EXPLORATORY ADVANCED **RESEARCH**

Federal Highway Administration

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Driver simulators to test shared controls, limited autonomy vehicle systems

Identification of the use of driver simulators for semiautonomous (or shared control) vehicle systems (2012–present), including related research from other modes of transportation (e.g., rail or aviation). Focus is on the research method and use of driving simulators.

TOPIC

CONTENTS

U.S. Department of Transportation
Federal Highway Administration

REFERENCE RESULTS: LITERATURE AND RESEARCHERS

Multilevel planning for semiautonomous vehicles in traffic scenarios based on separation maximization

Author(s): Kala, Rahul;[1] Warwick, Kevin[1]
Year: 2013
Source: Journal of Intelligent and Robotic Systems, vol. 72, no. 3–4, pp. 559–590
Publisher: Springer Verlag
Author affiliation:
[1]School of Systems Engineering, University of Reading, Whiteknights, Reading, Berkshire RG6 6AY, United Kingdom, https://www.reading.ac.uk/sse/contact/sse-contact.aspx

The planning of semiautonomous vehicles in traffic scenarios is a relatively new problem that contributes toward the goal of making road travel by vehicles free of human drivers. An algorithm needs to ensure optimal real-time planning of multiple vehicles (moving in either direction along a road) in the presence of a complex obstacle network. Unlike other approaches, here the authors assume that speed lanes are not present and that different lanes do not need to be maintained for inbound and outbound traffic. The authors' basic hypothesis is to carry forward the planning task to ensure that a sufficient distance is maintained by each vehicle from all other vehicles, obstacles, and road boundaries. The authors present a four-layer planning algorithm that consists of road selection (for selecting the individual roads of traversal to reach the goal), pathway selection (a strategy to avoid or overtake obstacles, road diversions, and other blockages), pathway distribution (to select the position of a vehicle at every instance of time in a pathway), and trajectory generation (for generating a curve that is smooth enough to allow for the maximum possible speed). Cooperation among vehicles is handled separately at the different levels, the aim being to maximize the separation between vehicles. Simulated results exhibit behaviors of smooth, efficient, and safe driving of vehicles in multiple scenarios, along with typical vehicle behaviors including following and overtaking.

Effectiveness and driver acceptance of a semiautonomous forward obstacle collision avoidance system

Author(s): Itoh, Makoto;[1] Horikome, Tatsuya;[2] Inagaki, Toshiyuki[1]
Year: 2013
Source: Applied Ergonomics, vol. 44, no. 5, pp. 756–763
Publisher: Elsevier
Author affiliations:
[1]Faculty of Engineering, Information and Systems, University of Tsukuba, Tsukuba, Ibaraki 305–8573, Japan, http://www.sie.tsukuba.ac.jp/english/
[2]Isuzu Advanced Engineering Center LTD, Fujisawa, Kanagawa, Japan, http://www.isuzu.co.jp/world/index.html

The authors propose a semiautonomous collision avoidance system for the prevention of collisions among vehicles and pedestrians and objects on a road. The system is designed to be compatible with the human-centered automation principle, that is, the decision to perform a maneuver to avoid a collision is made by the driver. The system, however, is partly autonomous in that it turns the steering wheel independently when the driver applies only the brake, indicating his or her intent to avoid the obstacle. With a medium-fidelity driving simulator, the authors conducted an experiment to investigate the effectiveness of this system for improving safety in emergency situations, as well as its acceptance by drivers. The results indicate that the system effectively improves safety in emergency situations, and the semiautonomous characteristic of the system was found to be acceptable to drivers.

Shared steering control between a driver and an automation: Stability in the presence of driver behavior uncertainty

Author(s): Saleh, Louay;[1] Chevrel, Philippe;[2] Claveau, Fabien;[2] Lafay, Jean-François;[2] Mars, Franck[2]
Year: 2013
Source: IEEE Transactions on Intelligent Transportation Systems, vol. 14, no. 2, pp. 974–983
Publisher: IEEE
Author affiliation:
[1]Higher Institute of Applied Sciences and Technology, Damascus 31983, Syria, http://www.hiast.edu.sy/en
[2]IRCCyN, Institut de Recherche en Communications et Cybernétique Nantes, Ecole Centrale de Nantes, Nantes F-44321, France, http://www.irccyn.ec-nantes.fr/?lang=en

The authors present an advanced driver assistance system (ADAS) for lane-keeping, together with an analysis of its performance and stability with respect to variations in driver behavior. The automotive ADAS as proposed is designed to share control of the steering wheel with the driver in the best possible way. Its development was derived from an H2-preview optimization control problem, which is based on a global driver–vehicle–road (DVR) system. The DVR model makes use of a cybernetic driver model to take into account any driver–vehicle interactions. Such a formulation allows for (1) consideration of driver-assistance–cooperation criteria in the control synthesis, (2) improvement of the performance of the assistance as a cooperative copilot, and (3) analysis of the stability of the whole system in the presence of driver model uncertainty. The results have been experimentally validated with one participant using a fixed-base driving simulator. The developed assistance system improved lane-keeping performance and reduced the risk of a lane-departure accident. Good results were obtained by using several criteria for human–machine cooperation. Poor stability situations were successfully avoided due to the robustness of the whole system, in spite of a large range of driver model uncertainty.

Sharing control with haptics: Seamless driver support from manual to automatic control

Author(s): Mulder, Mark;[1] Abbink, David A.;[1] Boer, Erwin R.[1, 2]
Year: 2012
Source: Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 54, no. 5, pp. 786–798
Publisher: SAGE Publications, Inc.
Author affiliations:
[1]Delft University of Technology, 2629 HS Delft, Netherlands, http://www.tudelft.nl/en/
[2]Entropy Control, Inc., La Jolla, CA 92037, United States

The authors investigated haptic shared control as a human–machine interface that can intuitively share control between drivers and an automatic controller for curve negotiation. As long as automation systems are not fully reliable, a role remains for the driver to be vigilant to the system and the environment to catch any automation errors. The conventional binary switches between supervisory and manual control have many known issues, and haptic shared control is a promising alternative. A total of 42 respondents of varying ages and driving experience participated in a driving experiment in a fixed-base simulator, in which curve negotiation behavior during shared control was compared with curve negotiation behavior during manual control, as well as to three haptic tunings of an automatic controller without driver intervention. Under the experimental conditions studied, the main beneficial effect of haptic shared control compared with manual control was that less control activity (16 percent in steering wheel reversal rate, 15 percent in standard deviation of steering wheel angle) was needed for realizing an improved safety performance (e.g., 11 percent in peak lateral error). Full automation removed the need for any human control activity and improved safety performance (e.g., 35 percent in peak lateral error) but put the human in a supervisory position. The authors concluded that haptic shared control kept the driver in the loop with enhanced performance at reduced control activity, mitigating the known issues that plague full automation. Haptic support for vehicular control ultimately seeks to intuitively combine human intelligence and creativity with the benefits of automation systems.

Highly automated driving, secondary task performance, and driver state

Author(s): Merat, Natasha;[1] Jamson, A. Hamish;[1] Lai, Frank C. H.;[1] Carsten, Oliver[1]
Year: 2012
Source: Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 54, no. 5, pp. 762–771
Publisher: SAGE Publications, Inc.
Author affiliation:
[1]Institute for Transport Studies, University of Leeds, Leeds LS2 9JT, United Kingdom, http://www.its.leeds.ac.uk/

The authors conducted a driving simulator study, which compared the effect of changes in workload on performance in manual and highly automated driving. Changes in driver state were also observed by examining variations in blink patterns. With the addition of a greater number of advanced driver assistance systems in vehicles, the driver's role is likely to alter in the future from an operator in manual driving to a supervisor of highly automated cars. Understanding the implications of such advancements on drivers and road safety is important. A total of 50 participants were recruited for this study and drove the simulator in both manual and highly automated modes. In addition to comparing the effect of adjustments in driving-related workload on performance, the authors also investigated the effect of a secondary Twenty Questions task. In the absence of the secondary task, drivers' responses to critical incidents were similar in manual and highly automated driving conditions. The worst performance was observed when drivers were required to regain control of driving in the automated mode while distracted by the secondary task. Blink frequency patterns were more consistent for manual than automated driving but were generally suppressed during conditions of high workload. Highly automated driving did not have a deleterious effect on driver performance when attention was not diverted to the distracting secondary task. As the number of systems implemented in cars increases, an understanding of the implications of such automation on drivers' situation awareness, workload, and ability to remain engaged with the driving task is important.

Control task substitution in semiautomated driving: Does it matter what aspects are automated?

Author(s): Carsten, Oliver;[1] Lai, Frank C. H.;[1] Barnard, Yvonne;[1] Jamson, A. Hamish;[1] Merat, Natasha[1]
Year: 2012
Source: Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 54, no. 5, pp. 747–761
Publisher: SAGE Publications, Inc.
Author affiliation:
[1]Institute for Transport Studies, University of Leeds, Leeds LS2 9JT, United Kingdom, http://www.its.leeds.ac.uk/

The authors designed this study to show how driver attention to the road scene and engagement of a choice of secondary tasks are affected by the level of automation provided to assist or take over the basic task of vehicle control. The authors also designed the study to investigate the difference between support in longitudinal control and support in lateral control. There is comparatively little literature on the implications of automation for drivers' engagement in the driving task and for their willingness to engage in nondriving-related activities. The authors conducted a study on a high-level driving simulator in which drivers experienced three levels of automation: manual driving; semiautomated driving, with either longitudinal or lateral control provided; and highly automated driving, with both longitudinal and lateral control provided. Drivers were free to pay attention to the roadway and traffic or to engage in a range of entertainment and grooming tasks. Engagement in the nondriving tasks increased from manual to semiautomated driving and increased further with highly automated driving. There were substantial differences in attention to the road and traffic between the two types of semiautomated driving. The literature on automation and the various task analyses of driving do not currently help to explain the effects that were found. Lateral support and longitudinal support may be the same in terms of levels of automation but appear to be regarded rather differently by drivers.

Constraint-based planning and control for safe, semiautonomous operation vehicles

Author(s): Anderson, Sterling J.;[1] Karumanchi, Sisir B.;[1] Iagnemma, Karl[1]
Year: 2012
Source: 2012 IEEE Intelligent Vehicles Symposium (IV)
Publisher: IEEE
Author affiliation:
[1]Department of Mechanical Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139, United States, http://meche.mit.edu/

The authors present a new approach to semiautonomous vehicle hazard avoidance and stability control, based on the design and selective enforcement of constraints. This differs from traditional approaches that rely on the planning and tracking of paths. This emphasis on constraints facilitates "minimally invasive" control for human–machine systems: Instead of forcing a human operator to follow an automation-determined path, the constraint-based approach identifies safe homotopies and allows the operator to navigate freely within them, introducing control action only as necessary to ensure that the vehicle does not violate safety constraints. The method evaluates candidate homotopies based on "restrictiveness," rather than on traditional measures of path goodness, and designs and enforces requisite constraints on the human's control commands to ensure that the vehicle never leaves the controllable subset of a desired homotopy. Identification of these homotopic classes in off-road environments is performed by using geometric constructs. The goodness of competing homotopies and their associated constraints is then characterized by using geometric heuristics. Finally, input limits satisfying homotopy and vehicle dynamic constraints are enforced by using threat-based feedback mechanisms to ensure that the vehicle avoids collisions and instability while preserving the human operator's situational awareness and mental models. The methods developed in this work are shown in simulation and experimentally demonstrated in safe, high-speed teleoperation of an unmanned ground vehicle.

Internet-based shared control of vehicle steering when driver is under situation of tendency to accidents

Author(s): Zhong, Ming-En;[1] Wu, Ping-Dong;[2] Peng, Jun-Qiang[3]
Year: 2012
Source: Materials Science Forum, vol. 704–705, pp. 650–656
Publisher: Trans Tech Publications, Inc.
Author affiliations:
[1]Department of Mechanical Engineering, Xiamen University of Technology, Xiamen, China, http://english.xmut.edu.cn/
[2]School of Mechanical Engineering, Beijing Institute of Technology, Beijing, China, http://english.bit.edu.cn/AboutBIT/officesschools/SchoolsDepartments/78021.htm
[3]School of Mechanical and Electronic Engineering, Tianjin Polytechnic University, Tianjin, China, http://www.csc.edu.cn/laihua/universitydetailen.aspx?collegeId=268

Probability of traffic accidents grows when the driver's environment has a tendency to cause accidents. The authors introduce a new vehicle model under Internet-based shared control technology, modeling toward the Internet-based shared control of the steering system. The authors simulated influence of the network transmission delay on the steering performance and created a closed-loop control circuit model. The authors put forward a systematic controller algorithm, the input of which gains range from the viewpoint of the sufficient condition for delay-dependent robust stability and steady-state error and design, and shows a dynamic, self-switching, delay-dependent robust controller. Simulation and experimental results show the validity of the proposed method.

Shared lateral control of a passenger car: Design on the basis of cybernetic driver model and H2-preview control

Author(s): Saleh, Louay;[1] Chevrel, Philippe;[1] Claveau, Fabien;[1] Lafay, Jean-François;[1] Mars, Franck[1]
Year: 2012
Source: Journal Européen des Systèmes Automatisés, vol. 46, no. 4–5, pp. 535–557
Publisher: Lavoisier
Author affiliation:
[1]IRCCyN, Institut de Recherche en Communications et Cybernétique Nantes, Ecole Centrale de Nantes, Nantes F-44321, France, http://www.irccyn.ec-nantes.fr/?lang=en

The authors propose a cybernetic driver model that is able to perform lateral control. On the basis of this model, the authors designed an active assistance function that helps the driver in real time for lane-keeping. The device applies an additional torque

to the steering column in a continuous way, which achieves a shared lateral control with the driver. The driver model has been identified from experimental data collected on a fixed-base driving simulator. The designed control law takes advantage of the predictive capabilities of the driver model. The synthesis of this "electronic copilot" was performed by stating an H2 optimization problem with preview on the overall driver–vehicle–road system. Last, the authors evaluated the quality of the proposed shared steering control in terms of performance (quality of lane-keeping) and driver-assistance interaction coherence, which may guarantee its acceptability.

Optimal control with preview for lateral steering of a passenger car: Design and test on a driving simulator

Author(s): Saleh, Louay;[1] Chevrel, Philippe;[1] Lafay, Jean-François[1]
Year: 2012
Source: Lecture Notes in Control and Information Sciences, vol. 423, pp. 173–185
Publisher: Springer Verlag
Author affiliation:
[1]IRCCyN, Institut de Recherche en Communications et Cybernétique de Nantes, Ecole Centrale de Nantes, Nantes F-44321, France, http://www.irccyn.ec-nantes.fr/?lang=en

The authors studied the characteristics of the optimal preview control for lateral steering of a passenger vehicle. Such control is known to guarantee improved performance when the near future of the exogenous signal—here, the road curvature—is known. The synthesis is performed in continuous time and leads to a two-degrees-of-freedom feedback and feedforward controller, whose feedforward part is a finite impulse response filter. The controller has been implemented on the SCANeR™ Driving Simulator, available at IRCCyN, whose steering column is electrically powered. The authors propose a methodology for choosing the weighting matrices in the quadratic index and the preview time and also discuss the obtained experimental results.

Preface to the special section on human factors and automation in vehicles: Designing highly automated vehicles with the driver in mind

Author(s): Merat, Natasha;[1] Lee, John D.[2]
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Source: Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 54, no. 5, pp. 681–686
Publisher: SAGE Publications Inc.
Author affiliations:
[1]University of Leeds, Leeds LS2 9JT, United Kingdom, http://www.leeds.ac.uk/
[2]College of Engineering, University of Wisconsin–Madison, Madison, WI 53706, United States, http://www.engr.wisc.edu/

In this special section, the authors bring together diverse research regarding driver interaction with advanced automotive technology to guide the design of increasingly automated vehicles. Rapidly evolving vehicle automation will likely change cars and trucks even more in the next 5 years than the preceding 50, radically redefining what it means to drive. This special section includes 10 articles from European and North American researchers, who report on simulator and naturalistic driving studies. Little research has considered the consequences of fully automated driving, with most focusing on lane-keeping and speed-control systems individually. The studies reveal two underlying design philosophies: automate driving versus support driving. Results of several studies, consistent with previous research in other domains, suggest that the automate philosophy can delay driver responses to incidents in which the driver has to intervene and take control from the automation. Understanding of how to orchestrate the transfer or sharing of control between the system and the driver, particularly in critical incidents, emerges as a central challenge. Designers should not assume that automation can substitute seamlessly for a human driver, nor can they assume that the driver can safely accommodate the limitations of automation. Designers, policy makers, and researchers must give careful consideration to what role the person should have in highly automated vehicles and how to support the driver if the driver is to be responsible for vehicle control. As in other domains, driving safety increasingly depends on the combined performance of the human and automation, and successful designs will depend on recognizing and supporting the new roles of the driver.

Haptic steering direction guidance for pedestrian–vehicle collision avoidance

Author(s): Itoh, Makoto;[1] Inagaki, Toshiyuki;[1] Tanaka, Hiroto[2]
Year: 2012
Source: Conference Proceedings, 2012 IEEE International Conference on Systems, Man and Cybernetics, pp. 3327–3332
Publisher: IEEE
Author affiliations:
[1]Faculty of Engineering, Information and Systems, University of Tsukuba, Tsukuba, Japan, http://www.sie.tsukuba.ac.jp/english
[2]Graduate School of Systems and Information Engineering, University of Tsukuba, Tsukuba, Japan, http://www.sie.tsukuba.ac.jp/english

The authors discuss an assistance system that momentarily adds tiny torque to the steering wheel to help the driver choose the direction for avoiding collision with a pedestrian. To investigate the effectiveness of the system, the authors conducted an experiment with a medium-fidelity driving simulator. The results of the experiment showed that there existed situations where the system was effective to enhance the driver's appropriate selection of steering direction. In addition, the system reduced driver reaction time significantly; however, there were cases in which the driver completely disagreed with the system's proposal. To make such a system acceptable to drivers, drivers' ways of choosing a direction should be taken into account.

An adaptive driver support system: User experiences and driving performance in a simulator

Author(s): Dijksterhuis, Chris;[1] Stuiver, Arjan;[1] Mulder, Ben;[1] Brookhuis, Karel A.;[1] De Waard, Dick[1]
Year: 2012
Source: Human Factors: The Journal of the Human Factors and Ergonomics Society, vol. 54, no. 5, pp. 772–785
Publisher: SAGE Publications, Inc.
Author affiliation:
[1]University of Groningen, Groningen 9712 TS, Netherlands, http://www.rug.nl/

The aim of this study was to test the implementation of an adaptive driver support system. Providing support might not always be desirable from a safety perspective, as support may lead to problems related to a human operator being out of the loop. In contrast, adaptive support systems are designed to keep the operator in the loop as much as possible by providing support only when necessary. A total of 31 experienced drivers were exposed to three modes of lane-keeping support: nonadaptive, adaptive, and no-support. Support involved continuously updated lateral position feedback shown on a head-up display. When adaptive, support was triggered by performance-based indications of effort investment. Narrowing lane width and increasing density of oncoming traffic served to increase steering demand, and speed was fixed in all conditions to prevent any compensatory speed reactions. Participants preferred the adaptive support mode mainly as a warning signal and tended to ignore nonadaptive feedback. Furthermore, driving behavior was improved by adaptive support in that participants drove more centrally, displayed less lateral variation, and drove less outside the lane's delineation when support was in the adaptive mode compared with both the no-support mode and the nonadaptive support mode. A human operator is likely to use machine-triggered adaptations as an indication that thresholds have been passed, regardless of the support that is initiated. Therefore, supporting only the sensory processing stage of the human-information processing system with adaptive automation may not feasible. These conclusions are relevant for designing adaptive driver support systems.

REFERENCE RESULTS: ORGANIZATIONS AND RESEARCHERS

Modeling of a haptic shared control system: Application to lateral control of car

Research Institution: Delft University of Technology, Faculty of Aerospace Engineering, 2628 CD Delft, Netherlands, http://www.lr.tudelft.nl/en
Author: Mulder, Mark
Technical Contact: Abbink, David
http://www.lr.tudelft.nl/en/organisation/departments/control-and-operations/control-and-simulation/organisation/staff-members/mark-mulder/master-assignments/modeling-of-a-haptic-shared-control-system/

The goal of this research is to determine a haptic shared control system that is based on models of human steering interaction. There is a need to determine, or assume, which sensor input to the control system is suitable for conversion into haptic guidance. With this sensor input, the controller determines the optimal angle for the steering wheel such that the vehicle is steered toward its desired reference state. Based on the known steering wheel dynamics and assumed (static) neuromuscular properties of the human driver, the optimal angle yields a guidance force.

Proposed Haptic Shared Control System Architecture
Project Outline
Preliminary phase

1. Create research literature review on lateral control of cars: Which feedback variables do humans use?

2. Become familiarized with the control models that describe the human–machine interaction (MATLAB®).

3. Develop a simulation model with which to test different controllers.

4. Carry out simulations with model to test the influence of model parameters (from the controller, the steering wheel, and the neuromuscular system) on performance and control activity (MATLAB).

5. Present results to the Control and Simulation Group.

Final phase

1. Design a driving simulator experiment to test the controller in a more realistic setting based on the most promising controller parameters and parameter values.

2. Analyze the results of the experiment.

3. Write a report in the form of a paper and appendices.

4. Present final results.

Driving simulator test bed

Research Institution: University of Southern California, Ming Hsieh Department of Electrical Engineering, Ming Hsieh Institute, http://mhi.usc.edu/
Contact: Ioannou, Petros
http://mhi.usc.edu/about/news/2013/04/11/mhi-supports-driving-simulator-test-bed/

The driving simulator project will enable University of Southern California (USC) researchers to carry out studies on a variety of topics, including human factors, vehicle dynamics and interaction with drivers, impact on drivers of sensors and warnings, impact on drivers of different control techniques and automation, driver assistance systems, and information systems. The simulator developed for this research is improved by the use of computer science techniques to develop additional driving scenarios and visualizations. The driving simulator will be used for the research topics mentioned above, as well as for individual-directed research studies and projects. The simulator will be accessible to all members of the USC Electrical Engineering Department and (with permission and on a case-by-case basis) to students and researchers outside the department.

Activity 1: Safety Evaluation of Advanced Driver Attention Systems (ADAS)
The analysis of ADAS using an actual vehicle could be costly and dangerous, as subject drivers cannot ethically be subjected to dangerous driving situations; as a result, the use of driving simulators to assess the effectiveness of these systems is crucial. In this activity the researchers are developing vehicle-following and lane-changing scenarios in which different drivers will operate in conjunction with the Institute's version of ADAS, which will provide warnings regarding unsafe situations as well as directions as to when to change lanes or merge into traffic. The drivers' responses will be assessed for compliance and safety and used to modify and improve ADAS.

Activity 2: Truck Driving in a Platoon
Under this activity, the researchers plan to develop a driving environment that will be used to perform human factors tests associated with trucks in a platoon. In such situations they will study how truck drivers respond to joining and exiting a platoon. They will start with

manually driven trucks and progress to trucks that can be driven in the automated mode; in such cases, the driver response in switching between the manual and automated mode will be studied using the simulator.

REFERENCE RESULTS: WORKSHOP

SMC 2013 Workshop on shared control: Predict, Assist, and Assess Human Movements

Session Chair: Honghai Liu[1]
Keynote Speaker: Robert Riener[2]
Year: 2013
Meeting: IEEE SMC 2013: International Conference on Systems, Man, and Cybernetics, Manchester M60 2DS, United Kingdom, http://www.smc2013.org/programfc45.html?cid=361
Sponsor: IEEE
Presenter Affiliation:
[1]School of Computing, University of Portsmouth, Portsmouth P01 2UP, United Kingdom, http://www.port.ac.uk/school-of-computing/staff/professor-honghai-liu.html
[2]Sensory-Motor Systems Laboratory, ETH Zürich, Zentrum, 8092 Zurich, Switzerland, http://www.sms.hest.ethz.ch/

Mechatronic systems and their clinical applications play an increasingly important role in neuroscience and neurorehabilitation. Novel technical systems are being developed—or are, in some cases, already in regular clinical use—within the different therapeutic phases of this field of research, which range from diagnostic neuroimaging via neurosurgical technologies to therapeutic treatments in the acute, subacute, and chronic stages of neurorehabilitation. The presenter focused on different types of interaction technologies that will allow future rehabilitation robotic systems to (1) detect motion intention that will support patients in an intuitive way during therapy, (2) assist patients as needed during the performed patient movements of a therapy session, and (3) quantitatively assess the motor functions of patients during and after a therapy session. As part of this research, one way to engage human subjects in a movement task is to let the assisting robotic system estimate the subject's movement intention and support the subject continuously during his freely chosen task rather than imposing upon the subject a predefined robotic action. The researchers developed a method for predicting targets of human reaching motions that uses different sensing technologies, such as electroencephalography, electrooculography, camera-based eye tracking, electromyography, hand position, and an estimate of the subject's personal preferences. Supervised machine learning was used to make predictions at different points in time (before and during the motion), with each individual sensor and with various combinations of sensors. Furthermore, during the movement therapy, audiovisual displays and rendering methods were used to present a virtual environment to the subject and allow the subject to perform games, virtual functional tasks, or virtual activities of daily living. For purposes of this research, the human subjects were integrated into the robotic system not only to provide a biomechanical view but also to monitor psychophysiological effects. Psychophysiological integration involves recording and controlling the subject's physiological reactions, so that the subject receives appropriate stimuli and is challenged in a moderate but engaging way without causing the subject undue stress or harm. Last, assessment routines integrated into the robotic training can enhance patient diagnosis, quantify the progress of therapy, identify patient impairment level, and adapt a patient therapy program to optimize therapy outcomes, which will eventually contribute to an optimization of a patient's rehabilitation. Different robot-assisted assessment routines were presented that have been implemented into different training devices that allow objective and quantitative evaluation of biomechanical functions in patients with neurological deficits (e.g., deficits that have occurred as a result spinal cord injury or stroke). This talk presented several virtual reality display methods and psychophysiological recording and assessment strategies that have been implemented and tested on different rehabilitation devices, such as the actuated gait orthosis Lokomat® and the arm therapy device ARMin.

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