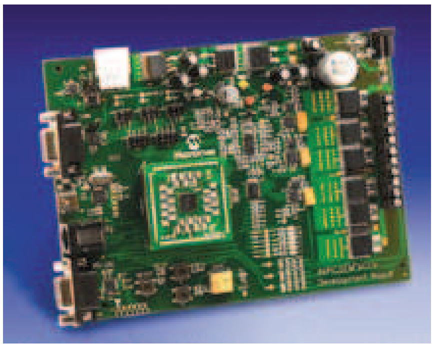

Figure 3. The dsPICDEMTM MCLV Development Board

The Figure 2 is showing the schematic of the tool used in the HMI experiments. The steering wheel position and driving torque is controlled by a brushless dc motor (BLDC) and timing belt transmission which is free from backlash. The four quadrant power electronics servo system (Figure 3 and Figure 4) incorporates the experimental feedback logic software.

The steering shaft is driven also by a high torque servo with timing belt. The high torque is required because also vehicles with no hydraulic support are going to be analyzed.

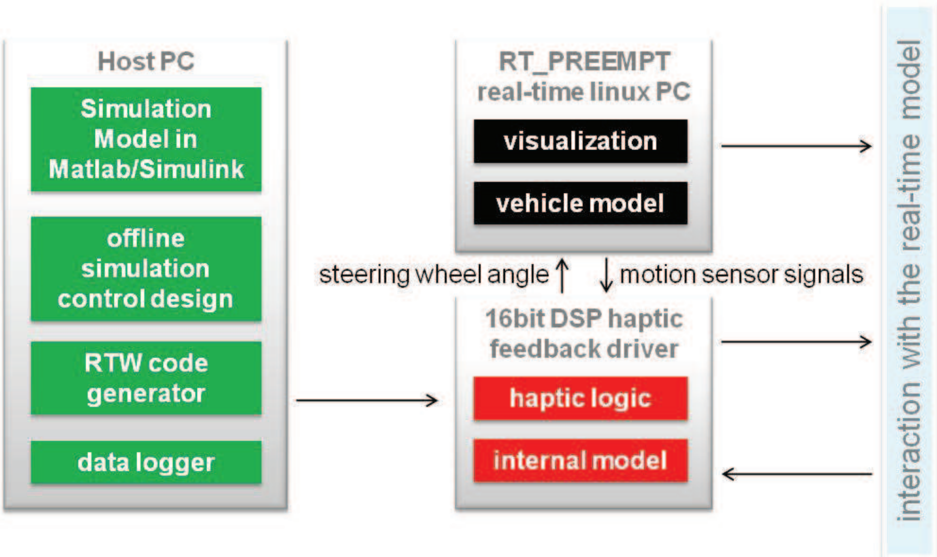

Figure 4. Human-in-the-Loop simulation tool chain

The motion of the steering wheel and the steering shaft are independent, therefore ratio, torque and timing could be programmed according to the analyzed effect. In case of locked clutch in the transmission, makes the ratio between steering wheel and steering shaft fixed and experiments with superposition torque control can be executed.

4 FEEDBACK SIGNALS REPRESENTED BY THE HUMAN MACHINE INTERFACE

As mentioned in the previous section, the steering wheel regarded as a Human Machine Interface, can present several signal types to the operator. Let us overview first the signal types and their possible use in control of agricultural mobile machines.

Some of the possible emulated signals are of physical nature, and can be derived from the tire-soil/road interaction or vehicle dynamics. Some others are artificial feedback signals, like warnings or guiding signals. Physical or artificial feedbacks are programmable, and can be activated or suppressed dependent on the work-environment context, driving situation or user preferences.

4.1 Emulated aligning moment and tire side forces

It has been proven [4], that intentional modification of the steering wheel torque has a positive impact on vehicle stability. State-of-the-art control technology used extensively in driver assistance systems like ESP [7],which is able to estimate state variables of vehicle motion, using signal processing algorithms (based on Kalman filtering), and set of low-cost sensors (wheels speed, lateral acceleration). This state information derived from the internal model can be used to calculate simulated aligning moment of the wheels.

This information of vehicle dynamics fed to the operator by emulating with the steering wheel haptic feedback (Illustrated in Example 1). Aligning moment can be also decreasing if wheel slip increases; this gives information about front wheel traction.

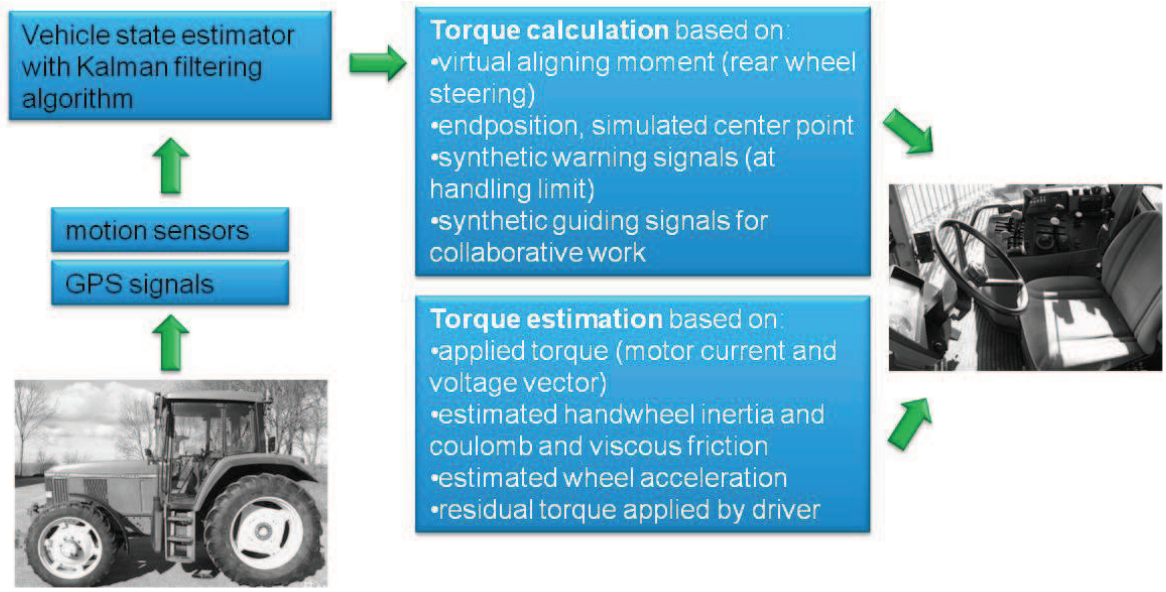

Figure 5. Control concept for Haptic Feedback

In certain operational context it is advantageous; if operator is able to realize if the turning torque of the wheel is rapidly increasing. In case of ploughing, guiding vehicle in furrow, or hitting an object, lateral forces on tire are transmitted to the steering wheel, and are interpreted by the operator as guiding or warning signals.

Off-road vehicles using hydrostatic steering lacks on steering feedback, which have a negative impact on vehicle handling, especially at higher speeds. An active steering feedback have an advantage, that only positive effects are emulated which can improve response time and quality, cornering predictability, center point feeling and reduce overshooting and unwanted steering torque oscillations. Feeling of the applied steering torque and or aligning moment support the operator to control vehicle in turning (Figure 5). This is one the most important haptic information on the steering wheel, which should be emulated by the active force feedback device. The aligning moment is present until steering wheel and the wheels get back to a neutral position, which is very useful (and safe) for vehicles, which have hard to see rear wheels. The emulated steering provides information about traction conditions, side forces, friction coefficients or slip. If the driver gets closer to traction limit the emulated aligning torque decreases.

4.2 Warning and guiding signals

Warning signals are of great importance, because haptic information is realized significantly faster than audio or visual signals. Collision avoidance or other operator actions requiring fast response should be placed on steering wheel actuator, for example as vibration. This could be combined with guiding signals, which gives the operator a proposed direction of safe steering wheel motion.

Guiding signals offers several application possibilities (see application on passenger cars [6]): proposed driving direction based on GPS position, or local sensors. The driver can override anytime the guiding signals, and system will go back to the original proposed direction. The guiding signal feels like a magnetic conveyor. The guided direction could be a GPS based straight running, returning to steering wheel zero position or “centre point feeling”. The last one could be interesting, if no aligning moment available or vehicle have any visible steered wheels.

Guiding signals can be used efficiently in collaborative working environment, whereby motion of machine-chains should be synchronized. In this case a guiding steering torque presented in both vehicle. If a handle with active feedback available, also speed could be synchronized.

4.3 Steering wheel used as hand force sensor

The steering wheel is able not only measure the position-velocity-acceleration, but also measures torque using current sensing of the motor drive. If velocity information and the driving torque available changes of inertia and reactive torque can be estimated. This information is used to determine the operator fitness or availability. If an automatic steering device available, often operators don’t hold the steering wheel, which represent a risk.

For most of the working machines (forklift, forage harvester) is essential to identify operator presence for safety, and for this mostly a simple switch is built in the seat. This simple sensor cannot identify if the driver is inactive, e.g. sleeping. The haptic feedback on the steering can be used to integrate an intelligent driver presence sensing algorithm.

The power electronics have build in current sense components, and the driving torque can be calculated very accurately, without using any additional sensors. Using the known calibrated rotational inertia of the system and the motor driving/braking torque, the hand force of the operator can be estimated. If no steering force required, on stand or driving on a straight line, the steering wheel can use a modulated “ringing” signal to check, if driver’s hands are still on the steering wheel.

Changing the steering ratio dynamically can improve the steering-kinematics. Unique functions can be implemented, like backing-up with trailer where a virtual relocation of the steered wheel from front to back is possible. Implements using three point hitch can be also regarded as a new option for relocation of the virtual steered wheels and create optimal new steering kinematics.

4.4 Hardware-in-the-Loop simulation

Figure 6 a-b shows the steering wheel angle and controller internal model outputs at different model settings. If lower damping (angular speed dependent viscous friction) is used the system response (yaw rate, slipping angle) oscillate (Figure 6/a-d), which is close to the handling experience with passenger cars on public roads. Increasing the damping these oscillations on the steering wheel can be reduced (Figure 6/e-f) and so the optimal value for comfort and safety can be achieved.

Figure 6/g shows an implementation of the above mentioned soft-end feel. Figure 6/h shows both soft-end implementation and an example for the synthetic warning signals at assumed handling limits (yaw rate).

5 CONCLUSIONS

Haptic feedback is an interesting new opportunity to improve functionality of agricultural mobile machines. There are numerous options to implement physical type of signals, like aligning moment, to increase safety and vehicle handling.

There is also a new and interesting opportunity to design synthetic haptic feedback to present fast, and not yet existing warning signals for the operator. Using the presented development environment and the human-in-the-loop simulation tools further investigation of the human-machine interaction must be analyzed.

The haptic feedback can be used in the same time as an intelligent sensor to detect driver presence and ability. This opportunity must be investigated further involving ergonomist expertise.

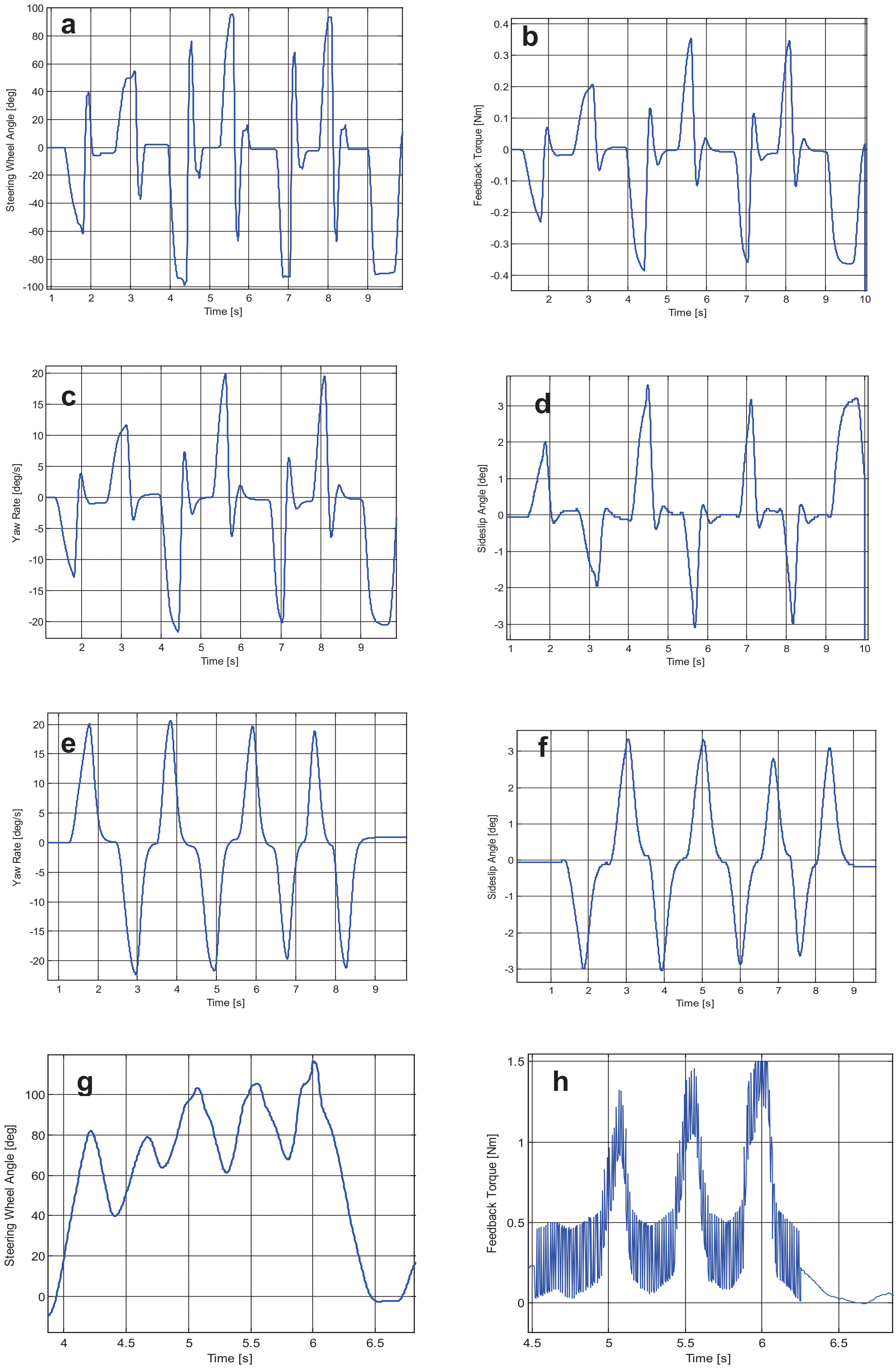

Figure 6: Human-in-the-Loop test results with different parameter set

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