The Influence of Numerical Displays on Human Performance in the Manual RVD Task

Wang Liu[1,2], Yu Tian[1(✉)], Chunhui Wang[1], Weifen Huang[1], Shanguang Chen[1], and Jun Wang[2]

[1] National Key Laboratory of Human Factors Engineering, China Astronaut Research and Training Center, Beijing 100094, China
{acc_liuwang, hwf_2006}@sina.com,
{cctian, shanguang_chen}@126.com, chunhui_89@163.com
[2] School of Aviation Science and Engineering, Beijing University of Aeronautics and Astronautics, Beijing 100191, China
wangjun@buaa.edu.cn

Abstract. The present study aims to identify the influence of the display of numerical data on human performance in the manually controlled rendezvous and docking (manual RVD) task. Two display schemes were designed and developed in a RVD simulator, one display scheme with numerical data (Display A) and the other without numerical data (Display B). Twelve male subjects completed four trials of RVD simulations on the RVD simulator each, two trials observing Display A, and two trials observing Display B. Deviation data, such as the horizontal deviation (Y), the vertical deviation (Z), the roll deviation ($\emptyset$), the pitch deviation (θ), the yaw deviation (φ), are automatically recorded. Results show that the display of the numerical data are helpful for the diminishing of the pitch deviation (θ) and the yaw deviation (φ), while the roll deviation ($\emptyset$) does not change significantly in the two conditions, the horizontal deviation (Y) and the vertical deviation (Z) indices seem to be affected negatively by the numerical display. Based on analysis of the results, we suggest that numerical data of the pitch deviation (θ) and the yaw deviation (φ) should be highlighted on the interface, meanwhile operators should pay more attention to the control of horizontal deviation (Y) and the vertical deviation (Z) when there are numerical displays.

Keywords: Manually controlled rendezvous and docking (manual RVD) · Numerical display · Human performance

1 Background

Manually controlled rendezvous and docking (manual RVD) of space vehicles is a complex human computer interaction (HCI) task for astronauts. Manual RVD task generally involves two spacecrafts, namely, a chaser spacecraft and a target spacecraft. In the manual RVD task, the operator, displays, and controllers form a closed loop [1], as shown in Fig. 1. Video image of the target spacecraft obtained from the cameras is

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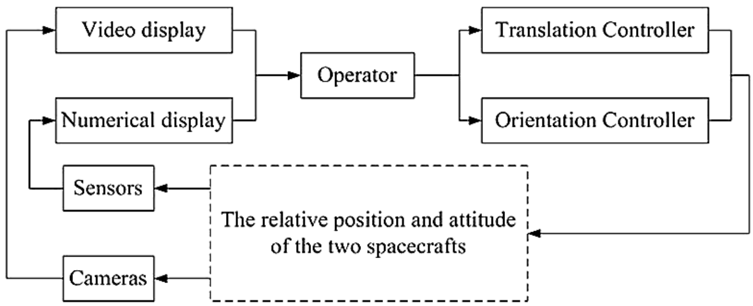

Fig. 1. The display-human-controller loop in the manual RVD task

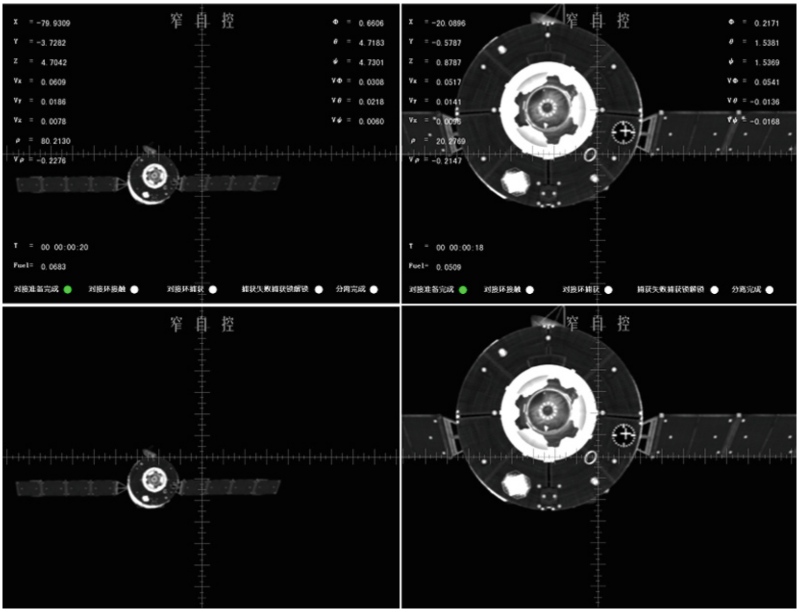

Fig. 2. Video images displayed on the monitoring interface in the manual RVD simulator. Left column: When the distance between the two spacecrafts is around 80 m, the whole profile of the target spacecraft can be seen; Right column: When the distance between the two spacecrafts is around 20 m, the cross drone on the target spacecraft can be viewed clearly, meanwhile only part of the target spacecraft profile can be seen. First row: Interface with numerical displays; Second row: Interface without numerical displays.

displayed on the monitoring interface, numerical data obtained from the sensors which indicate the relative position and attitude of the two spacecrafts can be overlaid on the edge of the interface (displaying the numerical data is optional in the manual RVD system) [2], as shown in Fig. 2. The operator observes the information displayed on the monitoring interface and manipulates the controllers to complete the manual RVD task. The system includes two controllers in the chaser spacecraft: one translation controller,

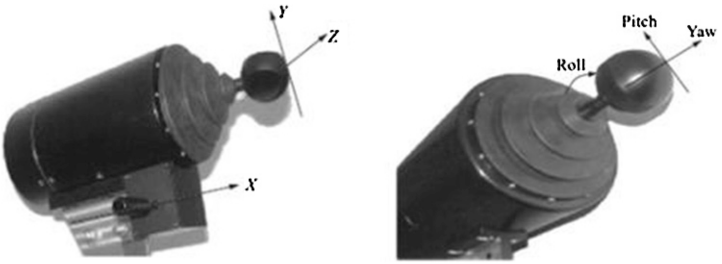

Fig. 3. The two controllers of the manual RVD system. (a) Left: the translation controller which controls the X, Y, and Z axes of the chaser's position. (b) Right: the orientation controller which controls the yaw, pitch, and roll of the chaser's attitude.

shown in Fig. 3a, which controls the X, Y, and Z axes of the chaser's position, and one orientation controller, shown in Fig. 3b, which controls the yaw, pitch, and roll of the chaser's attitude [3].

Researches have shown that human performance in the manual RVD tasks are influenced by many factors, such as the ergonomic design of the manual RVD system [4], the cognitive abilities of the operator [2, 5], and the complexity of the RVD tasks [3].

Researches concerning the influence of ergonomic design on human performance in manual RVD task have investigated several key factors in the display and control loop, such as the polarity of the controllers, the gain of the controller, the delay time for the system to respond, the size, shape, and color of the target cross-drone on the object space vehicle [6]. However, the influence of the display of numerical data on human performance in the manual RVD task has not been clearly indentified in previous studies, while displaying the numerical data on the interface is optional in the manual RVD system in China. So the present study aims to indentify the influence by empirical data, and to provide helpful guidance for the design of the monitoring interface of the RVD task.

2 Methods

2.1 Experiment Design

The current empirical research was conducted on a RVD simulation system. The manual RVD simulation system was designed and developed by technicians at the China Astronaut Research and Training Center [7]. The simulation system was established by modeling and simulating the Guidance, Navigation, and Controls Systems (GNC), the docking mechanisms, the instrumentation, the TV video system, and the cabin environment. The experimental schemes and initial parameters of the simulated RVD tasks can be configured.

Two display schemes were designed and developed in a RVD simulator, namely display scheme with numerical data (Display A) and display scheme without numerical data (Display B), as demonstrated in Fig. 2.

Each subject had to complete four trials of RVD simulations, two trials observing Display A, two trials observing Display B. The sequences of the trials were balanced among the subjects. The initial deviations of the two space vehicles in the four trials were set as Table 1. The four trials are at the same difficulty level. Deviation data, such as the horizontal deviation (Y), the vertical deviation (Z), the roll deviation (∅), the pitch deviation (θ), the yaw deviation (φ), are automatically recorded every 40 ms by the simulation system. Deviations of the Y, Z, ∅, θ, φ at the distance of 80 m, 50 m, 30 m, 20 m, 10 m, 5 m, 2 m were selected to indicate the dynamic control performance of the operators. The performance outcome of Display A and Display B were compared to analyze the influence of numerical display on human performance in RVD tasks.

Table 1. The initial deviations of the two space vehicles in the four trials of manual RVD simulations.

Task ID	Numerical display	X (m)	Y (m)	Z (m)	∅ (°)	θ(°)	φ(°)
T1	With	100	−10	10	−5	−6	−6
T2	With	100	−10	−10	5	6	−6
T3	Without	100	10	10	−5	−6	6
T4	Without	100	10	−10	5	6	6

2.2 Subjects

Twelve male subjects, technicians from the China Astronaut Research and Training Center, participated in the experiment. The subjects' ages range from 27 to 38 years. The subjects are all right-handed, have normal sight and hearing, and hold at least a bachelor's degree. The subjects had at least 6 h of training and practice before the current experiment, and had adequate knowledge and skills for completing the manual RVD simulations.

3 Results

3.1 The Orientation Deviations

The roll deviation (∅), the pitch deviation (θ) and the yaw deviation (φ) are three orientation parameters and are manipulated by the orientation controller. If any of the three orientation deviation at the docking moment exceeds 4°, the RVD task will fail. The orientation deviation data were shown in Figs. 4, 5 and 6. From the figures, we can see that:

(1) The orientation deviations of the subjects observing displays with numerical data are generally smaller than that without numerical data. However, there is an exceptional case, the roll deviations (∅) of the subjects observing displays with numerical data at the distance of 80 m is significantly larger than that without numerical data.
(2) Averagely, the pitch deviation (θ) and the yaw deviation (φ) are reduced to be less than one degree when the distance (X) between the two space vehicles is around

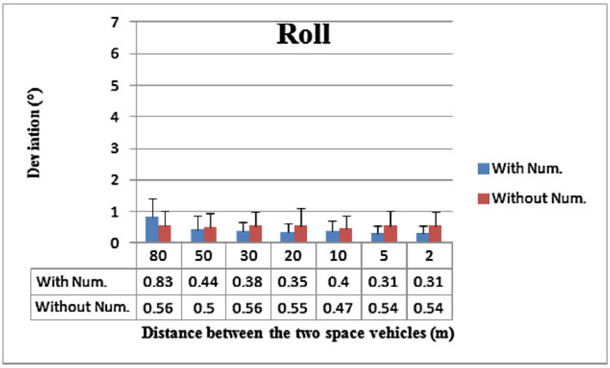

Fig. 4. Roll deviations at the distance of 80 m, 50 m, 30 m, 20 m, 10 m, 5 m, 2 m (Mean and STD of the twelve subjects). (Color figure online)

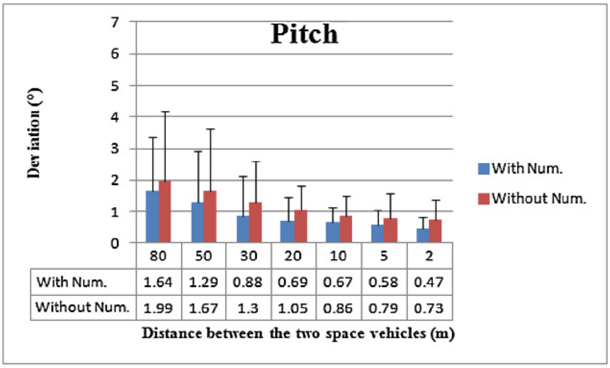

Fig. 5. Pitch deviations at the distance of 80 m, 50 m, 30 m, 20 m, 10 m, 5 m, 2 m (Mean and STD of the twelve subjects). (Color figure online)

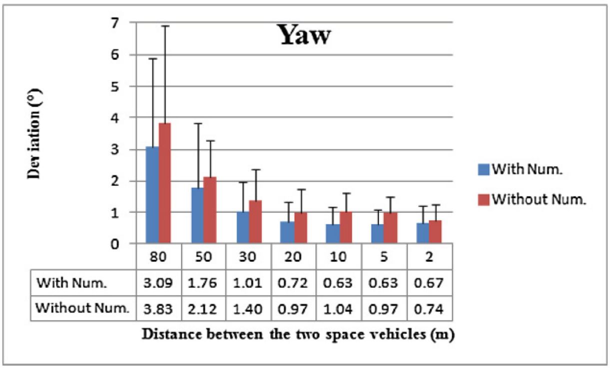

Fig. 6. Yaw deviations at the distance of 80 m, 50 m, 30 m, 20 m, 10 m, 5 m, 2 m (Mean and STD of the twelve subjects). (Color figure online)

30 m, while the roll deviations (∅) is reduced to be less than one degree when the distance (X) between the two space vehicles is as far as 80 m.

(3) The roll deviations (∅) are significantly smaller than the pitch deviations (θ) and the yaw deviations (φ) in the whole task process, especially when the distance (X) between the two space vehicles is over 30 m.

(4) The orientation deviations (∅, θ, φ) are mainly diminished before the distance reaches 30 m, there is no significant decrease of orientation deviations when the distance is closer than 30 m.

3.2 The Translation Deviations

The horizontal deviation (Y) and the vertical deviation (Z) are two main translation indices indicating human performance, and are manipulated by the translation controller. The distance (X) between the two space vehicles is always diminished to approximately zero at the moment of docking, so it is not listed as a performance index in the current paper. If the translation deviation (calculated by $\sqrt{Y^2 + Z^2}$) at the docking moment exceeds 0.15 m, the RVD task will fail. The translation deviation data were shown in Figs. 7 and 8. From the figures, we can see that:

(1) The translation deviations of the subjects observing displays with numerical data are bigger than that without numerical data in the early stage, when the distance (X) between the two space vehicles is over 30 m. When the distance (X) between the two space vehicles is less than 20 m, there is no significant difference between the translation deviations of the subjects observing displays with numerical data are bigger and that without numerical data.

(2) At the very early stage of the task, that is when the distance is over 80 m, the horizontal deviation (Y) have been reduced more than the vertical deviation (Z). When the distance (X) between the two space vehicles is less than 50 m, there is no significant difference between the horizontal deviation (Y) and the vertical deviation (Z).

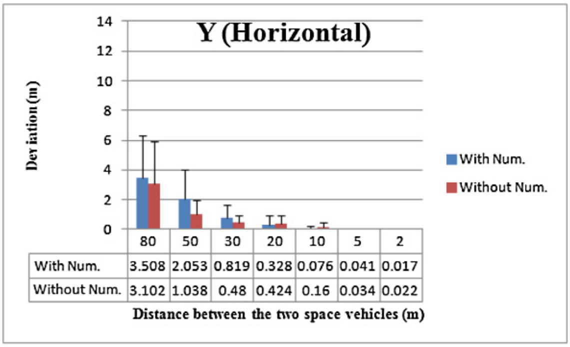

Fig. 7. Horizontal deviations at the distance of 80 m, 50 m, 30 m, 20 m, 10 m, 5 m, 2 m (Mean and STD of the twelve subjects). (Color figure online)

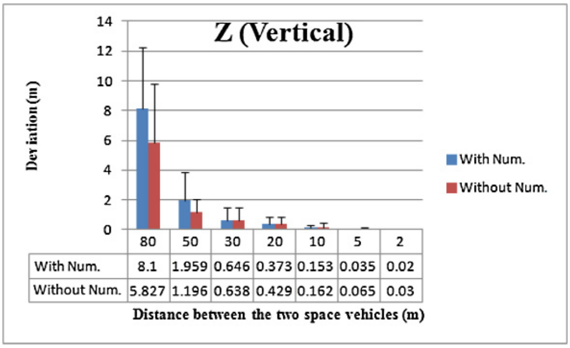

Fig. 8. Vertical deviations at the distance of 80 m, 50 m, 30 m, 20 m, 10 m, 5 m, 2 m (Mean and STD of the twelve subjects). (Color figure online)

(3) Averagely, the translation deviations have been decreased in the whole task process, and meet the success criteria when the distance (X) between the two space vehicles is closer than 10 m.

4 Discussions

From the empirical data we can deduce that the display of the numerical data are helpful for the diminishing of the pitch deviation (θ) and the yaw deviation (φ), while the roll deviation (∅) does not change significantly in the two conditions, the horizontal deviation (Y) and the vertical deviation (Z) indices seem to be affected negatively by the numerical display.

By interviewing with several manual RVD experts, the results were interpreted. The pitch deviation (θ) and the yaw deviation (φ) are difficult to perceive and judge from the video images of the target space vehicle, especially at a far distance, so numerical data of the pitch deviation (θ) and the yaw deviation (φ) reduce the perceiving workload and improve the judge accuracy, thus the pitch deviation (θ) and the yaw deviation (φ) are consistently lower in Display A than Display B. The roll deviation (∅) can be judged from the angle of the solar panels, which is relatively easy to judge even at a far distance, and the roll deviation is regulated to a quite small scale (less than 1° on average) in the first 20 m, so the numerical display does not influence control accuracy of the roll deviation (∅) significantly. The situation is quite similar for the horizontal deviation (Y) and the vertical deviation (Z), human operators generally obtain the translation deviation information from the video images and do not rely on numerical displays. Meanwhile, numerical display seems to change the priority of the control dimensions: while the roll deviation (∅) is always the first dimension to be controlled, the pitch deviation (θ) and the yaw deviation (φ) are more likely to be controlled more frequently in the early stages of the task when there are numerical displays. As a result the horizontal deviation (Y) and the vertical deviation (Z) receive less attention and the indices are worse in the early stages when there are numerical display.

The empirical data also show although the deviation data of the subjects observing Display A than Display B have significant differences in the early stages of the RVD task (when the distance is over 30 m in the current study), there is no significant difference in the final stages (especially when the distance is less than 10 m). Indicating that the designs of the video image display for the RVD task support effective perception and judgment.

Based on the results of the present study, we suggest that numerical data of the pitch deviation (θ) and the yaw deviation (φ) should be highlighted on the interface, and the operators should pay more attention to the control of horizontal deviation (Y) and the vertical deviation (Z) when there are numerical displays. The present study suggests that the overlying of numerical data on the HCI interfaces may cause complex effects for dynamic control tasks, and when we design interfaces with image displays and numerical displays, the information displayed and the layout of the numerical displays should be considered carefully.

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References

1. Jiang, T., Wang, C., Tian, Z., Xu, Y., Wang, Z.: Study on synthetic evaluation of human performance in manually controlled spacecraft rendezvous and docking tasks. In: Duffy, V.G. (ed.) ICDHM 2011. LNCS, vol. 6777, pp. 387–393. Springer, Heidelberg (2011)
2. Wang, C., Tian, Y., Chen, S., Tian, Z., Jiang, T., Du, F.: Predicting performance in manually controlled rendezvous and docking through spatial abilities. Adv. Space Res. **53**(2), 362–369 (2014)
3. Zhang, Y., Xu, Y., Li, Z., Li, J., Wu, S.: Influence of monitoring method and control complexity on operator performance in manually controlled spacecraft rendezvous and docking. Tsinghua Sci. Technol. **13**(5), 619–624 (2011)
4. Wang, C., Jiang, T.: Study on ergonomic design of display-control system in manual-control rendezvous and docking. Manned Spaceflight **17**, 50–53, 64 (2011). (in Chinese)
5. Du, X., Zhang, Y., Tian, Y., Huang, W., Wu, B., Zhang, J.: The influence of spatial ability and experience on performance during spaceship rendezvous and docking. Front. Psychol. **6**, 955 (2015)
6. Wang, C., Jiang, T. Tian, Y., Chen, S.: Human factors in manually controlled rendezvous and docking: implications for engineering better designs. In: Human Performance in Space: Advancing Astronautics Research in China, Science/AAAS, Washington, DC, pp. 26–27 (2014)
7. Wang, B., Jiang, G., Chao, J., Wang, X., Wang, Y., Wang, C., Lian, S.: Design and implement of manned rendezvous and docking ergonomics experimental system. Space Med. Med. Eng. **24**, 30–35 (2011). (in Chinese)