# Comparative Study on the Reachability Distance Measurement Method: Difference Between the Real Environment and Mixed Reality Simulation

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**Abstract.** The study aimed to analyze the feasibility of Mixed-Reality (MR) in measuring reachability distance and to compare it with the real environment method. The effect of participants' gender was also taken into consideration. Thirty-six subjects were recruited in this study. Subjects were asked to provide the reachability distance they perceived when they faced the confederate in both real environment and MR environment. Two-way ANOVA was used to clarify the relationship between the independent variables (participants' gender and measurement method) and the dependent variable (reachability distance). The intraclass correlation coefficient was used to indicate the reliability of these two measurement methods. The experiment results showed that the distance measured in the MR environment was consistent with that collected in the real environment, and the MR simulation method showed higher reliability. For the gender effect, the reachability distance of male subjects was larger than that of female subjects. In addition, there was no significant interaction effect between gender and measurement method. The findings of this study validated the reliability of the MR simulation method when collecting reachability distance and proposed that MR technology was a promising tool in conducting psychological experiments and studying human behaviors.

**Keywords:** Mixed reality · Reachability distance · HoloLens2 · Comparative evaluation

## 1 Introduction

In the neuro-cognitive field, the space around people is called peripersonal space (PPS), in which individuals can reach out and interact with other people and objects around themselves [1–3]. As the range is seen as the first barrier between people and the outside world, individuals feel safe from being violated by others outside of that space


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[4]. Besides, PPS is of great importance for the individual in predicting and detecting interactions [5].

The "reachability distance measurement" is a typical method to measure the size of peripersonal space [3, 6]. Subjects are required to estimate the reachability distance to the confederate when they interact with the confederate in a real environment and the distance was measured by the experimenter [6]. Previous studies indicated that the reachability distance people perceived can be modulated by many factors of confederate such as the facial expression, eye gaze, among others. It is hard to control these variables at a constant level by the real environment measurement method, and the expression has a great influence on the experimental results [7–9].

Virtual reality technology has been widely used in psychological experiments, which can easily simulate different social interaction scenes and virtual characters to save space and labor costs [10]. Although the results of Bailenson et al. [11] have demonstrated the feasibility of virtual reality technology in studying the interpersonal distance. The previous experiment showed that there are still differences between the virtual reality simulation and real environments in collecting the reachability distance [10]. Moreover, the study of Lee et al. [12] pointed out that both the reachability distance and comfort distance measured by virtual reality simulation was larger than that measured by the real environment method.

At the same time, mixed reality (MR) technology has become a noteworthy evaluation method. Previous studies applied MR and VR technology in the field of surgical simulation and medical training, and the results proved the superiority of the technique in authenticity and immersion through comparative experiments [13, 14]. MR technology can well mix the holographic model with the real environment, which helps the experimenter control unrelated variables such as confederation's facial expression and ambient light during the experimental procedure. Yu and Lee [12, 15] analyzed the influence of virtual reality on human comfort distance and reachability distance with the help of VR technology. To the best of our knowledge, however, there is little research on the difference between MR environment and real environment in measuring reachability distance. Therefore, this study aims to evaluate the difference between these two measurement environments and compare the reliability of the two methods.

## 2 Method

### 2.1 Subjects

This study recruited 36 university students (18 male) aged between 19 and 27. The subjects had normal vision. The average height and the average arm length of male subjects were 177.11 cm and 73.95 cm, respectively; the average height and the average arm length of female subjects were 164.11 cm and 68.38 cm, respectively. All the subjects didn't know the purpose of the experiment before the experiment and each of them made an informed registration.

### 2.2 Experimental Setting

The experiment was conducted in an empty room (5.8 m * 8.0 m). The facilities and lighting inside the room were always consistent. There was a 4 m yellow guideline on the ground to guide the subjects to walk along. The experiment recruited a 178 cm tall confederate who had a general appearance of Chinese and always maintains a neutral expression.

The experimental scene was developed by Unity 3D (Unity, Unity, California, United States) and was released to a pair of MR glasses (HoloLens2, Microsoft, Redmond, United States). Subjects wearing hololens2 could see a holographic model of confederate standing in a fixed position. Subjects were allowed to walk around in the room freely. The glasses have a 2K resolution screen and 60 Hz refresh rate, with a FOV of 43° horizontally and 29° longitudinally [16]. Since the interaction of the device can be conducted entirely by gesture and voice, the subjects didn't need to hold any other accessories.

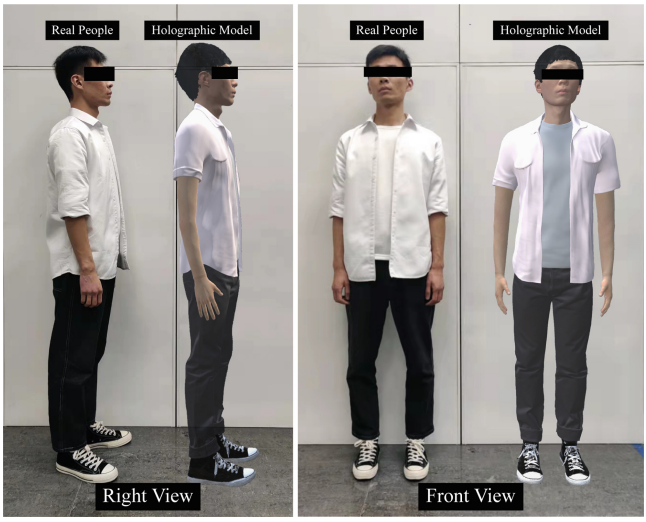


**Fig. 1.** The side view and front view of the holographic model and real person in this study

To control the confederate unchanged and enhance the immersion of subjects, as shown in Fig. 1, the holographic model of confederate was scanned by a 3D scanner (Reeyee Pro 2x, Reeyee, Nanjing, China) and then reconstructed in a three-dimensional modeling software (Maya, Autodesk, California, United States) to ensure that the holographic model is close to reality. The standing position, clothing, and hairstyle of the confederate in the real environment and the virtual environment were always the same.

### 2.3 Procedure

The experiment was divided into two stages: real environment and MR environment. Before the experiment, the subject was required to fill out the informed consent form and complete the basic information survey. The experimenter introduced the experimental process orally to each participant. A marked point was attached to the toe cap of the subjects to increase the measurement precision.

For the real environment measurement method, at the beginning of the experiment, the confederate should stand in the middle of the guideline naturally, align his feet with the ground marker, and keep his feet 15 cm apart. The subjects were asked to approach the confederate from a distance of 3 m at a speed of 0.5 m per second until they felt they could touch the confederate with their hands. After the subjects stopped and identified the position, the distance from the ground mark to the tip of the subject's shoe was measured using a laser rangefinder. During each trial, subjects were asked to see the chin of the confederate to reduce the effect of eye gazing [17]. Before the formal measurement, the subjects need to complete two pre-tests to become familiar with the experimental process.

As for the MR simulation measurement method, the experimenter helped the subjects wear the MR glasses comfortably. After confirming that the hologram was in the right position, the subjects were allowed to walk around the room for about five minutes to familiarize themselves with the environment. The measurement method, experimental details, and the movement of the subjects in the experiment are consistent with those in the real environment.

Each trial was repeated twice, a 5-min break was provided to each subject between two stages to avoid fatigue. Before each stage of the experiment, the laser rangefinder was calibrated to avoid measurement errors. The order of the two stages was randomly assigned and counterbalanced. Each trial took about 30 s, and each subject took about 20 min in total.

### 2.4 Statistical Analysis

SPSS 25.0 was used to analyze the data with a significance level of 0.05. According to S-W Test, the experimental data presented normal distribution. and the data passed the Levene Test. Descriptive statistics show the preliminary relationship between different dependent variables clearly. Two-way ANOVA was used to further analyze the effects of gender and experimental method on the reachability distance. Besides, the reliability and repeatability of MR and real measurement method were evaluated by intraclass correlation coefficient (ICC) analysis.

## 3 Results

The reachability distance of male and female subjects measured by the two methods was shown in Fig. 2, results showed that the reachability distance of female subjects ($M = 63.07$ cm, $SD = 8.45$ cm) was smaller than that of male subjects ($M = 70.53$ cm, $SD = 9.11$ cm). For both males and females, the data from MR and the real environment were very close.

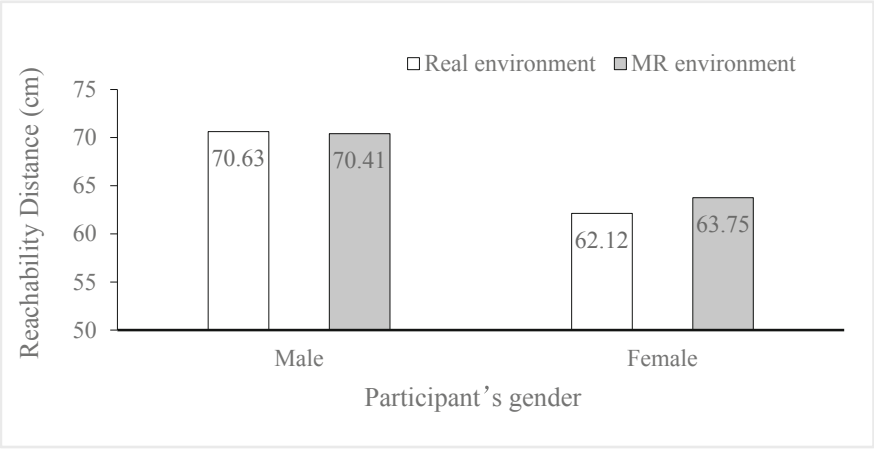


**Fig. 2.** Reachability distance of male and female participants in two methods

In further two-way ANOVA analysis as shown in Table 1, the effect of participants' gender on the reachability distance was significant ($F = 15.643$, $p < 0.001$, $\eta^2 = 0.201$). There was no significant difference between the real and MR method in measuring the reachability distance ($F = 0.134$, $p = 0.715$). In addition, there was no significant interaction between gender and measurement methods.

**Table 1.** Two-way ANOVA results on reachability distance (cm)

| Terms | F | df | p-value | $\eta^2$ |
|---|---|---|---|---|
| Participant's gender | 15.643 | 1 | 0.000 | 0.201 |
| Method | 0.134 | 1 | 0.715 | 0.002 |
| Participant's gender*method | 0.232 | 1 | 0.632 | 0.004 |

Table 2 showed the ICCs of two different methods under twice replicate measurements. The data indicated that both methods had high reliability and repeatability, the repeatability of MR simulation measurement (ICC = 0.96) was slightly higher than that of the real method (ICC = 0.95).

**Table 2.** Intraclass correlation coefficient (ICCs) results of two measurement methods

| Method | ICC |
|---|---|
| Real environment | 0.95 |
| Mixed reality simulation | 0.96 |

## 4 Discussion

The data analysis showed that the reachability distance of female subjects was smaller than that of male subjects, which was consistent with findings of Iachini et al. [17, 18]. The main reason for the difference was that the arm length of male subjects (M = 73.95 cm, SD = 2.51 cm) was larger than that of female subjects (M = 68.38 cm, SD = 4.09 cm).

From the analysis, we could know that as two methods, MR and real measurement showed same results in measuring the reachability distance, which means there was no difference in distance perception between the real person and the holographic model for the subjects. This finding indicated that MR technology is an effective tool for measuring reachability distance.

In a real-world environment, it's hard to control the posture of the confederate and remain the environment always the same. Previous research showed that experiment in a virtual reality environment needs a lot of work to build virtual scenes, and such visual effects were still difficult to be close to the real environment [10]. MR techniques can address both issues simultaneously, saving effort and better controlling for irrelevant variables.

The ICC levels of both measurement and real-world measurement were very high (both above 0.95), which showed that the overall design of the experiment and the two measurement methods both had sufficient reliability and repeatability. The ICC data of the MR measurement method was slightly higher than that of the real measurement method, possibly because the expression, posture, and eyes of the holographic model were more stable than those of the real person. Moreover, based on the observations in the MR measurement methods section, subjects would intentionally bypass or attempt to touch the holographic model in the scene, which also demonstrated that the experimental environment could give subjects a sufficient sense of authenticity and immersion. This finding was consistent with the post-experimental interview results.

Overall, there was no difference between the reachability distance measured by MR techniques and the real environment. Both MR and real environmental measurement methods collected highly consistent results for both male and female subjects. Besides, the MR simulation measurement method had slightly higher reliability than real environment measurement.

## 5 Conclusion

The homogeneity of the results in collecting reachability distance between two methods showed that the different methods don't affect the reachability distance, the MR technique can be used as a good alternative to the real measurement method. In the field of psychology, MR simulation can give subjects an environment with sufficient feelings of authenticity. The current experiment mainly focuses on the reachability distance in front of the confederate, and it is worth investigating whether the reachability distance in the lateral and back direction remains the same under different environment methods. In addition, the subjects for this experiment were all recruited from universities with high acceptance of the new technology, which needs to be extended to a wider age range

for future studies. This study verified the feasibility of MR technology in psychological experiments and provided a theoretical basis for other researchers to choose appropriate experimental methods for their experiments. With the advancement of mixed reality technology, experiments assisted by MR will show higher reliability, and MR will be applied in a wider scenario.

**Compliance with Ethical Standards.** The study was approved by the Logistics Department for Civilian Ethics Committee of South China University of Technology.

All subjects who participated in the experiment were provided with and signed an informed consent form.

All relevant ethical safeguards have been met with regard to subject protection.

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