Virtual Reality and Transport: A Short Review

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Abstract. *The development of virtual reality has been very intensive in recent years. Available systems combined together with very fast wireless communication networks have reached industry-level robustness and are being used more and more in industry, and not only for entertainment. One of the important areas for application is also the transport sector. In the transport sector, virtual reality-based systems improve the schooling of vehicle operators, serve as driver assistant systems, guide workers in warehouses and enable visualization of complex traffic solutions. This paper gives a short overview of the current state and application of virtual reality in the transport sector.*

Keywords. Virtual Reality, Road Traffic, Smart City, Logistics

1 Introduction

Virtual Reality (VR) systems started to evolve more intensively with the broader application of computers for creating various graphic representations. Prior to that era, there existed only simple systems of some sort of virtual reality related to visualization of the surrounding world. Ancient people made drawing in caves to visualize the living conditions, two closely spaced pictures created the effect of stereo vision to present distance events to people in 3D, SENSORAMA attempted to simulate operating different vehicles (Heilig, 1992) without any interactivity, etc.

The development of computing power and fast information sharing enabled the inclusion of VR technology into the industry. The concept of augmented reality, where additional information is presented to workers, has gained special attention (Fite-Georgel, 2011). Tele-training of workers is also one such application (Boulanger, 2004). Even improvement of the very complex system of old industry sectors, bringing them into the current concept of industry 4.0 is in focus. Shipyards give a relevant example (Fraga-Lamas et al., 2018).

The transportation sector is also one that benefits from VR technology. Well-known applications are various simulators or realistic setups for vehicle operator training (car, bus or truck drivers, pilots, and train drivers) (Gąsiorek et al., 2020). Such a concept enables training in different (dangerous) scenarios with the option that a respective scenario can be repeated as many times as needed in the same conditions until the vehicle operator trainee has mastered the correct response. Also, new areas like traffic planning can use the VR technology where traffic simulators can be connected with a virtual environment enabling testing of new solutions prior to building them in the real world (Hasan et al., 2021). Advanced driver assistant systems are also one of the areas of VR application, making our roads safer and driving more easier. Logistics also benefit from this technology where warehouse workers can be guided more efficiently to the respective item location or receive help how to apply new mobile robot based systems (Kalinov et al., 2021).

With the inclusion of VR into the transport sector in different areas combining new simulation approaches, there is a need for an analysis of the possibilities of these technologies. This is the aim of this paper to create a short review of the most important VR applications in the transport sector, ranging from better simulation approaches, concepts for the intelligent city, and new better logistics.

This paper is structured as follows. After the Introduction section, a brief description of the development of virtual reality is given in the second section. The following third section elaborates on the use of virtual reality for simulations. A description of intelligent city applications is given in the fourth section. Application in the logistics sector is continued in the fifth section. The paper ends with the sixth section containing the conclusion and perspective on transport sector applications.

2 Development of Virtual Reality

As mentioned, the very beginning of VR dates to ancient times when people made visualizations of their environment in caves creating the first visualization effects. This resulted in realistic murals and stereoscopic images presenting important events at the end of the 19 century. The development of VR systems as we know them today was driven by the improvement of computers and the increase in their computing power. Additional miniaturization led to the first head-mounted displays increasing the interactivity of the user with the simulated virtual world. Thus, mass production of VR systems began at the end of the 20 century with many applications in entertainment, training, and simulations for military and space exploring agencies.

At the beginning of the 21 current century, several companies brought to the market VR systems easily connectable to a standard PC. Some systems were produced to be compatible with smartphones. Expect of tracking only the eyes and view direction of the user, today's systems can also track the movement of the hands; with 6 degree of freedom wireless tracking sensors, the whole body can be tracked, and the user gestures can be deciphered. New lightweight glasses for augmented reality give the opportunity to present a lot of different additional information to the user. Thus, the application of VR in every sector dealing with complex systems is possible by using state-of-the-art VR systems.

3 Virtual Reality Based Simulators

Virtual reality test systems have been present in the automotive industry for a long time and have been widely used. Their typical use is testing during Research and Development (R&D) processes, as well as testing in certification processes, such as emission certification. Application areas of virtual reality in the automotive industry can be divided into two main groups; (i) purely simulated test systems and (ii) Hardware-In-the-Loop (HIL) test systems.

Purely simulated test systems are used in the early phase of the R&D process. With this type of test system, everything is simulated and modeled in virtual reality - vehicle chassis, engine, road, traffic, pedestrians, etc. Due to advances in simulation technology and the development of cars with automated and autonomous driving, this type of simulation is becoming more important, and its usage is increasing significantly.

HIL testing is a type of testing where Unit Under Test (UUT), i.e., engine, small vehicle part,or the entire vehicle, is not simulated but is real, while the rest of the components are simulated in virtual reality - vehicle chassis, gearbox, road, and wind resistance, etc. This type of testing is used when more precise testing and measurement are needed, and UUT simulation cannot be applied because current technologies do not support the required level of reality approximation. HIL testing is typically used in the final stage of the R&D process for calibration, optimization, and certification of the vehicle itself. The two most common cases of HIL testing are engine testing on an engine test bed and vehicle testing on a chassis dyno test bed. Engine testing on an engine test bed is real, and the rest, wheels, vehicle chassis, road, and wind resistances,are placed into virtual reality. In the case of vehicle testing on the chassis dyno test bed, the entire vehicle is real, and the rest, road and wind resistances, traffic, pedestrians, and infrastructure are placed into virtual reality. Emission certification is an example in which testing on the HIL system is used in the certification process. This type of testing and certification is being used globally, and it is conducted on a chassis dyno test bed.

On the other hand, systems for automated and autonomous driving are very complex, consisting of multiple hardware and software systems and subsystems with a lot of sensors. Purely simulated test systems play a huge and important role in R&D process because the number of tests, test cases, and testing hours are thousands or tens of thousands. With the current technology development, validation and certification of these systems are only possible by driving on the roads or in "Fake cities." This approach to testing has numerous limitations. Some of them are:

- Very dependent on external conditions, like day, night, rain,
- Limited by geographic position and season (e.g., testing in rain or snow is limited to certain periods of the year, if possible at all),
- Limited number of possible testing scenarios and test cases,
- Difficult measuring and data acquisition,
- Difficult and slow software debugging process,
- Potentially very dangerous for all persons involved in the testing process (especially the test driver or surrounding test pedestrians),
- Test automation is limited or not possible at all.

The consequence of all these limitations is that validation and certification processes are very time-consuming and costly. An additional and very important limitation is that the test scenarios and test cases are neither repeatable nor reproducible. By testing in general and especially by certification testing, repeatability and reproducibility are of key importance. All of the previously mentioned obstacles and limitations could be eliminated by testing and validating in virtual or augmented reality. Current simulation technology is still not developed enough to be applied in such tests, and currently, automotive companies are putting a big effort into the development of virtual reality test systems, which provide more realistic validation and/or certification testing possibilities.

On the other hand, VR simulators can also be utilized in a Microscopic Traffic Simulation (MTS) framework, including human control using VR technologies (Hasan et al., 2021). One such approach developed in (Hasan et al., 2021) allows up to 10 geographically distributed users to run and guide vehicles in MTS online using the widely available retail VR devices. The main goal of the framework is set to the improvement of precision of MTS by developing as close to real VR immersive scenes and environments. The use of low-cost, affordable VR devices in the proposed distributed MTS expands the usability of MTS for many users, thus, significantly improving MTS results by incorporating realistic human behavior. A different approach to VR simulation based on a driving simulator game-based learning system that assists divers in practicing driving behavior and real-world traffic situations was developed in (Muhammad Amirul Fawwaz Nik Abdullah et al., 2022). One key aspect of the research was to analyze human behavior when interacting with driving simulator game-based learning. Therefore, the authors developed five assessment criteria, including simulation satisfaction, interaction with the simulator, motivation to complete challenges, challenges to enhance driving skills, and effectiveness of the simulation framework.

VR systems play an important role in the automotive industry, and with the development of vehicles with automated and autonomous driving, their importance is growing exponentially. At the moment, VR technology is behind the market needs, and therefore, companies are investing a lot in research and development. Testing and validation in or with VR is the future of testing, and it is a field with great potential for scientific, engineering, and business activities.

4 Intelligent City Applications

Intelligent cities represent the new strategy used to improve current cities' problems that include traffic, safety, pollution, resource management, and waste processing/recycling. The design of a smart city includes more efficient transport and intelligent mobility, a feasible environment, and controlled urbanization. Therefore, new technologies, in particular, VR, can be utilized in the development of various aspects that contribute to building a smart, sustainable city. The active user immersion and participation in the constructed three-dimensional virtual environment help in designing an intelligent city. The construction of the virtual scene according to the perception of the real environment in an immersive and interactive way gives insights into current city problems. Most importantly, it offers virtual solutions before implementation in the real world. A vast majority of recent VR frameworks lie upon gathered relevant and real-time data from sensors.

The implementation aspect of VR in developing a road traffic virtual environment that replicates the real-world in various conditions (Bourhim & Cherkaoui, 2019). This environment can be simulated by altering various traffic parameters that include: signal length, traffic flow, the type of vehicle, time and speed, and many more. According to (Bourhim & Cherkaoui, 2019), this framework can help in the development of new solutions using VR technology for validation, evaluation, and simulation of multiple materials, environmental, financial, and traffic-related scenarios. The development of such a VR environment is beneficial for road planning and design in a 3D virtual city for testing and comparing different design schemes that involve modifying the physical properties of traffic infrastructure (Yan et al., 2021).

The application of VR technology can also be beneficial to train drivers, as discussed in (Zhang, 2021). The idea of VR is to convey the input driving signals, such as throttle opening and steering position, into the VR framework system. Therefore, drivers can also be trained to adapt to new traffic regulations and imposed intelligent traffic control systems. Furthermore, the prototype of a VR educational platform was developed to address the design and implementation of VR systems for learning through serious games and the creation of a mobility web observatory for disseminating information through digital activism and data visualization and analysis (León-Paredes et al., 2020). The main idea of the VR prototype is to offer a new interactive road learning platform. The main goal is to train citizens and collect data to detect and analyze the participants' routines and mishaps when driving, transit, walking, or transporting.

Another aspect of VR application lies in the control and monitoring of traffic flows for users. The development of such a system allows users to analyze traffic flows in multiple scenarios and roads to support better decision-making to control and monitor traffic flow in a smart city (Yao et al., 2018).

In (Roldán-Gómez et al., 2022), VR based system was proposed, developed, and validated as a smart monitoring system for the smart city based on an aerial robotic swarm in a simulation environment. Drones were used to develop a behavioral algorithm to monitor traffic, pollution, and ecological aspects in a smart city. The immersive VR interface can perceive the state of the city, determining and detecting the most relevant events in a city.

One of the newest concepts to foster the intelligent city concept is the digital twin approach. In this case, a whole city or only a part of it can be modeled in a virtual environment, and the digital twin is constantly improved during operation. Thus, city operators have the whole time accurate insight into what is happening with improved visualization. The advantage to common VR-based city models is that real-time traffic measurements can be included in the execution of the VR model, ensuring a constant correction of the simulated traffic flows and mobility entities' behavior. The latest example of such a constantly improving digital twin is the Geneva motorway example described in (Kušić et al., 2022).

5 Logistics Applications

The development and introduction of VR into the transport sector also branch to the logistics sector. The need for improved logistics distribution is especially evident due to the fast-growing e-commerce in recent years. Therefore, the standard logistics distribution path display system that is built on a geographic information system only displays the information about the transfer center and goods on a two-dimensional map. The VR-based e-commerce logistics distribution path display system has a better user experience and reliability with the interactive and intuitive features was developed in (Min, 2020). The VR distribution center scene was created in Unity3D software by combining the two-dimensional road satellite map and the positioning information on the satellite map to establish a plane gridded scene.

VR can also be used to set up a virtual logistics laboratory, as shown in (Li et al., 2009). The proposed VR structure of three-dimensional storage laboratory mainly consists of four modules, including automatic storage and retrieval system, automatic conveyor system, automatic picking system, and warehouse management system (Li et al., 2009). The developed VR model can be used to record, search, sort, modify, and print. Furthermore, checking-in management module incorporates management of goods, weighing, checking and acceptance of goods, stock pre-allocation, and more. Two more modules include warehouse management and customer relationship management.

VR was successfully implemented in the port container terminal that serves as an intermodal global transportation network (Shu et al., 2007). The port logistics information platform incorporates port management sub-systems and an information-sharing platform to help visualize data. Data mining and visualization are combined and integrated with communication among port entities. VR-based container operation management system was developed based on an existing real-time system that drives objects in motion in a 3D scene. Furthermore, the developed system can simulate the movement of objects in a 3D scene operated by a human through an interface. In (Chen et al., 2010), authors analyzed the existing problems in a port container terminal simulation and developed a methodology to construct the container terminal VR system faster. The advantages of using component technology to deploy a container terminal VR system, according to the authors, include an efficient, reusable, and flexible method to develop component VR container terminal simulation. In a recent paper (Liu et al., 2021), authors developed a platform for port safety training. The platform includes an interactive training learning function in a VR scene to increase the interest of safety training and solve the problem of insufficient learning motivation. Furthermore, the interactive assessment is developed in the VR scene to evaluate the quality of safety training results. Lastly, the port VR provides an immersive sense of substitution to help develop required safety skills quickly and effectively for a port management system.

6 Conclusion

The development of new VR technologies opens new possibilities in various industry areas and not just entertainment. One of the industry sectors, which is getting more and more benefits from VR, is the transport sector. In addition to the well-known vehicle operators learning application of VR, new approaches related to better visualized and more accurate simulations and new guiding systems for workers in highly automatized warehouses are being put into use. The latter is especially beneficial in optimal item placement warehouses where only the warehouse management system knows where each respective item is.

Also, a synergy of other new technologies is happening with VR in the transport sector. The best example is the digital twin technology with which an accurate modeling/calibration backbone to the virtual world can be made. Thus, more realistic simulation environments for training vehicle operators, traffic management centers, and urban planning departments can be made. It can be expected that VR will become a new important tool to alleviate solving current problems in the transport sector, making the current transport network more green, intelligent, integrated, and resilient to various disturbances.

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