Capability for Collision Avoidance of Different User Avatars in Virtual Reality

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Abstract. Virtual Reality applications transfer users into immersive virtual environments, which can be shared with other remote or local users. Yet, multiple local users may collide, since the HMD obscures the view on the other party. To overcome this issue, a user avatar allows to estimate the location of others and to avoid collisions. However, different avatar representations can be used. We compare four avatars in a 28 participant user study. The comparison shows that the different avatars affect the number of collisions and the overall feeling of safety. As a result, local VR collaboration applications should represent the body of the user or highlight his or her location to increase user safety.

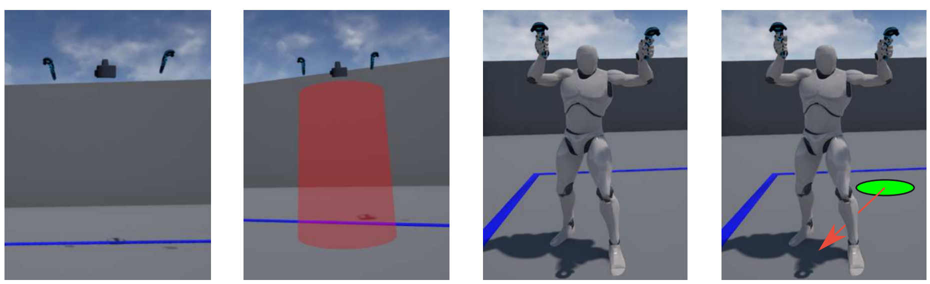
1 Introduction

Virtual Reality (VR) applications allow user collaboration in a remote or locally shared physical space. A multi-user environment lets users engage in collaborative work to achieve better results [5, 7]. Local collaboration has several advantages that a remote system cannot offer. Two local users in the same physical space can touch each other or exchange real objects, e.g. a controller or a hammer. Furthermore, only one area needs to be freed and equipped with a VR tracking system, which saves money. Also, local users can talk to each other and do not need to use a voice communication tool. A disadvantage of the local approach is the possibility of user contact, which can damage the hardware or even hurt the involved parties. To overcome this issue we present users with different avatar representations of the surrounding users. The various avatars are then compared regarding their ability to signal the other user's location and therefore provide collision avoidance guidance and a feeling of safety.

2 Related Work

Several systems use local user collaboration to solve tasks in VR [9, 1]. Salzmann et al. [6] developed an assembly training system using prop-based and virtual manipulation techniques. Two users, each wearing a Head Mounted Display (HMD), insert a windscreen into a virtual car. The users stood on a fixed location with sufficient distance, therefore user collision was impossible. The prop-based interaction improves task performance and collaboration, as well as achieves higher subjective ratings. In addition to that the prop provides passive haptic feedback and gives a direct connection between both participants. Beck et al. [3] use a CAVE-based system approach for group-to-group communication. Several local users perceive the virtual world from their own viewpoint using shutter glasses. All of them are projected into the virtual world via a 3D camera. This setup allows collision avoidance, because the local users do not wear a HMD and see each other. However, all users of a local group move as a unit through the VR world and individual user locomotion is not possible. Azmandian et al. [2] solve the collision problem of local users by altering their paths of movement. In a theoretical experiment they test different strategies for redirected walking to keep users apart. The disadvantage of this approach is that it does not aid collision avoidance when users are standing close to each other.

3 User Avatars for Collision Avoidance



Basic avatar (BA) Cylinder avatar (CA) Full-body avatar (FA) Shifted avatar (SA)

Fig. 1: The four different avatars that are compared regarding their capability to avoid collisions. The green circle of the shifted avatar represents the real position of the user and the avatar is shifted towards the location of the current user.

A user avatar allows to estimate the location of others and therefore to avoid collisions. However, different avatar representations can be used. Several VR applications use a very basic user representation and only show the HMD and the two controllers that the user holds. We call this the basic avatar (BA) (see Fig. 1). This representation is very easy, since the location of the hardware is known and no additional effort is needed to use the BA. However, the floating HMD and controllers are very subtle. To increase the visibility of this avatar, we fitted it with a static bounding cylinder that can be seen by other users. Due to its strong indication, the cylinder avatar (CA) highlights the current location of the user and aids the users perception. With the use of pose tracking, a full-body avatar (FA) can be displayed. The FA brings all the movements of the user into VR. If external pose tracking is not available or unwanted it is furthermore possible to use inverse kinematic to estimate the location of the joints from the pose of the HMD and controllers, which is given through the VR system. Since we aimed to minimize effort and hardware cost to integrate the avatars in any application, we chose the second option. Because only the information about the head and hands was available, the legs of the FA did not move. If additional tracking is added to the feet this issue can be resolved. Because of network or application lag, it is possible that during a quick motion a user avatar is not updated as quickly as it needs to. The result might be that another user appears further away than he really is. With the shifted avatar (SA) a user appears to be closer in VR than he is in the real world, thereby introducing a buffer to further decrease the risk of collision.

4 Evaluation

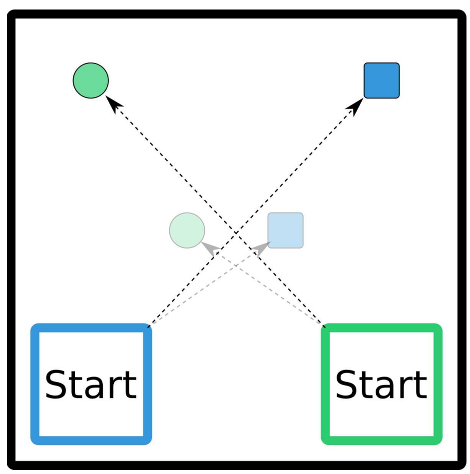


Fig. 2: The setup of the competitive user study. Both participants need to access an object, but their path's cross. The objects were placed at different distances with an even distribution.

We compared the four presented avatars in a 28 participant user study. To evaluate the capabilities of the different avatars a scenario was designed that would provoke collisions. In a competitive task, two users were asked to reach a target object as fast as possible without colliding with the other participant. The objects were placed at two different distances (evenly distributed) and so that the path of the users crossed (see Fig. 2). For each avatar a set of eight rounds, three training rounds and five timed rounds, was performed. One round begins with a countdown and both users standing in their respective start zone. The round ends when a user grabs the object assigned to him/her. At the end of a set, users were presented with a questionnaire containing six questions rated on a five point Likert-scale.

Two participants completed one set of rounds, both using the same avatar. Each pair used all four avatars and performed four sets in total. The order of the used avatars was randomized to compensate for training and fatigue effects. At the very end a final questionnaire was given to the participants.

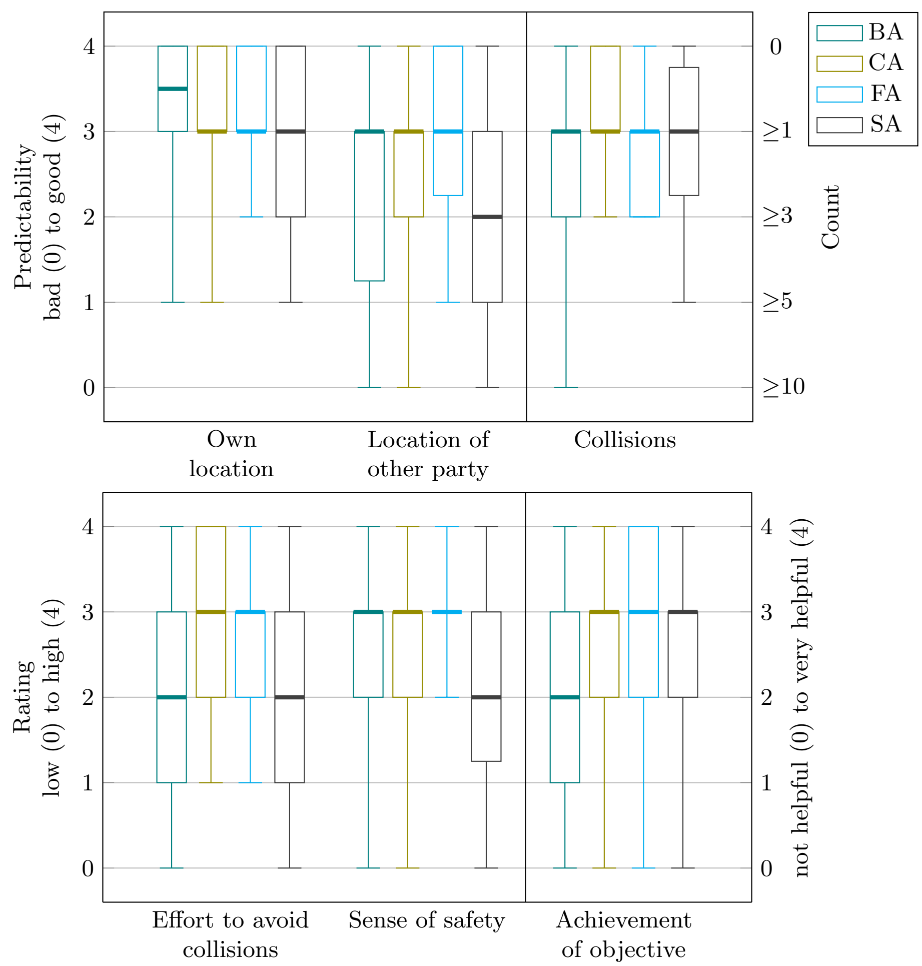


Fig. 3: Questionnaire with box-and-whisker plots for the different avatars.

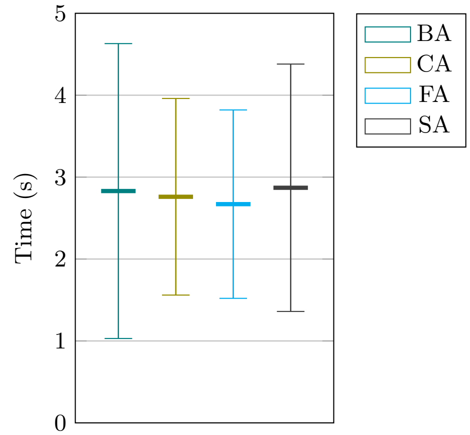


Fig. 4: Timings with average and standard deviation for the different avatars.

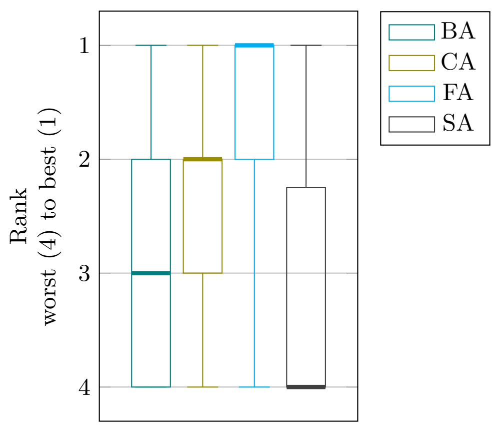


Fig. 5: Preference rating with box-and-whisker plots for the different avatars (only ratings of users that noticed the shift).

The results of the questionnaire (see Fig. 3) show that the different avatars affect the number of collisions and the overall feeling of safety. Values of the ordinal scales are compared using a pairwise Dunn-Bonferroni test with $\alpha = 0.05$ All avatars are appropriate to predict the user's own location with no significant difference. When asked how well the users could predict the location of the other party there are significant differences between FA-BA and FA-SA. Users counted the number of collisions with each other. The results show a significant difference between BA and CA. In addition to that, users were asked how much effort was needed to avoid collisions. There are significant differences between CA-BA and CA-SA. The participants assessed their sense of safety and evaluated the avatars with a significant difference between FA and SA. At last, users were asked how helpful the avatar representations are, when it comes to achieving the objective. They rated the avatars BA and FA significantly different. In conclusion, CA is better rated than at least on other avatar in the category effort to avoid collisions and number of collisions. FA is better rated than at least one other avatar in the category predictability of the location of the other party, sense of safety and helpfullness for the achievement of the objective. Both, CA and FA have the lowest number of collisions.

In addition to the questionnaire, the duration of each round was measured (see Fig. 4). The timings show no significant differences between the avatars.

To assess the effects of the shift of the SA, the participants were not told that the avatar of the other party was shifted towards them. 20 users (71.43%) noticed the shift of the fourth avatar and felt unsafe, since they could not estimate the real location of the other user. Those users ranked the SA lower than the other avatars (see Fig. 5). The full-body avatar is rated significantly better than BA and SA.

5 Discussion

The results of the user study show, that the representation of the avatar influences the number of collisions and the user's sense of safety. The minimal representation of the BA is not very suitable for local multi-user interaction, as it has the highest amount of collisions in the user study. In addition to that, it is rated worse than the other avatars in many categories and never rated better in any category. The CA shares the lowest amount of collisions with the FA[1]. Furthermore, the effort to avoid collisions is low. Its representation is very easy to implement and does not need any additional calculations for avatar animation or additional hardware setup. It can be integrated into an existing system very easily. However, the strong indication of the user might disturb the immersion of the VR experience. The FA leads to a high sense of safety and to a low amount of collisions and is preferred by the participants of the user study. Additionally, it facilitates the predictability of the other user's location. The representation of the avatar needs body pose tracking or inverse kinematic calculations. Yet, the implemented inverse kinematic calculations are only an estimate of the users body pose and contain a high error for the legs. A simple solution to this problem is a floating avatar without legs [4]. Another way to increase the accuracy of this method is to attach additional trackers to the user's feet [8] and other locations, like the hip [10]. The shifted version of the full-body avatar leads to a bad predictability of the location of the other user, since it is intentionally modified. However, this modification leads to bad ratings and insecurity among users. The shift is readily noticed and should be avoided.

[1] It should be noted that the given task was designed to provoke collisions and it can be expected that a small amount of collisions always occurs.

6 Conclusion

Virtual reality applications allow multiple users collaborate to achieve the given target. Yet, even though users meet in a virtual room, their physical location can be either local or remote. If users collaborate in the same physical space, they need to be aware of the other parties to avoid collisions. We presented and evaluated four different avatars in a user study for their capabilities and support in the context of collision avoidance. The results show, that a basic representation of only the HMD and the controllers is not enough to achieve that goal. Further indications of the user's location, i.e. through an approximate cylindrical indication or a full-body avatar, help to avoid collisions and boost users feeling of safety. A shifted user representation, that acts as a safety buffer, did not serve its purpose and did lead to bad ratings and user insecurity. Therefore, local multi-user interaction should use sufficient user representation and always meet user expectations. For future work the legless avatar and other forms could be evaluated regarding their safety for local collaboration and immersion. Furthermore, the current setup does not allow users to independently teleport or move around. If they would do so, the virtual avatar looses sync with the real location of the user. To avoid collisions in this scenario, a *ghost* user could be displayed that shows the location of the other local users even though their virtual avatars might be at another location. To avoid breaking the immersion, the ghost could be displayed only if the two users are close to each other.

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