Combining Virtual Reality (VR) Technology with Physical Models – A New Way for Human-Vehicle Interaction Simulation and Usability Evaluation

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Abstract. With the popularity of virtual reality technology, it has already been wide applied in the current automotive industry. However, most of these applications are aimed at the consumer market, and remain to provide the consumers with a method to have an overall experience of the vehicle visually. Based on the development of the automotive industry and the virtual reality technology, this study attempts to utilize the current popular virtual reality technology to solve the contradiction between the increasingly complex technologies applied in the automotive and the gradual shortening design and development cycle of the automotive due to market pressure. This study innovatively combines virtual reality technology and physical model, produces a virtual model in the virtual reality environment with the 1:1 size in real world, and uses the car seat, the steering wheel and the physical air-conditioning button model with 3D printing to produce the preliminary simulation test bench for human-vehicle interaction. After analyzing the completion time and the operational validity of the participants' same interactive operations on the test bench and in the real car, the thesis preliminarily verifies the usability of the bench, and analyzes the advantages and disadvantages of it. The bench created by combining virtual reality technology and physical model can give the designers a better sense of immersion, and because of the addition of the physical model, the designers can evaluate their designs both visually and tactilely, with one more physical dimension. Besides, thanks to the advantages of virtual reality technology, the test bench of this study can achieve quick design update, provide the designers with more convenient solution comparison method, and can save a lot of time and money, which is a novel, concrete, and resource-saving design evaluation method with great application potentials.

Keywords: Human-vehicle interaction · Virtual reality · Evaluation

1 Background

Product development in the automotive industry is driven by a highly complex series of market requirements that stem from a wide range of product variants and functionalities. Stagnating sales volumes in traditional markets and increased competition are leading to both growing product diversification and reduced time-to-market processes

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[1]. Given the pressure on car companies to reduce time-to-market and to continually improve quality, original Equipment Manufacturer and suppliers have to develop more flexible assembly chains, manufacturing services and methods for job planning [2, 3]. In order to ensure the quality of cockpit design, the traditional method requires the production of a full-size physical prototype of cockpit, which is expensive and time-consuming. And it is hard to modify the physical prototype after it has been made, therefore a physical prototype is not suitable in the early phase of car development during which comparisons among various of versions and agile optimizations and iterations of design are involved. During the phase of car cockpit conceptual design, the responsible departments need to compare, evaluate, optimize and iterate different design plans. Design prototypes should be real enough in order to guarantee the quality of design evaluations, the prototype should also be easy to be modified to ensure the efficiency of the iterations. In respect of these needs during the early phrase of modern automobile development, traditional physical car cockpit prototypes are in a dilemma of increased technical complexity and decreased development period. Because of progressing digitization in the automotive industry, it is increasingly assessed using virtual 3D models [4]. The field of computer graphics is greatly increasing its overall performance enabling consequently the implementation of most of the product design process phases into virtual environments [5]. Virtual reality (VR) technology has the potential to make evaluations of computer-generated models possible in very early phases of the process, which could significantly reduce the number of required hardware mockups as well as the number of design iterations [6].

2 Current Research Status

2.1 Current Research of Automotive Design, Virtual Reality and Virtual Reality Applied in Automotive Design Industry

The academic background research of this paper will be carried out in three aspects, namely the traditional automobile design, virtual reality technology and its application in the automotive industry. The research on the traditional automobile industry is conducive to discovering the pain points and the blue ocean of virtual reality application. The research on virtual reality technology aims to figure out the current situation, functions and effects of virtual reality technology. Finally, the existing applications of virtual reality technology in the automotive industry will be learned about. A considerable number of scholars have conducted research in these three aspects (Table 1).

2.2 Virtual Reality

A complete virtual reality system consists of three modules, namely hardware system, interactive device and virtual content [11]. The hardware system supports the production and operation of virtual content. The interactive device is the bridge between the users and the virtual world. And the virtual content is the object directly perceived by the users. For the hardware system, firstly, there must be a high-performance

Table 1. Current research

Year	Author	Title	Main research content
2018	Winkelhake [7]	"Vision Digitised Automotive Industry 2030, in The Digital Transformation of the Automotive Industry: Catalysts, Roadmap, Practice"	This paper mainly discussed the tendency that established automotive companies are going to change into a comprehensive digitisation strategy and roadmap
2017	Stefania et al. [3]	"FCA Ergonomics Proactive Approach in Developing New Cars: Virtual Simulations and Physical Validation. in Advances in Applied Digital Human Modeling and Simulation"	In this paper, the authors have shown the approach used in FCA based on simulation methods and experimental facilities to analyse ergonomics aspects of future workcells
2017	de Clerk et al. [4]	"Interaction Techniques for Virtual Reality Based Automotive Design Reviews. in Virtual Reality and Augmented Reality"	In this paper, researchers investigated interaction techniques for the design assessment of automotive exteriors. The study results confirm that "Direct Touch" and "First Person" provide best overall quality with respect to these aspects
2017	Ihemedu-Steinke et al. [8]	"Virtual Reality Driving Simulator Based on Head-Mounted Displays, in Automotive User Interfaces: Creating Interactive Experiences in the Car"	As vehicles become more complex and connected, there is need to implement solutions that avoid and reduce any form of distraction to the driver. The application of DS is preferable to real-life experiments on the road because it is cost-efficient and enables rapid prototyping but most especially, it is a controlled environment and totally risk free for the users"
2014	Mihelj, Novak, and Begus [9]	"Introduction to Virtual Reality, in Virtual Reality Technology and Applications"	This article provides an overview of the history of virtual reality and briefly describes the main feedback loops used in virtual reality and the human biological systems used to interpret and act on information from the virtual world
2007	Guo, and Zhou [10]	"VR-Based Virtual Test Technology and Its Application in Instrument Development"	To supply a new approach for the solution of complex engineering test problems, this paper first gave a modified model of VR-based virtual test technology, and then discussed its application in instrument development

workstation system that can ensure the virtual world data can run smoothly in real time. Secondly, a software platform is necessary for building 3D virtual data, based on which, users can restore the real-world environment in the digital virtual world, or establish the world that is only imagined by people but does not exist in the real world. Furthermore, for a fully immersive experience in the virtual environment, extra control devices are necessary for an optimal interaction with virtual objects. These devices aid to navigate freely within the virtual world. For example, the Virtualizer (Cyberith 2014) aids to move freely (walk, jump, sit, and run) in the simulated world, tracking the position of head, hand, or the entire body [8]. For virtual content, there must be a virtual reality environment in the form of 3D data, whose content is what users can see visually. In the latest research, virtual reality is applied to test the efficiency of advanced driver assistance systems, verify the validity and assess the risk of autonomous vehicle algorithms, train simulation assembly in manufacturing industry and so on [12–14]. And it can be figured out in the research that the current virtual reality technology has reached a fairly high level of simulation, which is sufficient for a variety of simulation tasks.

Characteristics of Virtual Reality Technology in Automotive Design
There are five characteristics of the virtual reality technology applied in the automotive design industry, namely immersion, interactivity, imagination, flexibility and economy.

Immersion. It allows designers to immerse themselves in virtual cars and have almost the same experience in real cars. In the 3D car model created by the computer, everything inside and outside the car can be visible, audible, or touchable.

Interactivity. If virtual reality is to be realistic, it must respond to the user's actions; in other words, it must be interactive [9]. Designers could interact with cars in the virtual environment through the input and output of interactive devices to assess the rationality of the car's design plan.

Imagination. The production of physical models is often constrained by the real technologies. While, in the virtual environment, designers could get rid of the constraints of reality temporarily, use bolder ideas, and apply new, even immature, and still imaginary technologies to their own designs and show them.

Flexibility. The production of physical models requires a high time cost, and some designs may have been reversed during the production process. While the virtual models could be produced very fast, and the designers can select materials and set illumination according to different parts and feelings that need to be achieved. These modifications can be quickly reflected on the virtual models for comparison, analysis and improvement.

Economy. Although virtual design does not produce actual economic returns on it own, it will bring considerable economic benefits. In a usual 18-month molding cycle of a vehicle development project, it is necessary to produce the frames and interiors of several non-full-size or full-size data verification clay models, and color-texture verification models in all stages including option screening, modeling review, and data distribution [15]. By utilizing virtual design, the production cost of clay modeling in traditional development processes can be significantly reduced, and the time of modeling development can be saved.

Applications of Virtual Reality Technology

In *Simulation Sickness Evaluation While Using a Fully Autonomous Car in a Head Mounted Display Virtual Environment* by *Rangelova et al.* [16], the study used the virtual reality system to simulate the disease assessment in automated vehicles, and proposed the concept of HMD VR driving simulation (Fig. 1), using Unreal engine4 to create driving scenarios for the study (Fig. 2).

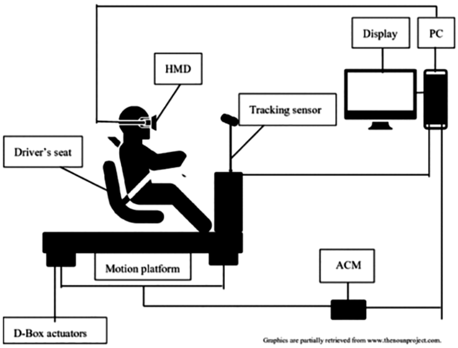


Fig. 1. Concept map of HMD VR driving

Fig. 2. Virtual scenario made by Unreal engine4

In 2015, EVOX Images launched a VR app "RelayCars" for consumers who want to buy a car, allowing users to experience almost all the latest cars on the market at home using their smartphones, tablets or VR helmets (Fig. 3), and the users can select the vehicles in the database of RelayCars, change the color, and view the stereo models from inside and outside.

Fig. 3. 3Relay Cars website show https://www.relaycars.com/

At the latest CES 2019 show, Unity demonstrated a real-time vehicle configuration solution (Fig. 4), in which users could select their favorite colors and interior style in 4S stores without having to communicate with salesmen by using mobile phones, VR devices or PCs.

Fig. 4. Real-time vehicle configuration function exemplified by Lexus LC 500 by Unity at CES 2019 show

As can be seen from the above examples, the virtual reality technology has been developed very mature, and it is possible for various research simulations, and the display of the models in the virtual environment has been able to achieve very realistic effects.

2.3 Advantages of Virtual Reality Technology in the Design and Evaluation Processes of Automotive

The application of Virtual Reality (VR) has been an important supporting method in human-vehicle interaction developments. During the design process of car cockpits, conducting human-vehicle interaction usability evaluations (usability means the validity of interaction processes and results, interaction efficiencies and user's satisfactions when a user is using a product to accomplish certain task in a certain environment) ahead of time can help designers to find perceived issues, reduce or even avoid revisions and realize the agile iteration cycle of "design-analyze-optimize".

2.4 Disadvantages of Virtual Reality Applied in the Design and Evaluation Processes of Automotive

In recent years there is a strong trend to leave the world of physical modeling as early as possible in the styling process and to create digital models even from the scratch. In consequence, industrial designers and deciders are losing the physical experience of the models [4].

Limited by invisibility of depth information and reduced size, common practice of visualization based on CAD 3D digital model is hard to be immersive enough to assess designer's and tester's real feelings and judgements. The applications of immersive VR techniques make the design evaluation more convenient by putting the designers and testers in a full-size 3D virtual car cockpit. However, purely virtual displays and interactions are not able to offer the reality of the real interactions with the product, VR peripheral devices will also distract the testers from the virtual car cockpit and thus interfere the reliability of car cockpit design evaluation.

Taking the perceived concerns above into consideration, a hybrid car cockpit simulation environment that combines VR display and physical models of operative parts is worth to be applied in human-car interaction usability evaluation. By touching and operating the physical models, testers can get real physical feedbacks. These physical models should:

1. Correspond with the size and shape of the certain operative parts that are displayed in the VR environment.
2. Be as modularized as possible in order to fulfill the need of design plan comparison, design iteration and saving budget.

Driven by computer hardware, advanced display and information technology, the applications of VR have been developed rapidly in recent years and thus provide decent technical condition for making car cockpit human-vehicle interaction simulation test benches. Such benches can reach a relatively high fidelity.

3 Methods

In order to verify the usability of the test bench built by combining virtual reality and physical model in the evaluation of the car design, that is, the spatial location and physical experience of the users of the bench can be close to the 1:1 cockpit physical model made with the traditional method, and even the real car, this study uses the user test method. The study uses a 2018 Mercedes-Benz E200L car as the experimental vehicle in control group, combines a virtual reality device and a physical model to build the test bench, selects the air-conditioning button as the example of this experiment, and demands the participants to perform the same operation in the actual vehicle and on the test bench. Finally, the measurers record and analyze the operation time of the participants, the operational validity, and the subjective feedback of the participants. The flow chart is shown in Fig. 5.

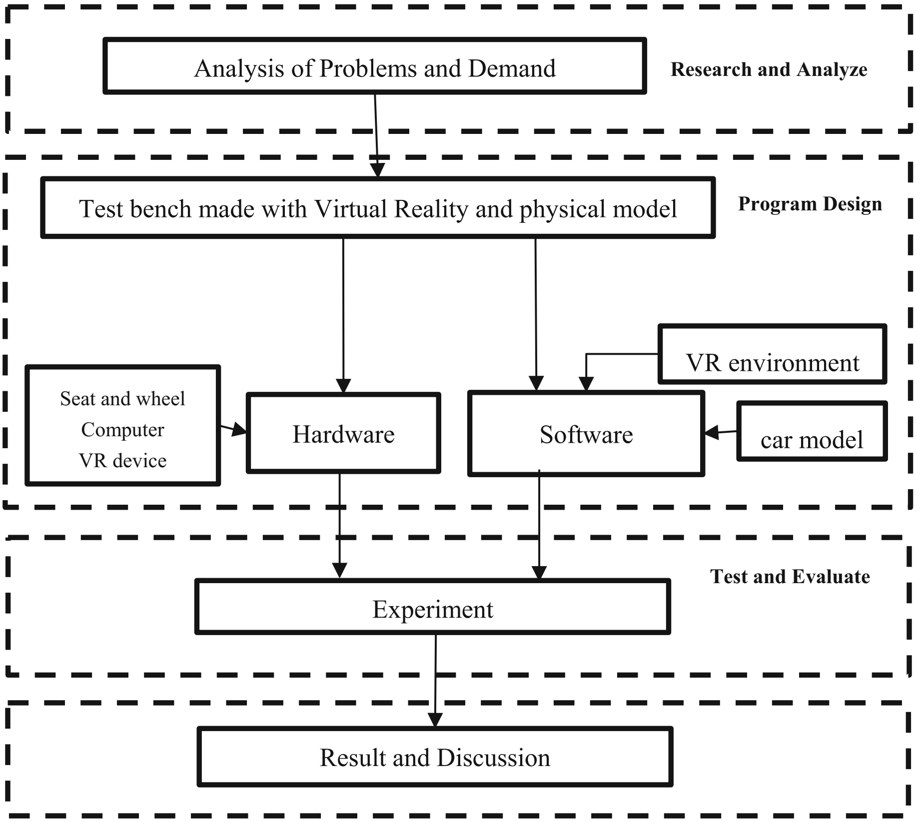


Fig. 5. Method and flow chart of the study

3.1 Establishment of Test Bench

A traditional PC and HTC vive virtual reality helmet are used as the hardware system for building virtual reality scenarios. First, the measurers build the virtual model with the 1:1 size of the frame and interiors of the real vehicle in 3d max and import it into Unity (Fig. 6).

The model is used to build a virtual reality scenario applicable for HTC vive in Unity (Fig. 7).

Meantime, in order to facilitate the subsequent research, the simulated driving bench consisting of Logitech G29 game steering wheel kit and real car seat is selected for the physical platform of the cockpit (Fig. 10).

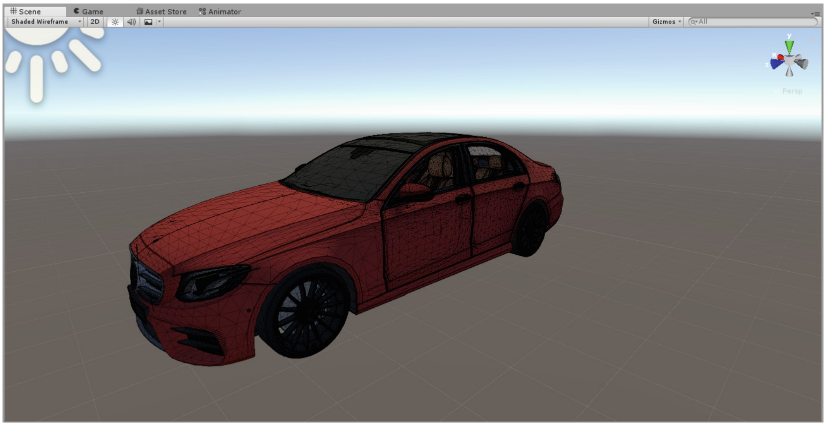


Fig. 6. Full-size model of 2018 Mercedes-Benz E200L

Fig. 7. Driver's vision in HTC vive

Since the example of the experiment is adjusting the air-conditioning button, as well as the advantages brought by the virtual reality bench, it is only necessary to produce the physical model of the air-conditioning button. The measurers make it with 3D printing method, as is shown in Fig. 8. Number 1–6 is the air-conditioning buttons controlling the six air-conditioners near the driver's seat.

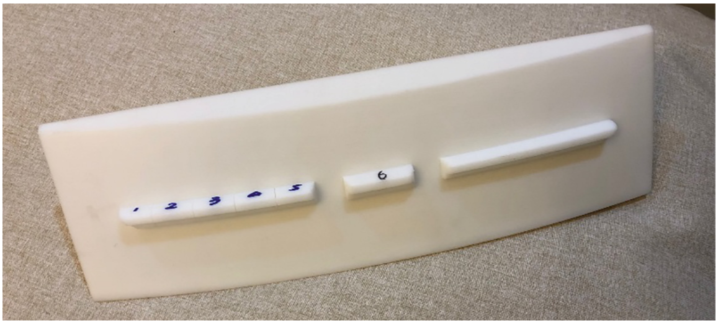


Fig. 8. Air-conditioning button model of Mercedes-Benz E200L by 3D printing

3.2 Participants

There are 12 participants in the study, aged between 21 and 27, 8 of whom are male, all having a driver's license, but none of them had ever driven this car.

3.3 Measures

The experiment takes the user test method. First, the participants are required to sit on the driver's seat in the real car and keep the hands on both sides of the steering wheel. The measurers first introduce the functions of each air-conditioning button to the participants, and after all the participants confirm that they understand the functions and keep them in mind, the measurers issue an instruction (the experiment demands the participants to touch the air-conditioner menu button Fig. 9), and the participants perform the corresponding operation, and then the measurers record the completion time of the operation with the stopwatch (touching the button is counted as the completion of the operation), and finally record the time and the operational validity (i.e. whether the participants touch the correct button) on the table.

Fig. 9. Demand participants to touch the menu button in the middle in the real car

Then, the participants are asked to sit on the test bench. Due to the limitations of the HTC vive hardware platform, the measurers replace the HTC vive handle with the hand model and fix it on the participants' hands. After putting on the device on the bench, each participant adjusts the relative position of the physical model of the air-conditioning button, and the hand model as well as the handle model in the virtual environment, to ensure that the position of the air-conditioning button seen by each participant in the virtual environment is consistent with that of the physical model in the real world. Then, the measurers issue the same instruction as in the control group, and record the operation time and the operational validity on the table. The experimental scenario is shown in Fig. 10.

Fig. 10. A participant carries out the experiment on the virtual reality test bench

Finally, the measurers interview and record the subjective feelings of the participants on the experiment.

4 Results

4.1 Data Analysis Results

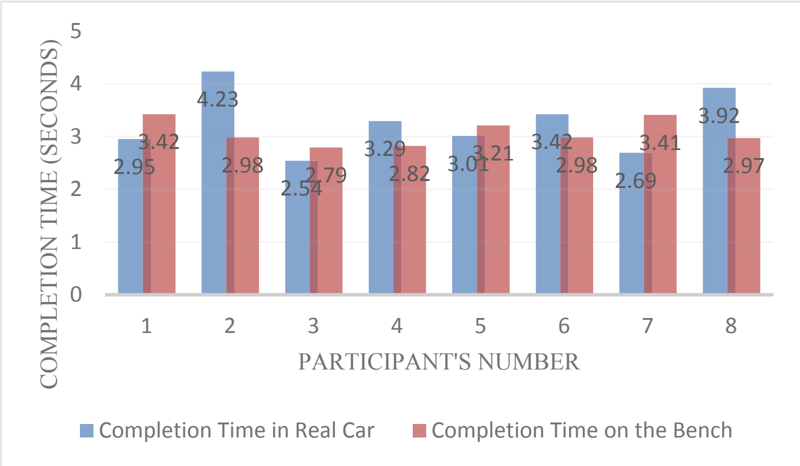
In order to verify the usability of the bench combining virtual reality and physical model in the rational evaluation of human-vehicle interaction in automotive design, this study separately observes the time and the operational validity of the same operation performed by the participants in the control group and on the test bench, as is shown in Table 2.

Table 2. Completion time and operational validity of 12 participants' operations in the controlled experiment

Participant's number		1	2	3	4	5	6	7	8	9	10	11	12
Control group	Completion time	2″ 95	4″ 23	2″ 43	2″ 54	3″ 67	3″ 12	3″ 29	3″ 01	2″ 64	3″ 42	2″ 69	3″ 92
	Validity (Y/N)	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**N**	**Y**	**Y**	**Y**
Test group	Completion time	3″ 42	2″ 98	5″ 52	2″ 79	2″ 62	3″ 74	2″ 82	3″ 21	2″ 71	2″ 98	4″ 41	2″ 97
	Validity (Y/N)	**Y**	**Y**	**N**	**Y**	**N**	**N**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**

It can be seen from the table that in the real car, 11 of the 12 participants have completed the operation, which means the operational validity ratio is about 91.7%. On the test bench, 3 of the 12 participants did not complete the test (they touched the wrong button), which means the operational validity ratio is 75%. For the 8 participants whose two operations are both valid, their average completion time in the control group is about 3.26 s, and that on the bench is about 3.07 s, as is shown in Table 3.

Table 3. Two groups of time data of 8 participants who have completed the tests



In order to verify whether there is significant difference between the two groups of data, this study carries out T-test (Tables 4 and 5), and obtains t value = 0.817, $p > 0.05$. In the circumstance that the degree of freedom is 14, and the significance level is greater than 0.05, the original hypothesis is supported. That is, there is no significant difference between the test bench and the control group in terms of the user performing the interactive operation.

Table 4. T-test group statistics

Group	Number of cases	Mean	Standard deviation	Standard error mean
Control group	8	3.2563	0.58612	0.20723
Test bench	8	3.0725	0.24633	0.08709

Table 5. T-test independent sample test

	Levene Variance Equivalence Test		Mean Equivalence T-test						
	F	Significance	t	Degree of Freedom	p	Average Error Value	Standard Error Value	95% Confidence Interval of the Difference	
								Lower Limit	Upper Limit
Equal Variances Assumed	4.442	0.054	0.817	14	0.427	0.18375	0.22478	-0.29836	0.66586
Equal Variances Not As-sumed			0.817	9.398	0.434	0.18375	0.22478	-0.32148	0.68898

From the above results, limited by the positioning accuracy of the hardware platform, the users' operation accuracy in the control group is still higher than that on the virtual reality test bench, but for all the participants whose both operations are valid, their average completion times are very close. And it can be derived from the t-test that there is no significant difference between the test bench and the control group in terms of the user performing the interactive operation. Therefore, the test bench of this study can be used to evaluate the human-vehicle interaction.

In the post-experimental interviews with the participants, the measurers conclude that most participants believe that this is a very novel evaluation method by which they can see the interiors and structure of the car comprehensively and clearly on a virtual bench. Some of the participants who have previously contacted the VR device hold the view that it has one more dimension combined with the physical model compared with the pure VR, to help them feel the interiors, styling, etc. of the car. Besides, some participants have pointed out some shortcomings, such as the car in the virtual scenario cannot achieve the same texture as the real car, and sometimes the hand location offset would occur, and there is only one single hand model that leads to no feeling of the hand action.

In general, on the premise of accurate positioning, the interaction on the bench combining virtual reality and the physical model can get the experimental results close to those of the real car. Therefore, this experiment preliminarily verifies the usability of the bench.

5 Discussion and Conclusion

In order to provide automotive designers with a faster, concrete and resource-saving design test bench, this study makes use of the increasingly mature virtual reality technology, combined with the physical model to create a virtual test bench for human-vehicle interaction.

In order to figure out the rationality, achievability and usability of the bench application, this study starts from the research of the development of the traditional automotive design industry, the virtual reality technology and related fields, and then verifies the usability of the virtual test bench by experiments.

Traditional car design methods require a lot of time, money and manpower. While the application of virtual reality technology in automotive design can great help car designers to evaluate their designs in all aspects, and flexibly update their designs and compare multiple solutions. Some automakers have also used virtual reality technology to evaluate the styling and interior design in the early stage of car design. And due to the development of virtual reality technology, virtual reality devices and programs on the market can provide very high-precision images. These all verify the rationality and achievability of the bench.

However, most of the applications remain on the visual level, only allowing the users to observe the whole vehicle by rotating the device without interaction. This research is aimed at automotive design. It pioneers to combine physical models and virtual reality technology, allowing designers to not only "see" their designs visually, but also "touch" them tactilely, which provides the designers with simulated interaction solutions in the early stage of design. And because of the advantages of virtual reality technology, designers only need to produce the models that need to be tested, which greatly reduces the time and money costs, and is also conducive to the comparative evaluation of multiple solutions.

Finally, it is concluded from the experiment that the data and experience close to those in the real car can be obtained on the bench of this study.

Of course, there are still some shortcomings in this research. For example, the image in the virtual environment is not fine enough, and limited by the hardware devices, the movement of the participants' hands cannot be well simulated, and the positioning offset often occurs. If possible, the handle can be replaced by data gloves to simulate the movement of the hands.

Since it is only a preliminary verification of the usability of the bench, this research's experiment only includes the interactive test in the static process of the car, and there are still considerable potentials of the bench needing to be explored. For example, the internal interactive interface of the car can be tested and evaluated, and various processes and surface treatments can be added to the physical model to simulate a more realistic tactile sensation, and the real buttons can be added to the physical model to make it truly "interactive", and feedback is got in the virtual environment through circuits and programming.

Furthermore, this experiment is carried out when the car is stationary. In the further study, the simulation when the car is moving can be added to evaluate the impact of the driver's operation during the car's movement on the concentration, etc., and to assess the rationality of the design during driving, which is not possible with traditional full-size physical models.

All in all, the simulation test bench combining virtual reality and physical model has quite great application potentials.

References

1. Hirz, M., Dietrich, W., Gfrerrer, A., Lang, J.: Automotive development processes. In: Hirz, M. (ed.) Integrated Computer-Aided Design in Automotive Development, pp. 1–24. Springer, Heidelberg (2013). https://doi.org/10.1007/978-3-642-11940-8_1
2. Lawson, G., Salanitri, D., Waterfield, B.: Future directions for the development of virtual reality within an automotive manufacturer. Appl. Ergon. **53**, 323–330 (2016)
3. Stefania, S., et al.: FCA ergonomics proactive approach in developing new cars: virtual simulations and physical validation. In: Duffy, V. (ed.) Advances in Applied Digital Human Modeling and Simulation. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-41627-4_6
4. de Clerk, M., Schmierer, G., Dangelmaier, M., Spath, D.: Interaction techniques for virtual reality based automotive design reviews. In: Barbic, J., D'Cruz, M., Latoschik, M.E., Slater, M., Bourdot, P. (eds.) EuroVR 2017. LNCS, vol. 10700, pp. 39–48. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-72323-5_3
5. Bordegoni, M., Giraudo, U., Caruso, G., Ferrise, F.: Ergonomic interactive testing in a mixed-reality environment. In: Shumaker, R. (ed.) ICVR 2007. LNCS, vol. 4563, pp. 431–440. Springer, Heidelberg (2007). https://doi.org/10.1007/978-3-540-73335-5_47
6. Moehring, M., Froehlich, B.: Natural interaction metaphors for functional validations of virtual car models. IEEE Trans. Visual Comput. Graphics **17**(9), 1195–1208 (2011)
7. Winkelhake, U.: Vision digitised automotive industry 2030. The Digital Transformation of the Automotive Industry, pp. 77–126. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-71610-7_5
8. Ihemedu-Steinke, Q.C., Erbach, R., Halady, P., Meixner, G., Weber, M.: Virtual reality driving simulator based on head-mounted displays. In: Meixner, G., Müller, C. (eds.) Automotive User Interfaces. HIS, pp. 401–428. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-49448-7_15
9. Mihelj, M., Novak, D., Begus, S.: Introduction to virtual reality. In: Mihelj, M., Novak, D., Beguš, S. (eds.) Virtual Reality Technology and Applications, pp. 1–16. Springer, Dordrecht (2014). https://doi.org/10.1007/978-94-007-6910-6_1
10. Guo, T., Zhou, X.: VR-based virtual test technology and its application in instrument development. In: Shumaker, R. (ed.) ICVR 2007. LNCS, vol. 4563, pp. 468–477. Springer, Heidelberg (2007). https://doi.org/10.1007/978-3-540-73335-5_51
11. 邵景峰, 刘优中, and 喻志强, 基于汽车造型评审的虚拟现实环境设计. 上海汽车, pp. 3–9, April (2017)
12. Schuldt, F., Reschka, A., Maurer, M.: A method for an efficient, systematic test case generation for advanced driver assistance systems in virtual environments. In: Winner, H., Prokop, G., Maurer, M. (eds.) Automotive Systems Engineering II, pp. 147–175. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-61607-0_7
13. Leudet, J., Mikkonen, T., Christophe, F., Männistö, T.: Virtual environment for training autonomous vehicles. In: Giuliani, M., Assaf, T., Giannaccini, M.E. (eds.) TAROS 2018. LNCS (LNAI), vol. 10965, pp. 159–169. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-96728-8_14
14. Werrlich, S., Lorber, C., Nguyen, P.-A., Yanez, C.E.F., Notni, G.: Assembly training: comparing the effects of head-mounted displays and face-to-face training. In: Chen, J.Y.C., Fragomeni, G. (eds.) VAMR 2018. LNCS, vol. 10909, pp. 462–476. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-91581-4_35

15. 唐明星, et al.: 全虚拟设计在 Vision-R 概念车研发中的应用. 机械制造 **55**(06), 7–10, 23 (2017)
16. Rangelova, S., Decker, D., Eckel, M., Andre, E.: Simulation sickness evaluation while using a fully autonomous car in a head mounted display virtual environment. In: Chen, J.Y.C., Fragomeni, G. (eds.) VAMR 2018. LNCS, vol. 10909, pp. 155–167. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-91581-4_12