19th IEEE International Symposium on Robot and
Human Interactive Communication
Principe di Piemonte - Viareggio, Italy, Sept. 12-15, 2010

Robotic Arm for car dashboard layout assessment in Mixed Reality Environment

Giandomenico Caruso and Paolo Belluco*

Abstract

Mixed Reality (MR) technologies allow us to create different environments, by merging real and virtual objects, and can be successfully used for the assessment of industrial products during the product development phases. This paper describes the integration of a MR environment including an industrial robotic arm for the ergonomics assessment of the driving seat in the automotive field. The robotic arm has been used to configure the MR environment automatically while guaranteeing the correct merging between real and virtual objects and the repeatability of the testing sessions. The user's presence, near an industrial robot, arises some issues on the safety and on the human-robot interaction that we have been addressed in order to improve the performing of the ergonomic test. Finally, the developed system has been validated through some testing sessions with end users to verify the effectiveness of our solution.

1. INTRODUCTION

The development of an industrial product implies the performing of different evaluation tests necessary for optimizing the final product. In particular, the data acquired during an evaluation test with the end users can determine the commercial success of a product. These tests, where the interaction of humans with the designed products is validated, are complex: ergonomics, reachability, usability are just few examples of issues investigated before making the final product available on the market.

Automotive industries are strongly interested in such types of issues, and in particular in those concerning the development of the driver's cab. Nowadays, two ways are used to evaluate the quality of a driver's cab: creating a physical prototype of the vehicle or using a driver's cab simulator, named seating buck. The first solution is very expensive and does not enable us to perform comparative tests among different cab configurations. The seating buck, instead, is a configurable structure that, coupled with Virtual Reality (VR) technologies, enables the simulation of different driving seat set-ups. The main application area of the seating buck is related to ergonomics studies that are performed to reduce tiredness and stress during driving by evaluating comfort conditions such as, habitability, accessibility, visibility and reachability of the dashboard. The automotive seating bucks allow simulating many vehicles interior to study different adjustments of primary driver controls, such as seat, steering wheels, pedals, gear shifter, etc.

Many research groups and industrial research centers use these kinds of systems to simulate the car interior and to perform visibility and ergonomic analysis of the driving seat [11, 17, 20, 23]. However, most of these systems provide only the possibility to set the configuration of the driver's seat, pedals and steering wheel while it would be interesting to simulate also the dashboard with its knobs, buttons, display and other control systems. Besides, it would be very useful to provide the possibility to configure in real time the dashboard in order to compare different layout solutions by performing several tests. Another limit of these seating-buck systems is related to the visualization and interaction issues. Actually, when the user is immersed in a virtual reality environment, the perception of real objects, which are present in the scene, is distorted. Obviously this issue has a negative impact when the seating-buck system is used to perform ergonomics and usability evaluations. For these reasons, the trend for seating-buck systems is to integrate physical objects in the virtual scene and to develop, de facto, the so-called Mixed Reality (MR) environment [9]. The sense of touch, given by physical objects, is effective when the computer-generated imagery is accurately registered and superimposed. Our MR environment aims at addressing and solving these issues by integrating an industrial robotic arm that is

*G. Caruso and P. Belluco are with Departement of Mechanical Engineering, Politecnico di Milano, 20156 Via La Masa 1, Italy. giandomenico.caruso@polimi.it, paolo.belluco@mecc.polimi.it

978-1-4244-7990-0/10/$26.00 ©2010 IEEE

used to configure the MR environment automatically by guaranteeing the correct merging between real and virtual objects and the repeatability of every testing session. In particular, the robotic arm is used to manipulate a physical prototype of car dashboard and a haptic device that simulates the behavior of the dashboard knobs. In addition, the robotic arm enables us to collect evaluation data, related to the users preferred positions, that are very important for the approval of a new driver's dashboard layout. In the next sections, we describe the hardware and software implementation of our MR environment and the results of evaluation tests that we have performed in order to validate the correct functioning.

2. BACKGROUND

The use of a robot coupled with VR technologies introduces various issues related to the Human-Robot Interaction (HRI). Principally, robots coupled with VR technologies are used for developing teleoperating systems, e.g. in surgical telerobotics, in high-dangerous environment or for manipulating hazardous products [13]. In these situations, the robot simulates the human presence of the operator, who controls it remotely, while VR technologies provide a synthetic representation of the operative conditions where the robot is operating. A typical example of this HRI is provided by the haptic devices, which can simulate the physical presence and the behavior of virtual objects. Another example of synergy between robots and VR is the motion simulator, useful in different tasks, such as the well-know flight-simulator and for the research on multi-sensory perception in virtual environments [22].

In the research field of product development, the haptic devices enable the researchers to perform better and with more effectiveness some tests in VR environment related to ergonomics, usability and assembly of the industrial products [8]. An example is the VADE (Virtual Assembly Design Environment), where Jayaram S. et al. developed a VR-based engineering application that allows engineers to plan, evaluate, and verify the assembly of mechanical systems [14]. Haptic devices are used also to help the robot operator during the performing of its tasks by providing a force feedback that simulates the robot behavior [21, 6, 18].

Different is the situation where humans have to interact directly with a robotic system, as in our case, where the robot becomes active part of the MR environment. In this situation it becomes fundamental to take into account the human safety. During the robot's tasks execution, humans have to be within the robot's working space, where unintended operations could result in injuries. For this reason, a real-time control of

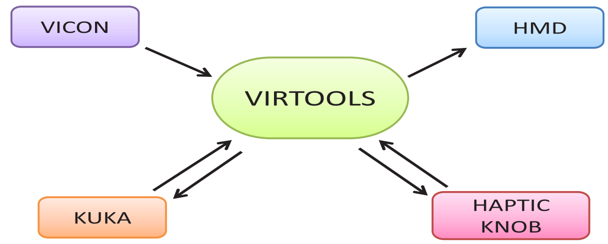

Figure 1. Graph of the main hardware and software components of our MR Environment.

the robot is needed. Different strategies are studied in order to avoid possible accidents or woundings. Kulić and Croft proposed a real-time trajectory generation using a dangerous index calculated on factors affecting the potential collision between human and robot [16] or using a methodology for integrating sensor-based information about the user's position and physiological reaction to the robot into medium and short-term safety strategies [15].

3. MR ENVIRONMENT

Our MR environment consists of different hardware and software components that we have integrated for enabling the end user to correctly interact with the simulated driver's cab, as shown in Figure 1.

The visualization of the interior of the vehicle has been implemented by using the Optical See-Through Head Mounted Display (OST-HMD) nVisor ST [2]. The use of this HMD allows the simultaneous visualization of both virtual and physical objects. The user will continue to see himself inside the scene; this condition increases his sense of presence within the environment. In order to improve the visualization of the arm of the user we have used a lighting system directed onto the subject. This contributes to increase the occlusion of the virtual objects with the real ones when it is necessary.

The virtual representation of the driver's cab components must be registered with the real ones. For this reason, it is necessary to use a tracking system in order to obtain the user's head tracking and the registration of the seating buck in the MR environment. We have used the VICON 460 optical motion capture system [5] equipped with 6 infrared cameras.

The robotic arm, which we have been used, is the industrial manipulator KR3 from Kuka Robotics [3]. It is a 6-axes robotic arm with a payload of $3Kg$, repeatability of $\pm 0,05mm$ and a work envelope volume of $0,679m^3$. KR3 is managed by an external control box named KRC, where the Windows XP™Embedded operating system is installed.

The end-effector, which we have used for a fast lock of our equipments, is an electromagnet (MAX. payload $40Kg$) activated by the host computer. In the set-up of our tests, the robotic arm carries, alternatively, a haptic device and a dashboard prototype manufactured through a rapid prototyping technique.

The haptic device is the new version of the haptic knob developed by our research group [12]. It is a device with 1 Degree Of Freedom (DOF), which allows the simulation of a real mechanical knob. The knob is connected to a control unit that reads the information from the knob and generates the voltage required to obtain the proper haptic feedback. The haptic feedback is defined both in terms of step numbers, rotation interval and torque, which can be constant or variable as desired.

The software used to develop our MR environment is the 3DVIA Virtools software [1]. This software is a development platform widely used in industrial fields for the development of interactive 3D applications. It is natively capable of integrating different third parts hardware components by visual programming, named building blocks, and gives the possibility to add new ones. In particular we have developed two new building blocks in order to connect our haptic knob and the KR3.

The software running on the Kuka KR3 has been developed by using the proprietary language *KRL*™ (*KUKA Robot Language*). *KRL*™ is a programming language that provides the commands to move the mechanical arm by using common control- flow statements (e.g. *IF*, *WHILE*, *DO-WHILE*, *LOOP*) and it gives the possibility to create sub-routines in order to simplify and make more comprehensive the program code. The communication, with remote computer, is provided by a specific module named *KUKA Ethernet KRL XML*™*(v. 1.1.0)*, which has to be integrated in the *KRL*™ code.

3.1. Seating Buck

The fundamental part of our system is certainly the seating buck that we home-made developed in order to obtain a configurable structure suitable for our purposes. The major requirements were the development of a flexible structure allowing us to represent different types of vehicle and the possibility of optimizing the design process of driver's cab layout. The seating buck is made up of four modules: the skeleton module, the pedals module, the steering wheel module and the seat module (Figure 2). The skeleton is a simple frame where all the other modules and the principal elements have been hooked together. We decided to configure each part of the seating buck starting from the seat position, which is provided with the vertical translation only. Therefore

Figure 2. The developed seating buck with its main modules: skeleton module, pedals module, the steering wheel module and the seat module.

the pedals apparatus replaces the longitudinal translation of the seat, by moving it near to far from the seat. The whole apparatus takes advantage of the particular shape of the profile of the skeleton as rails on which the footrest slides. In addition each pedal, which is mounted on the footrest frame, is provided with one DOF: the rotation in the x-z plane. Thus, it is possible to set the angle of the pedals. The steering-wheels present four DOFs, three for translations and one for rotation in the x-z plane. As regards the seat, we have developed an actuated mechanism, based on the Scott-Russel mechanism [19], in order to simply manage the vertical DOF of the seat.

3.2. Software Implementation

The aim of our software implementation is to integrate all the above-described hardware and software in order to make automatic and safe the configuration of MR environment during the testing sessions.

The MR environment assumes that the user's point of view is tracked according to the virtual objects, which have to be superimposed on the corresponding real ones. The tracking, as said before, is provided by the Vicon tracking system that is able to recognize and track different maker-sets, which we set on the OST-HMD, on the right user's wrist and on the steering wheel. All the tracking data refer to the origin of the Vicon, which can be positioned inside the control volume. For convenience, we set the origin on the back-right edge of the seating buck skeleton module (Figure 3). The coordinates of the different components, which are transferred to the Virtools by Ethernet connection, are used to manage position and orientation of the virtual camera, according to the user's point of view, and position and orientation of virtual steering wheel, according to the real one.

Subsequently, we needed to control and monitor the robot functioning through Virtools. For this reason, we have developed a new building block, written in C++, thanks to which it is possible to retrieve information, from the KRC controller, about robot axes, position and orientation of the end-effector and, furthermore, it is possible to send commands for moving the KR3 in pre-registered positions or according to the user's preference. In particular, to define a preferred position, the user moves the virtual representation of the knob in a new position by using his tracked hand. During the movement, the user sees a ghost-image of the knob that is useful to compare the new position with the older one. When the user finishes the definition of his preferred position, the robot moves its end effector to this position.

The building block communicates with the KR3 through a software that we implemented on the KRC by using the *KRL*™language. At first, the software initializes the robot, then moves the KR3 in its *HOME* position and finally initializes, as a client, the Ethernet connection, with the application server developed into our Virtools building block. Now, the KR3 is waiting for external commands formatted into a specific XML schema. The XML message mainly consists of four elements: the first is a number, which identify the functions implemented in the code, while the other elements are the arguments of these functions. To stop remotely the robot during its movement, we have created a so-called *INTERRUPT* function that is able anytime to abort each activity of KR3.

Figure 3. The virtual representation of our MR environment, with coordinate axes and virtual human simulation.

Table 1. The fields of the three tables of the database.

User's info	*user-defined* phase	*validation* phase
ID	ID	ID
Profession	Dashboard Position	Dashboard Pos#1
Height	Knob Step	Dashboard Pos#2
Weight	Knob Torque	Hapt.Be#1 Pos#1
Age	Knob End-Stop	Hapt.Be#2 Pos#1
Glasses		Hapt.Be#1 Pos#2
Gender		Hapt.Be#2 Pos#2

The origin of the KR3, obviously, is different from the origin of our MR environment, since the KR3 is mounted on a mobile separate module. Consequently, we elaborated a calibration procedure in order to set the robot's root origin, according to the origin of the environment. The calibration procedure consists in acquiring the coordinates of a calibrated frame fixed on the center of the end-effector while it is moved by the KR3. The acquired data are subsequently elaborated to define the transformation matrix that converts the coordinates of the end-effector according to our system's origin. This procedure is needed only if the KR3 module is moved or when the tracking system needs to be re-calibrated.

Another building block was developed for controlling the haptic knob in order to manage the devices directly by Virtools. This building block allows us to set the behavior of the device (torque, number of steps, end-stop) and for acquiring in real time the value of the knob angle in order to move the virtual representation of the knob according to the physical one.

Moreover, we used Virtools also to populate automatically the database, developed using MySQL, to manage the data of a testing session. The database, updated through XML message, is divided into three tables: the first table collects information about the user, the second and third tables collect data acquired during the testing sessions (Table 1). The information about users, registered before the testing session, refers to: unique ID (the primary key), profession, height, weight, age, if the user wears glasses or not and gender. The data collected during the testing session are related to the preferred behavior for the haptic knob and the user-defined dashboard position.

The second table of the database collects the data during the testing session that we called *user-defined* phase (see the next section). The first field is the unique ID of the user, the second field is the user-defined position of the dashboard, the third field is the number of steps in a complete round of the knobs, the fourth field is the torque selected for the haptic knob behavior and the fifth field is the position of the end-stop.

The third table of the database collects the data about the layouts proposed during the testing session that we called *validation* phase. The first field is the unique ID of the user, the second and third fields are the evaluation values about the two proposed positions for the dashboard, and the last four fields are evaluation values about the combination of haptic behaviors and positions. All these values vary from 1 to 10.

3.3. User's safety

Using an industrial robot and at the same time in the same space where users operate and move their hands, involves an issue about the user's safety. It is very important that the robot during its movement does not collide with the seating-buck structure and, above all, with the user. To avoid this situation, we have planned different safety measures.

At first, before the execution of the test, we simulated the movement of the KR3 robot within the Virtools environment by using virtual human (see Fig 3). The simulation consists in checking if the path of the KR3, during the automatic positioning of our equipments (dashboard prototype and haptic knob), interferes with the virtual human. The movement of the virtual representation of the KR3 in Virtools is calculated by acquiring the joint position from KRC controller during a user-less test session cycle.

During the testing session, the user wears a marker-set put on his wrist. This marker-set is used to calculate position and orientation of a volume, which we called *hand-volume*, that is accounted as a rectangular cuboid (50×30×30 cm^3). If this volume collides with the volume regarding the working space of the KR3, Virtools sends a command to stop immediately any movement of the robot, with the same function of dead-man's switch button. In Figure 4, the representation of the two volumes is shown.

Finally, to improve the overall system safety, we have reduced the maximum speed of the KR3 to 10% of its velocity and two emergency buttons are located near the operator and the user.

4. EVALUATION TEST

The aim of the evaluation test is to assess the feasibility and the effectiveness of the integration of an industrial robot in our MR environment. The evaluation test consists in the definition of the best dashboard layout, which means the most ergonomic and the most usable position of the dashboard and the most comfortable behavior of the dashboard knob. The test is divided in two different phases: the *user-defined* phase and the *validation* phase. The *user-defined* phase consists in collecting and storing in the database, the user's preference about the position of the dashboard and the behavior of the haptic knob. The *validation* phase consists in the user's evaluation of some layouts that are elaborated starting from the data collected in the previous phase.

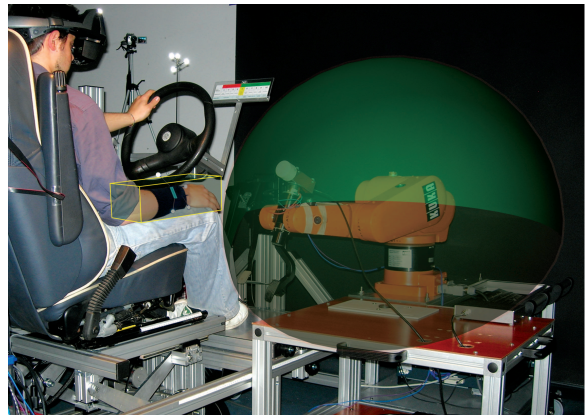

Figure 4. The representation of the safety volumes during a testing session.

4.1. *User-defined* phase

During the *user-defined* phase, users can see the starting position of the knob and original shape of the dashboard through the OST-HMD. When the user chooses a new position, a ghost-image of the current position of the dashboard overlaps the original one. The population of the users, which have been involved, consists of 40 people, 30 male and 10 female, and is composed by students and researchers from 25 to 35 years old and with a height between 160 and 185 *cm*. A session of the *user-defined* phase was performed as follows:

- KR3 picks up the dashboard prototype and carries it near the user;
- User demands to the external robot operator to move the dashboard prototype;
- User evaluates different positions;
- KR3 picks the haptic knob and carries it in the position defined before;
- User evaluates different haptic behaviors (torque, step and end-stop);
- Database is automatically updated by Virtools.

The time for every testing session cannot exceed 20 minutes since we observed, during other similar tests [10, 7], that the user feels some discomfort due to the weigh of the OST-HMD. At the end of the *user-defined* phase, the collected data have been elaborated to create the dashboard layouts that have to be definitively evaluated by the users in order to define the best one.

4.2. *Validation* phase

During the *validation* phase, users have to evaluate the dashboard layouts elaborated starting from the data collected in the *user-defined* phase. We have estimated that the right number of layouts had to be limited to two since, as said before, the time of every session does not exceed 20 minutes. The data collected during the *user-defined* phase have highlighted that the preferred position of the dashboard is related to the height of the users while the preferred haptic behavior has no relationship with other physical aspects of the users. Consequently, we have divided the population of the users in two samples according to the median value of the height, which is 170 *cm* and, subsequently, we have calculated the two median values of the positions relative to the two samples and we have used them as the positions of the two layouts. For the definition of the best haptic behavior, instead, we decided to evaluate the two haptic behaviors values that appear more frequently in the collected data. The population of the users, which have been involved in this phase, is the same of the *user-defined* phase. A session of the *validation* phase was performed as follows:

- KR3 picks up the dashboard prototype and carries it alternatively in the two positions;
- User evaluates the two positions;
- KR3 picks the haptic knob and carries it alternatively in the two positions;
- User evaluates two different haptic behaviors in the two positions alternatively.

For each evaluation, the user gives a judgment according to a table based on the SAE [4] settlements. The table, which is positioned on the seating buck in front the user, is a graduate scale with values from 1 to 10 that summarize the comfort felt by the user. All judgments are collected in the database for subsequent syntheses.

5. DISCUSSION

The use of an industrial robotic arm in MR environment arose several issues during the integration. The programming language used by the KR3 is not very practical to control and monitor the robot functionalities remotely and in particular for our interactive simulation the presence of a robot operator is fundamental yet. This programming language not allows multitasking and/or multi-threading operations, consequently it is difficult to handle subroutines that perform operations concurrently with the main part of the code. Sometimes, the linear interpolation, which we used to define the point-to-point trajectory from user's preferences, generates a path that puts the joints outside the dexterous workspace of the robot. The choice of the best point-to-point interpolation could reduce sensibly the robot fails and the user could move the robot farther than now it is possible. The calibration of the whole system is still a delicate and time-consuming phase since it involves some activities that are carried out manually for better performing the simulation. These activities are mainly related to the definition of the trajectories that the robot has to follow for the automatic configuration of the system.

The complete and quick reconfigurability of our system allowed us to perform several tests in order to evaluate the different issues related to the dashboard layout such as reachability, visibility and perceived comfort. The evaluation test has been carried out correctly and safety problems have not been observed. Moreover, thanks to the limited time dedicated to each session, the users did not suffer discomfort due to the use of the OST-HMD.

The use of the robot enabled us to automatically populate the database, with the positions preferred by the users, and these data have been very useful to define the two layouts for the final evaluation. The repeatability of the KR3 enabled us to carry out the *validation* phase correctly and in short time and, at the end of this phase, we were able to identify the best dashboard layout by analyzing the users' judgments collected in the database. These data may be useful also to study the relations between the user's layout preferences and the information about the user's profile, such as height, gender, age and so on.

It is important to observe that our system improves the classical ergonomic analysis approach in VR by demonstrating how an industrial robotic arm can be used as an I/O interactive device for MR environments.

6. CONCLUSIONS

This paper has presented the integration of a 6DOF industrial robot manipulator in a MR environment in order to study the best layout for car cabin. In particular, we are interested in the definition of the best positioning of the car dashboard and the best force feedback of the dashboard knob. The robot has been used to set the position of the dashboard, in our MR environment, according to the user's preferences. The evaluation test has demonstrated the feasibility and the effectiveness of our evaluation method based on the use of an industrial robotic arm in MR environment. The interaction between the user and the end effector of the robot enable us to capture the user's preferences effectively and objectively. These kinds of assessments, performed with our system, could allow assessing important data, relating to the ergonomics of the dashboard, during the preliminary and conceptual phases of dashboard development without creating any kind of physical prototype. In the next future, we intend to extend our system and our methodologies to the assessment of ergonomics and usability aspects of systems not only in the automotive field, but also in different areas, by improving the interaction between the user and the robot.

7. ACKNOWLEDGMENTS

The authors gratefully acknowledge Niccolò Passolunghi and Samuele Polistina for their technical support. The research work presented in this paper has been supported by the Italian Ministry of University and Research, in the frame of FIRB-PROGIMM project (http://www.kaemart.it/progimm).

References

[1] 3dvia VirTools. *http://www.3ds.com/products/3dvia/3dvia-virtools/welcome/*.

[2] nVisor ST. *http://www.nvisinc.com/*.

[3] KUKA KR3. *http://www.kuka-robotics.com*.

[4] SAE: Society of automotive engineers. *http://www.sae.org/*.

[5] Vicon. *http://www.vicon.com*.

[6] D. Barnes and M. Counsell. Haptic communication for mobile robot operations. *Industrial Robot: An International Journal*, 30(6):552 – 563, 2003.

[7] M. Bordegoni, G. Caruso, and F. Ferrise. Mixed-reality environment based on haptic control system for a tractor cabin design review. In *CIRP Design Conference*, Enschede, April 7-9, 2008.

[8] M. Bordegoni, U. Cugini, P. Belluco, and M. Aliverti. Evaluation of a haptic-based interaction system for virtual manual assembly. In *Virtual and Mixed Reality*, volume 5622, pages 303–312. Springer Berlin / Heidelberg, 2009.

[9] M. Bordegoni, U. Cugini, G. Caruso, and S. Polistina. Mixed prototyping for product assessment: a reference framework. *International Journal on Interactive Design and Manufacturing*, 3(3):177–187, 2009.

[10] M. Bordegoni, U. Giraudo, G. Caruso, and F. Ferrise. Ergonomic interactive testing in a mixed-reality environment. In *Virtual Reality*, volume 4563, pages 431–440. Springer Berlin / Heidelberg, 2007.

[11] F. Caputo, G. D. Gironimo, G. Monacelli, and F. Sessa. The design of a virtual environment for ergonomic studies. In *Proceedings of ADM International Conference*, Rimini, 2001.

[12] G. Colombo, F. De Angelis, and L. Formentini. A mixed virtual reality - haptic approach to carry out ergonomics tests on virtual prototypes. In *Proceedings of TMCE*, Ljubljana, Slovenia, April 18-22, 2006.

[13] M. A. Goodrich and A. C. Schultz. Human-robot interaction: a survey. *Found. Trends Hum.-Comput. Interact.*, 1(3):203–275, 2007.

[14] S. Jayaram, U. Jayaram, Y. Wang, H. Tirumali, K. Lyons, and P. Hart. Vade: A virtual assembly design environment. *IEEE Computer Graphics and Applications*, 19:44–50, 1999.

[15] D. Kulić and E. Croft. Pre-collision safety strategies for human-robot interaction. *Auton. Robots*, 22(2):149–164, 2007.

[16] D. Kulić and E. A. Croft. Real-time safety for human-robot interaction. *Robotics and Autonomous Systems*, 54(1):1–12, 2006.

[17] M. Moehring, A. Gloystein, and R. Doerner. Issues with virtual space perception within reaching distance: Mitigating adverse effects on applications using hmds in the automotive industry. In *Proceedings of IEEE Virtual Reality Conference*, pages 223–226, 2009.

[18] C. Peña, R. Aracil, and R. Saltaren. Teleoperation of a robot using a haptic device with different kinematics. In *EuroHaptics '08: Proceedings of the 6th international conference on Haptics*, pages 181–186, Berlin, Heidelberg, 2008.

[19] J. Rao and R. Dukkipati. *Mechanism and Machine Theory*. New Age International, 2nd edition, 2009.

[20] H. Salzmann and B. Froehlich. The two-user seating buck: Enabling face-to-face discussions of novel car interface concepts. In *Proceedings of IEEE Virtual Reality Conference*, pages 75–82, 2008.

[21] A. Shirinov, J. Kamenik, and S. Fatikow. Haptic interface for a nanohandling robot. *Assembly Automation*, 24(1):78 – 87, 2004.

[22] H. J. Teufel, H. G. Nusseck, K. A. Beykirch, J. S. Butler, M. Kerger, and H. H. Bülthoff. Mpi motion simulator: Development and analysis of a novel motion simulator. In *Proceedings of the AIAA Modeling and Simulation Technologies Conference and Exhibit*, pages 1–11, Reston, VA, USA, 08 2007.

[23] O. Toshikazu, K. Tsuyoshi, Y. Hiroyuki, and T. Hideyuki. A mixed reality system with visual and tangible interaction capability - application to evaluating automobile interior design. In *Proceedings of 2nd IEEE/ACM International Symposium on Mixed and Augmented Reality*, 2003.