

Current research on human-computer interaction based on VR in flight simulation driving

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Abstract. With the rapid development of the aviation industry, the demand for pilots in the world is increasing day by day, and the flight simulator industry has received more and more attention and attention. However, due to the rapid upgrading of flight simulation technology, many problems arise. This review aims to deeply explore the application of human-computer interaction technology including VR technology in flight simulation driving, so as to reduce the driver's work burden during driving and improve the learning efficiency of flight simulation. Starting from virtual reality technology and human-computer interaction technology, this paper reviews the development and application of human-computer interaction technology based on virtual reality (VR) in the field of flight simulation and driving, and discusses the application of VR technology and human-computer interaction technology in the field of flight simulation and driving development and testing. Finally, this review summarizes the current application status and challenges of human-computer interaction technology in the field of flight simulation driving. Although human-computer interaction technologies such as VR have made remarkable progress in the field of flight simulation, there are still problems such as high cost of hardware equipment, operational stability, and fidelity that need to be solved. In the future, it is worth looking forward to the continuous innovation of VR-based human-computer interaction technology in flight simulation driving, bringing more development opportunities for flight training and the aviation industry.

Keywords: Virtual Reality, Human-computer Interaction, Flight Simulation Driving.

1. Introduction

With the rapid development of the aviation industry and the increasing importance of flight safety, flight simulation system plays an increasingly important role in the field of flight training and research. The use of flight simulators provides pilots with a safe, efficient and cost-effective training platform that allows them to practice and familiarize themselves with complex flight operations in a simulated environment, thereby enhancing their flight skills and decision-making abilities[1]. In recent years, the continuous progress of virtual reality (VR) technology has brought the development of flight simulation driving system to a new stage[2]. As an important element in flight simulation system, human-computer interaction plays a vital role in pilot training and flight skills development[3]. This paper will focus on the application of human-computer interaction in flight simulation driving, and explore the influence of different human-computer interaction strategies on pilot operation and decision making. In addition, it

will also discuss the limitations and shortcomings of the current human-computer interaction technology in flight simulation driving, and propose the direction of improvement. Through the comprehensive study of flight simulation system, this paper aims to provide theoretical and practical reference for further improving the effect of flight simulation training and the skill level of pilots, promoting the development of flight simulation technology, and improving the safety and reliability of aviation field. Ultimately, it is expected that this review will provide insight and inspiration to scholars and practitioners in the fields of aviation training, flight simulation technology research and virtual reality applications, and contribute to the continued development of related fields. Throughout this review, the historical development and existing research will be reviewed, focusing on the application of VR technology in aircraft simulation driving, especially the impact of human-computer interaction on flight simulation driving systems. Through the comprehensive analysis of the existing results, it is hoped to provide useful guidance for the improvement and innovation of flight simulation driving system in the future, so as to promote the continuous progress and perfection of aviation technology.

2. Related Works

2.1. *Historical development and research status of aircraft simulation*

The history of flight simulators dates back to the early 20th century. Early flight simulators used simple mechanical devices to simulate the movements of an aircraft, such as a model of an aircraft suspended on a rotating ring. These simulators are primarily used for pilot basic training. With advances in electric technology, electric flight simulators appeared in the mid-20th century. These simulators use electric motors to simulate the motion of the aircraft, increasing the accuracy and complexity of the simulation[4]. In the late 20th century, with the development of computer technology, computerized flight simulators were realized. With the introduction of computer, the simulator can more accurately simulate the movement and flight of the aircraft, and provide a more real flight experience for the pilot[5][6]. In recent years, flight simulators have been greatly developed and improved. The comprehensive flight simulator uses advanced computer technology, virtual reality technology and simulation system, which can simulate flight in a high degree of reality, including the power, maneuverability, aerodynamic characteristics and environmental conditions of the aircraft[7]. Due to the complexity of aircraft driving, including the complex parameters of the aircraft situation, the cockpit components that need to be operated, and the conditions of the external environment received by the aircraft, the research on aircraft driving and aircraft simulation is still an active field, involving the technical improvement of flight simulators, the optimization of training methods, the application of virtual reality technology and human-computer interaction technology. In these areas, there is still room for improvement in aircraft simulation. The following, will mainly introduce the topic of human-computer interaction technology.

2.2. *Application of human-computer interaction in aircraft simulation*

2.2.1. *Virtual Reality (VR)*. Case: VR has brought a revolutionary shift to the world of flight simulation, fundamentally transforming pilot training. One striking application lies in the incorporation of VR headsets into flight simulators. These headsets seamlessly replicate the intricate details of a cockpit environment, encompassing controls, instruments, and visual elements. This immersive experience grants trainees the opportunity to rehearse procedures, navigate through challenging scenarios, and react to emergencies within an extraordinarily authentic virtual cockpit. Moreover, the inherent head-tracking functionality of VR headsets augments spatial awareness, enabling pilots to naturally survey their surroundings and interact with the simulated environment. Another noteworthy application is the realistic visualization of flight scenarios. VR-based flight simulation software offers high-fidelity, 3D visuals that accurately mimic real-world landscapes, weather conditions, and airport environments. This visual authenticity enables trainees to practice flying under diverse conditions, including adverse weather and unfamiliar terrain, all from the safety of a virtual environment.

These VR applications not only elevate the realism of pilot training but also contribute to cost-efficiency, accessibility, and enhanced safety. They hold the potential to revolutionize aviation training, making it more effective and accessible than ever before.

Cost-Effective Training: One of the most notable advantages of VR-based flight simulation is its significant reduction in training costs compared to traditional methods. Traditional flight training entails substantial expenses associated with aircraft operation, maintenance, fuel, and instructor fees. In contrast, VR-based simulators eliminate these costs, offering a highly realistic training experience at a fraction of the price. This cost-effectiveness democratizes aviation training, making it more accessible to individuals from diverse socioeconomic backgrounds. Aspiring pilots no longer face financial barriers, potentially expanding the talent pool and fostering greater diversity within the aviation industry. Moreover, this cost-efficiency benefits airlines, flight schools, and training centers, allowing them to offer more extensive and affordable training programs[8].

Training Realism and Effectiveness: VR-based flight simulators excel in replicating the real-world cockpit experience with exceptional fidelity. The incorporation of VR headsets into simulators enables trainees to step into a virtual cockpit that closely mirrors the controls, instruments, and visual aspects of actual aircraft. This immersive environment enables trainees to practice a wide range of procedures, from basic maneuvers to complex emergency responses, within a highly authentic setting. The ability to interact with switches, buttons, and controls in a tactile manner enhances muscle memory and operational proficiency. Furthermore, VR's inherent head-tracking features play a pivotal role in enhancing spatial awareness and situational understanding. Pilots can freely move their heads to examine different parts of the cockpit or gaze out of the virtual window, just as they would in a real aircraft. This natural head movement closely aligns with real-world pilot behavior, contributing to more effective training. The realism and effectiveness of VR-based flight simulation extend to visual representation as well. Modern VR flight simulation software provides highly detailed and accurate 3D visuals that closely replicate real-world landscapes, weather conditions, and airport environments. This visual authenticity allows trainees to experience flying in diverse scenarios, including adverse weather, unfamiliar terrain, and complex airspaces. Consequently, trainees develop a broad skillset and increased confidence to handle a wide array of in-flight challenges.

Enhanced Safety: Safety is a paramount concern in aviation, and VR-based flight simulation plays a pivotal role in enhancing safety by providing a controlled and risk-free training environment. Trainees can practice a myriad of scenarios, including critical emergencies, without endangering lives or equipment. This capability is instrumental in developing the skills and confidence required to respond effectively to unforeseen real-world challenges. As a result, aviation safety is greatly improved, reducing the occurrence of accidents attributed to pilot error. Moreover, the ability to recreate complex and high-risk scenarios in VR fosters a proactive approach to safety training. Instructors can expose trainees to challenging situations that are difficult or even impossible to replicate in real flight. This proactive training equips pilots with the skills and knowledge needed to handle emergencies confidently, further reducing the likelihood of accidents. In addition, VR-based flight simulation provides a safe platform for assessing pilot performance. Instructors can monitor trainees' responses to various scenarios, identify areas for improvement, and tailor training accordingly. This data-driven approach ensures that each pilot reaches the desired level of proficiency, contributing to overall aviation safety.

Broader Industry Implications: Beyond its immediate training benefits, the integration of VR into flight simulation holds significant implications for the broader aviation industry. Firstly, the cost-effectiveness of VR-based training can potentially alleviate some of the financial burdens associated with pilot training and alleviate pilot shortages. By reducing the cost of obtaining a pilot's license, VR-based training may attract more individuals to pursue careers in aviation, increasing the pool of skilled pilots. Secondly, the enhanced safety and skill development facilitated by VR-based training can significantly reduce aviation accidents attributed to human error. This has the potential to lead to lower insurance costs for airlines, reduced accident-related expenses, and an overall improvement in aviation safety records. Safer skies benefit not only the industry but also passengers and the general public. Additionally, VR's data analytics capabilities present an opportunity to continuously refine and optimize

training programs. By analyzing trainee performance data, training curricula can be tailored to address specific weaknesses and optimize the learning process. This data-driven approach could lead to more efficient training, shorter training durations, and higher overall training quality.

2.2.2. Human-Machine Interface (HMI) Design. Case: HMI design is pivotal in the field of flight simulation, enabling effective interaction between pilots and the simulated aircraft environment. Several application examples underscore the significance of HMI design:

Cockpit Instrumentation: HMI design ensures that cockpit instruments closely replicate real-world counterparts. For instance, digital displays mimic authentic aircraft displays, presenting vital information such as airspeed, altitude, and engine status. The design optimizes the presentation of this data, allowing pilots to monitor the aircraft's state accurately during simulation. **Touchscreen Interfaces:** Advanced flight simulators incorporate touchscreen interfaces, mirroring modern aircraft where physical controls are often replaced by touch-sensitive screens. Effective HMI design of these interfaces enables intuitive access and manipulation of systems like avionics, navigation, and communication, mimicking real aircraft experiences.

Head-Up Display (HUD): HUDs project crucial flight data onto a transparent screen, facilitating pilots' focus on the outside environment while receiving essential information. HMI design in HUDs dictates how data elements like attitude indicators and airspeed are presented, ensuring they are displayed unobtrusively. **Voice Commands:** HMI design integrates voice-activated systems, enabling pilots to control simulator functions via voice commands. Effective voice interface design ensures accurate recognition and response to commands, enhancing the immersive training experience.

Cockpit Instrumentation: Cockpit instrumentation in flight simulators plays a pivotal role in replicating the realism of actual aircraft. HMI design focuses on creating instrument panels that closely mimic the appearance and functionality of their real-world counterparts. This includes replicating the layout, design, and behavior of instruments such as altimeters, airspeed indicators, attitude indicators, and engine gauges. The significance of effective cockpit instrumentation design cannot be overstated. It allows trainees to develop a profound familiarity with the arrangement and operation of instruments within the cockpit, facilitating a seamless transition to real aircraft. The HMI design ensures that trainees can accurately interpret instrument readings, monitor the aircraft's status, and make informed decisions during simulation. This realism is a cornerstone of effective pilot training, building confidence and competence[9].

Touchscreen Interfaces: The integration of touchscreen interfaces in flight simulators represents a leap forward in HMI design. These interfaces simulate modern aircraft, where physical controls are often replaced by touch-sensitive screens. The HMI design of touchscreen controls is crucial in creating an intuitive and efficient user experience.

Effective HMI design of touchscreen interfaces begins with logical organization. Controls and functions should be arranged in a manner that mirrors real aircraft systems, allowing trainees to navigate and manipulate avionics, navigation, and communication systems with ease. Intuitive touch interactions, such as pinch-to-zoom or swipe gestures, are integrated to mimic real-world touchscreen behaviors. The immersive nature of touchscreen controls in flight simulation is enhanced by realistic touch feedback, such as haptic responses or visual indicators. These design elements ensure that trainees can interact with the simulated systems authentically, fostering muscle memory and operational proficiency. Overall, touchscreen interfaces exemplify how HMI design can bridge the gap between simulation and reality, providing an authentic training experience.

Head-Up Display (HUD): HUDs in flight simulators project critical flight data onto a transparent screen, allowing pilots to maintain their focus on the external environment while receiving essential information. HMI design within HUDs involves selecting and presenting data elements in a manner that does not distract from the outside world. The primary goal of HUD HMI design is to present data transparently and unobtrusively. Attitude indicators, airspeed readouts, altitude displays, and navigation cues are all meticulously designed to be displayed in a manner that aligns with real-world pilot behavior. These design choices ensure that trainees can maintain their situational awareness while effectively

monitoring critical flight parameters. HUD HMI design also extends to the customization of data presentation. Trainees should have the flexibility to configure the HUD display according to their preferences, allowing them to focus on the most pertinent information for a given training scenario. Overall, HMI design within HUDs promotes enhanced situational awareness and decision-making, enriching the training experience[10].

Voice Commands: Voice-activated systems in flight simulators represent a significant advancement in HMI design, enabling pilots to control simulator functions via voice commands. Effective voice interface design is paramount in ensuring that these systems accurately recognize and respond to pilot commands.

HMI design focuses on minimizing recognition errors through robust speech recognition algorithms and natural language processing. Voice commands should be clear, concise, and closely aligned with real-world aviation terminology. Furthermore, the responsiveness of the system is a key consideration. Pilots must receive timely feedback to confirm that their commands have been recognized and executed. The convenience of voice-activated systems in HMI design cannot be overstated. It provides a hands-free interaction experience, allowing trainees to focus on essential tasks without the need for manual input. However, effective voice interface design is crucial in ensuring that voice commands enhance rather than impede the training experience.

3. Discussion

The analysis of VR's application in flight simulation reveals a multitude of benefits and transformative possibilities. However, it also raises several key points for discussion, including the future development of VR in aviation training and potential optimization measures. Firstly, VR's integration into flight simulation has the potential to address the ongoing pilot shortage in the aviation industry. The cost-effectiveness and accessibility of VR-based training can attract a more diverse range of individuals to pursue careers in aviation. This is particularly pertinent as the industry faces a growing demand for pilots, and VR can help bridge the gap between training capacity and demand. Secondly, the enhanced safety and skill development facilitated by VR-based training can significantly reduce aviation accidents attributed to human error. Reduced accidents not only save lives but also contribute to cost savings for airlines in terms of accident-related expenses and insurance premiums. This could lead to a shift in the industry's safety culture, placing a greater emphasis on proactive training and risk mitigation. However, as VR continues to shape aviation training, it's crucial to address challenges and areas for improvement. One potential concern is the need for ongoing technological advancement to maintain the realism and effectiveness of VR-based simulations. This includes improvements in hardware, software, and data analytics capabilities. Furthermore, the development of standardized VR training programs and certification processes will be essential to ensure consistent training quality across different training centers and organizations. Collaboration between aviation authorities, training institutions, and VR technology providers will be crucial in achieving these standards.

And, VR's integration into flight simulation holds immense promise for the aviation industry. Its cost-effectiveness, enhanced safety, and potential to address the pilot shortage make it a powerful tool for the future. However, continued technological development and the establishment of industry standards will be key factors in harnessing VR's full potential and ensuring its long-term success in aviation training.

The analysis of Human-Machine Interface (HMI) design in flight simulation underscores its critical role in enhancing training realism, optimizing information presentation, and promoting user interaction. In the future, human-machine interface design in aircraft simulation still has many directions that can continue to optimize and develop. Firstly, the significance of HMI design in replicating realism cannot be overstated. The accuracy of cockpit instrumentation, touchscreens, HUDs, and voice commands greatly influences the effectiveness of pilot training. As technology continues to advance, the challenge lies in maintaining and even elevating the level of realism. Future HMI development may incorporate emerging technologies such as augmented reality (AR) and virtual reality (VR) to further blur the lines between simulation and reality. These technologies can provide more immersive and context-aware

displays, offering a training experience that mirrors actual cockpit environments to an even greater extent.

Secondly, the optimization of information presentation is essential for training effectiveness. HMI design has made strides in reducing cognitive load and enhancing situational awareness through well-organized displays and intuitive interactions. Future HMI enhancements could focus on adaptive interfaces that customize information presentation based on the trainee's skill level and the specific training scenario. These adaptive systems could dynamically prioritize data, ensuring that trainees receive the most pertinent information, thereby optimizing the learning experience.

Moreover, user interaction through HMI design plays a pivotal role in training engagement. Voice-activated systems have provided a hands-free alternative, but future developments should concentrate on refining recognition accuracy and response times. Additionally, the integration of natural language processing and AI-driven voice recognition systems could make voice interaction even more intuitive and effective.

And, the continued evolution of HMI design in flight simulation is essential for improving pilot training outcomes. The future holds exciting possibilities, including the incorporation of AR, VR, adaptive interfaces, and advanced voice recognition. These developments have the potential to elevate training realism, streamline information presentation, and further enhance user interaction, ensuring that pilots are better prepared for the complexities of real-world aviation.

4. Conclusion

The exploration of Virtual Reality (VR) technology and Human-Machine Interface (HMI) design within the context of flight simulation has illuminated their pivotal roles in revolutionizing pilot training. When concluding this literature review, it is evident that these two facets are shaping the future of aviation training in profound ways. In summary, VR technology has emerged as a transformative force in flight simulation. Its immersive capabilities provide trainees with an authentic, risk-free environment to hone their skills. The application of VR headsets and high-fidelity 3D visuals has greatly enhanced the realism of flight simulation, replicating cockpit environments and scenarios with remarkable accuracy. This technology has the potential to democratize aviation training, making it more accessible and cost-effective while significantly improving safety and skill development. Similarly, HMI design has demonstrated its critical role in elevating the effectiveness of pilot training. Cockpit instrumentation, touchscreen interfaces, HUDs, and voice commands have been meticulously designed to mirror real-world experiences, enhancing trainees' familiarity with aircraft systems and controls. Information presentation has been optimized to reduce cognitive load, while user interaction has become more intuitive and engaging. Looking ahead, the future of aviation training promises even more exciting developments. VR technology is poised to evolve further, potentially incorporating augmented reality (AR) and advanced haptic feedback systems, offering an even more immersive and interactive training experience. HMI design will continue to prioritize adaptive interfaces and advanced voice recognition, tailoring training to individual needs and further enhancing user engagement.

In conclusion, the synergy between VR technology and HMI design in flight simulation represents a transformative leap in aviation training. The horizon is rich with possibilities, and the aviation industry can look forward to a future where pilots are better prepared, safer, and more proficient, thanks to these innovative technologies. As they continue to evolve, the sky is no longer the limit for aviation training.

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