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“Integrating Human Factors into the Vision Design of Space habitat——hygiene area design”

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3.1 A CONCEPTUAL TIMETABLE FOR THE FOUNDING STEPS OF SPACE

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[abstract] --

ABSTRACT

With the rapid advances in manned spaceflight technology, astronauts will stay in orbit for a long time in the future, and on-orbit missions will be more diversified, which will place higher requirements on human-machine spacecraft systems. As an important visual element for interacting with astronauts, human-machine interfaces not only affect the astronauts’ physical, psychological and cognitive activities, but also their work efficiency and even the safety of the space mission. The purpose of this research is to take the hygiene area of the space station as an example and optimize the environment by analyzing the functions of the sanitary area and the design of the man-machine interface.

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PAPER

1 Introduction

Visual perception refers to the movement, shape and colour caused by the specific quality of light recognised by the human eye and interpreted by the brain. Therefore, light and colour are inseparable elements (Schlacht, et al. ,2011), and "colour and light" are artificially separated terms. As the main factors in the environment which directly affect people's psychological reactions and physical health (Jiang, 2019), light (in the sense of day and night time) and colour changes constitute the basic system that reminds the body to rest or be alert in response to the brain (Adams and Putcha, 2000). In the outer space habitat, however, the vestibular system becomes dull, meaning orientation can only be provided through vision. Colour and visual configuration are essential for positioning. Colour can support the sense of direction as well as the feeling of happiness (Kanas and Manzey, 2008). Therefore, colour and light play an important role in visual perception. Studying the influence of light and colour on astronauts is an important part of studying visual perception. In addition, due to the limited space of the spacecraft and the complexity of the equipment, one of the main problems encountered by astronauts is visual confusion (Gorbunov et al.,2014; Kanas and Manzey, 2008). This is the result of the unorganised arrangement of all items within the space environment, which leads to the deterioration of social relationships among the astronauts, reduces the efficiency of their work and produces negative emotions (Jiang, 2019). In addition, many studies have shown that astronauts suffer from myopia due to their limited living environment, which affects their vision and negatively affects their well-being (Schlacht et al., 2011). Therefore, the various interfaces in the spacecraft are an important factor that affects the vision of astronauts. Changes in visual perception in turn affect the astronauts’ physiology, their quality of life as well as the performance of the mission in space (Kanas et al.,2009). Research on visual optimisation has made rapid progress and has achieved many excellent results. It has been found, for example, that the secretion of melatonin can be influenced by changing the colour of the light or its brightness in the spacecraft. This improves sleep quality, which has a significant effect on the work efficiency of the astronauts in the spacecraft. However, no specific standard exists for measuring the impact of visual perception on astronauts (Merchant, 2014).

Long-term space flight and manned deep space exploration pose huge challenges to astronauts' physical and psychological load (Chen et al., 2015; Wang et al., 2018). At present, improving their ability to adapt to long-term flight by making the interior of the spacecraft safe, stable, reliable, and comfortable to live and work in is a key element of mission success (Kanas et al.,2009; Mallis and DeRoshia, 2005). There are many stressors in the spacecraft environment, such as microgravity, confinement, isolation, and narrowness, and the human visual system receives 85% of these stressors. Most of the visual stressors are related to the interfaces with the interior of the spacecraft (McCann and Spirkovska, 2005; Kanas et al.,2009). The human-machine interfaces enable astronauts to perform functions such as work or rest, enable hygiene, provide dining and health support, and cover displays, control, layout, human-intelligence collaboration and new interactive devices (Chen et al., 2015; Neerincx, 2011). However, the incomplete colour control and analysis of the human-machine interfaces of the spacecraft and insufficient overall colour matching design cause the astronauts’ visual stress load to be too high at this stage (Zhou et al., 2001; Sgobba and Schlacht, 2018). This easily results in visual confusion, fatigue, monotony and cognitive difficulties in the process of cognitive processing, which leads to reduced fault tolerance, temporary loss of cognitive and decision-making ability, emotional abnormalities, psychological disorders, etc. (Stokes and Kite,2017; Bourne and Yaroush, 2003). In particular, due to the limited space of the spacecraft and the complicated equipment and machinery, the colour design of the human-machine interfaces also affects the spatial positioning of the astronauts, the communication and cooperation of the crew, interpersonal relationships and cultural commonality (Kanas, 2015). Therefore, in this study, the Chinese space station “Tiangong” is used as a baseline to investigate the effects of colour on the astronauts’ abilities in the special factor environment of the hygiene area, and to establish a connection between the astronauts’ abilities.

2 Method for constructing a virtual hygiene area based on an immersive VR system

The immersive system uses a variety of interactive devices such as helmet displays and data gloves/handles that affect the user's vision, hearing and other feelings. Making the users truly participants in the system and having them operate these interactive devices to recreate space environmental factors gives the participants a sense of immersion (Bowman et al., 2008; Rönkkö et al., 2006).

The experimental process will be as follows:

In the immersive VR experiment, visual stimuli inside the hygiene area will be established and presented to the participants through the VR helmet display.

The participants will assume standard postures (including lying on a -6° head-down bed rest and sitting for 30 minutes)

The VR information input to the participants will include visual, force and auditory information. The helmet display is a visual output device, and the force feedback device is a force sense reproduction device. When a participant touches an object in a virtual environment, the glove/handle device feeds back the force sense to the participant's hand, and the scene is fed back through auditory information and operation sound effects, so as to realise a realistic interaction between the participants and the virtual environment. The system builds a virtual spacecraft environment, including an environment model of the space station cabin, a model of the equipment and facilities for interactive operations on board, and other related interfaces. At the same time, the instructor software can be set to control the simulation content, the experimental process, etc., and record and evaluate the experimental process data at the same time, as shown in Figure 12.

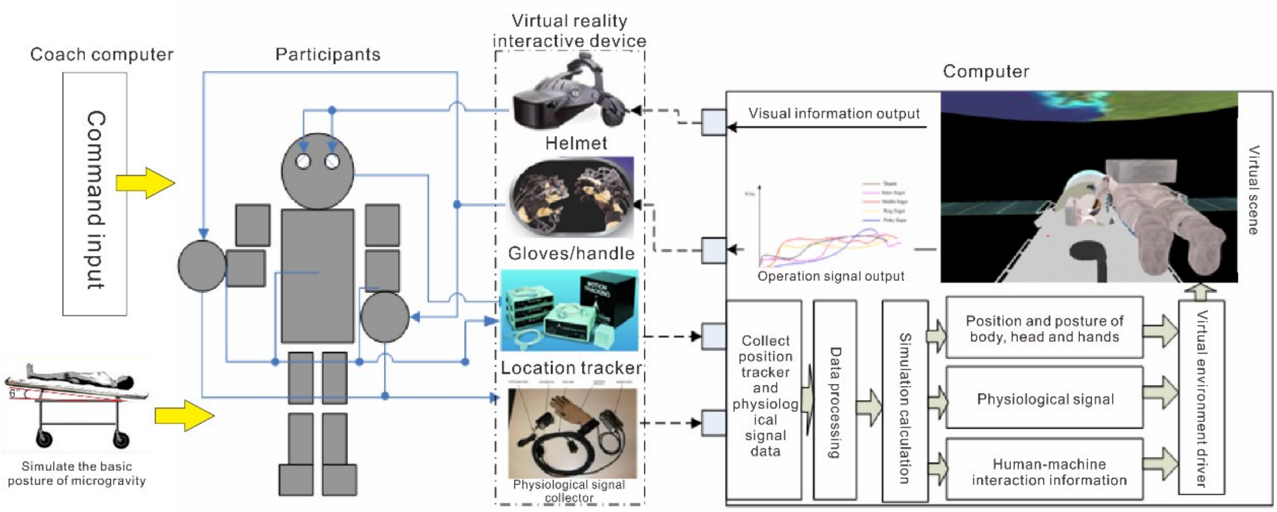


Figure 1. VR test system

When simulating the special factor of microgravity, the participants will be placed in a -6°head-down bed rest posture for 30 minutes. This will enable them to simulate physical feelings caused by microgravity (Buysse et al.1989). Some scholars also believe that this posture can simulate isolation and restrictive factors in spaceflight (De Chantemèle et al., 2006; Grassian, 2006).

Although the use of an immersive VR system to construct a virtual space station environment can imitate the special factors related to the spacecraft environment, it still cannot fully achieve the real environmental experience. Therefore, only when the participants carry out activities in the space station cabin training simulator can they obtain data feedback of approximate space-based cabins.

3 Analysis of the functions and mission needs of the Chinese Space Station “Tiangong”

The Chinese Space Station "Tiangong" is expected to complete assembly and start operation in 2022 (Zhang et al,.2014). The space station will include a core module, an experimental module Ⅰ and an experimental module Ⅱ. The ultimate goal is a large space station of 60 to 180 tons in low Earth orbit which can accommodate up to seven people (Wang et al,.2018).

The “Tiangong” will be dominated by the core module and will be a combination of unified control and management of a space station (Harvey, 2019). The node module of the core module will be used as the airlock module in the initial stage of the construction of the space station and in the technical verification stage. After the construction of the space station is completed, it will be used as the backup airlock module (Zhou,2013). The core cabin's sealed cabin will mainly contain the astronauts' living facilities. It has a specific payload test capability (Wu, 2017). The experimental module will be mainly used for space science experiments, space applications and space technology experiments. The experimental cabin I will consist of a sealed cabin, an airlock cabin and a resource cabin. In addition to scientific experiments, the sealed cabin will also be used to store consumables for the astronauts and replenishment cargo, and to back up part of the platform function of the core module of the space station (Zhou,2013). The experiment cabin II will be composed of a sealed cabin, an unsealed cabin with multi-functional survey optical facilities and a resource cabin (20), as shown in Figure 2.

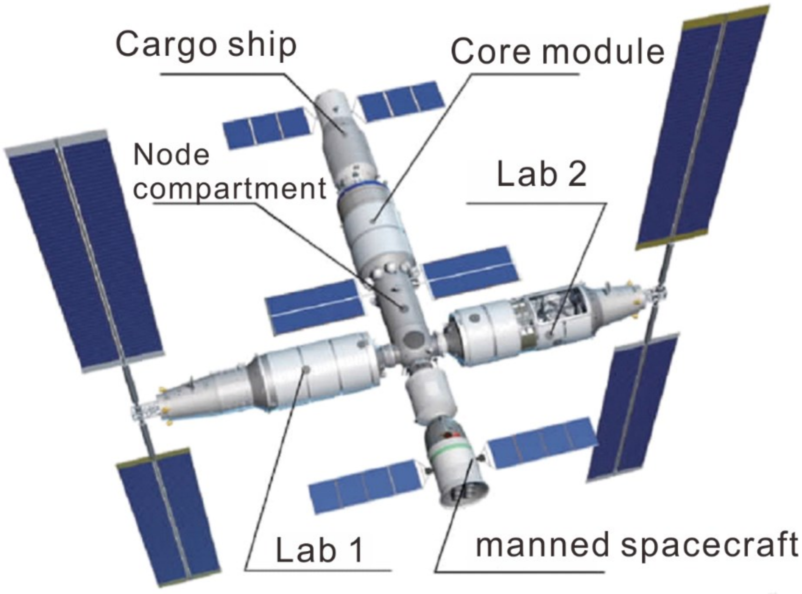


Figure 2. China Space Station Configuration

4 Design of space features in the hygiene area

According to the mission requirements and specific index requirements of the space station's hygiene area, the analysis of the hygiene cycle support function revealed that the astronauts' hygiene activities include urination and defecation, bathing, daily and regular cleaning. The toilet activities include preparation before defecation and activation of defecation collection equipment, defecation activities, self-cleaning after defecation, negative pressure sealing treatment of defecation collection bags, etc. Daily cleaning includes activities such as washing their face, brushing their teeth and shaving. The specific items and methods for each activity need to take into account the astronauts' ability to move in orbit. Regular cleaning includes activities such as shampooing and haircutting, each of which requires the use of special tools. Two astronauts are required to cooperate for on-orbit haircutting and shaving, and the waste generated by a haircut must be collected. According to the analysis of the astronauts' hygiene activities, manned spacecraft needs to provide a dedicated hygiene area, which should be an independent closed space. Its functions include a deodorising function, a lighting function, and adjustment of illuminance. Functional elements include a place for toilet paper, garbage bags, bathroom supplies, hairdressing supplies and daily cleaning supplies. It also requires the possibility to store and sort hygiene supplies and to receive alarm information. Furthermore, a power supply support function for hygiene facilities is necessary.

By analysing the functional elements of the International Space Station's hygiene area and the relevant data of the ISS, the hardware facilities corresponding to the mission needs and functions can be obtained. The human-machine interface of the hygiene area of the International Space Station includes stool collectors, vacuum pumps, urine collectors, urinal funnels, catheters, catheter holders, safety handrails, foot/leg limiters, hygiene kits (diapers, toilet paper, disinfectants), gloves, etc.), as shown in Figure 3.

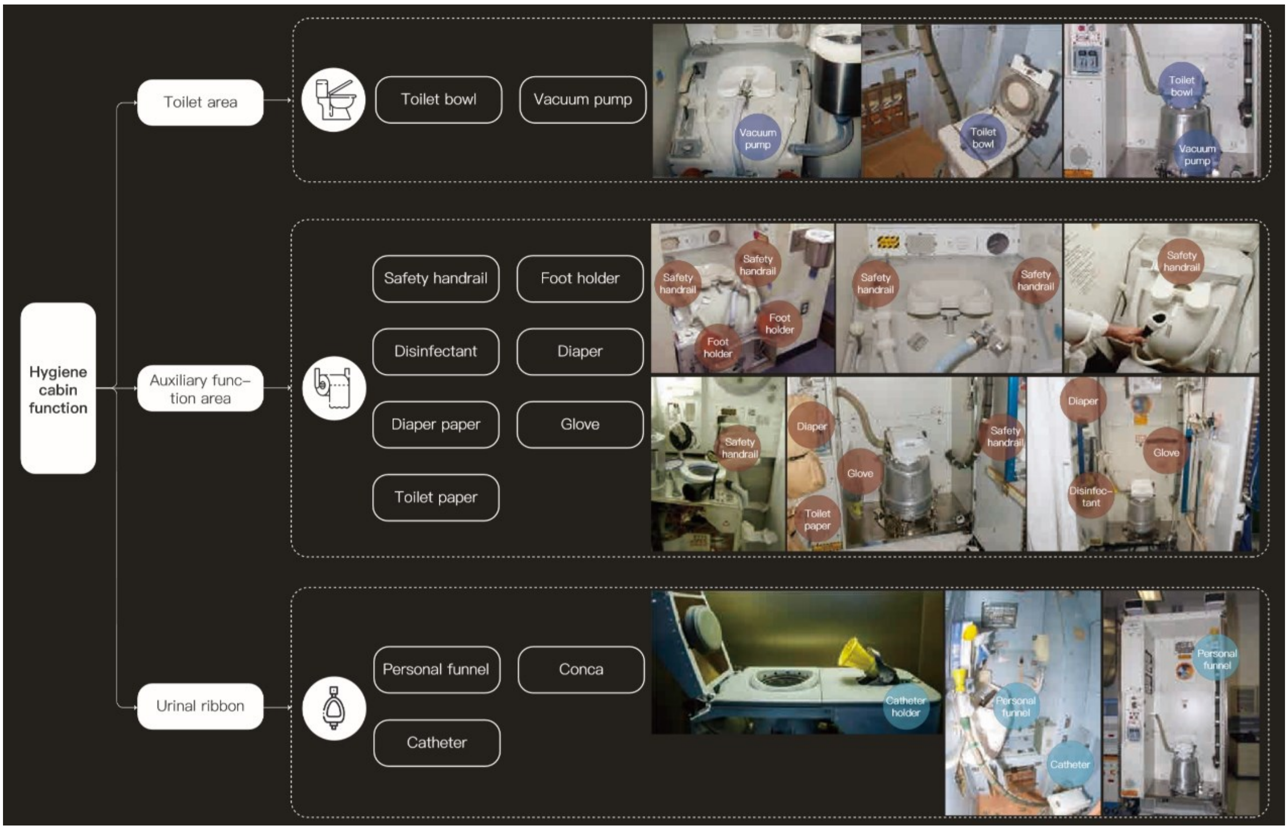


Figure3. Functional elements of the International Space Station's hygiene area

Using the functions and human-machine interface analysis of the above hygiene area as a basis, further analysis of the expected typical operations and behaviours of astronauts on the ISS has resulted in a flow chart of typical operations of the hygiene area. The main processes include the stool collection process and the urine collection process, as shown in Figure 4.

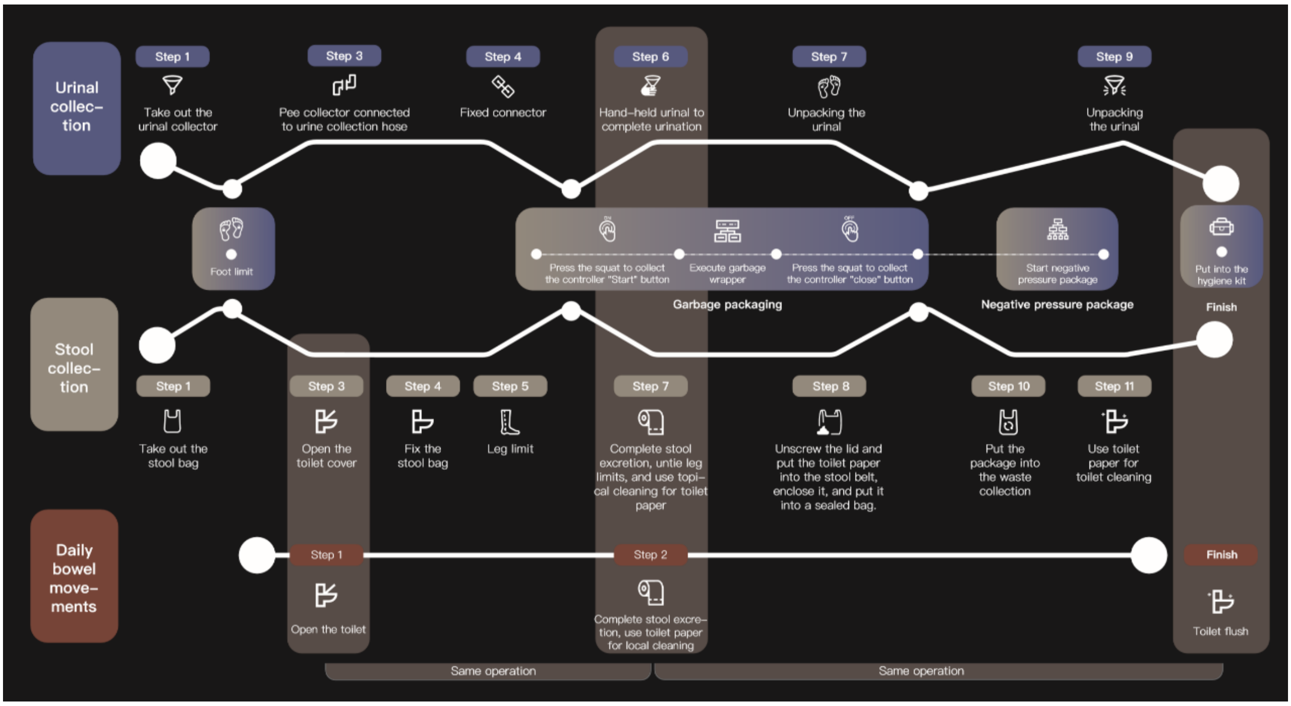
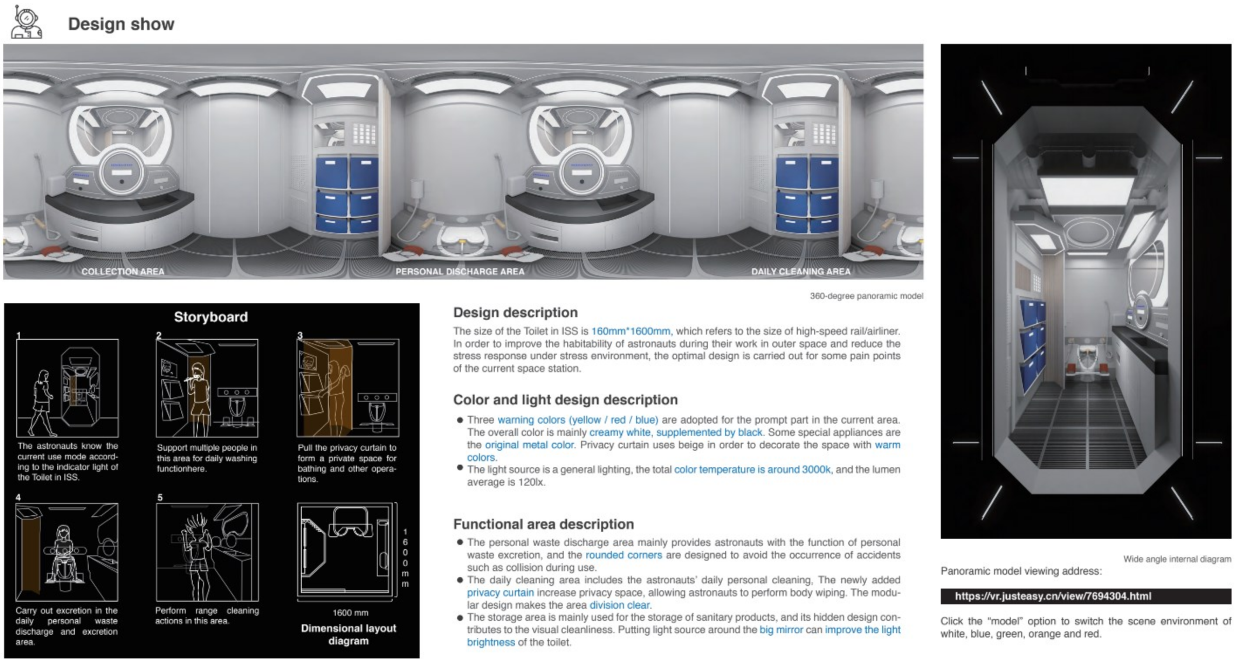


Figure 4. Diagram of the usage pattern of the hygiene area

According to the above space station mission needs and specific index requirements, important information such as the size of the area, the hardware composition, efficacy requirements, usage mode, etc. can be derived for the functional elements of the hygiene area in the Space Station. This was used to optimise space, function, layout and other elements of the design in a hand-drawn 3D design, as shown in Figure 5.



1. The astronauts know the current use mode according to the indicator light of the Toilet in ISS.
2. Support multiple people in this area for daily washing functionhere.
3. Pull the privacy curtain to form a private space for bathing and other operations.
4. Carry out excretion in the daily personal waste discharge and excretion area.
5. Perform range cleaning actions in this area.

Design description

The size of the Toilet in ISS is 160mm*1600mm, which refers to the size of high-speed rail/airliner. In order to improve the habitability of astronauts during their work in outer space and reduce the stress response under stress environment, the optimal design is carried out for some pain points of the current space station.

Color and light design description

- Three warning colors (yellow / red / blue) are adopted for the prompt part in the current area. The overall color is mainly creamy white, supplemented by black. Some special appliances are the original metal color. Privacy curtain uses beige in order to decorate the space with warm colors.
- The light source is a general lighting, the total color temperature is around 3000k, and the lumen average is 120lx.

Functional area description

- The personal waste discharge area mainly provides astronauts with the function of personal waste excretion, and the rounded corners are designed to avoid the occurrence of accidents such as collision during use.
- The daily cleaning area includes the astronauts' daily personal cleaning, The newly added privacy curtain increase privacy space, allowing astronauts to perform body wiping. The modular design makes the area division clear.
- The storage area is mainly used for the storage of sanitary products, and its hidden design contributes to the visual cleanliness. Putting light source around the big mirror can improve the light brightness of the toilet.

Panoramic model viewing address:

https://vr.justeasy.cn/view/7694304.html

Click the "model" option to switch the scene environment of white, blue, green, orange and red.

Figure 5. 3D scene of the hygiene area

5 Conclusion

The design will consider the colour design of the human-machine interfaces of the hygiene area. The project takes the basic knowledge about astronaut-related factors and ergonomics as the overall direction of the project and uses the astronauts' abilities as the baseline to design the human-machine interfaces of the space station. At the same time, the hygiene area's human-machine interface colour design was verified and optimised with spacecraft ergonomic requirements and evaluation as constraints. Also, the effects of colour and light in spacecraft on people were summarised, the influence of colour and light on human abilities in the space environment was understood, and directional support was provided for the colour experiment and colour feature selection of the project. Finally, by analysing the application of virtual reality technology in the field of human factors engineering in space, I now understand the usage principle and the experimental specifications of this new technology and can thus provide a guarantee for the effectiveness and credibility of the subsequent VR experiments of the project.

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