Obstacles Awareness Methods from Occupancy Map for Free Walking in VR

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Context

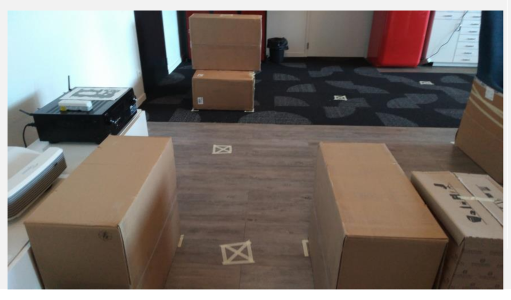
Current Head-Mounted-Displays (HMD) offer room scale VR experiences while mobile devices targeting AR applications like Google Tango or AR Core have more extended tracking features. With such devices, the main limitation to free walking in virtual scenes remains the presence of physical obstacles, i.e. the walls and furniture.

In this context, the user needs to be aware of the obstacles to make use of the extended tracking capabilities of the HMD.

As the occupancy information of a room can be stored in a simple 2D texture with low computations, we propose the use of such a map to display the boundaries of the uncluttered space and compare those visualization methods to the existing visualization as a point cloud.

Obstacle Visualization

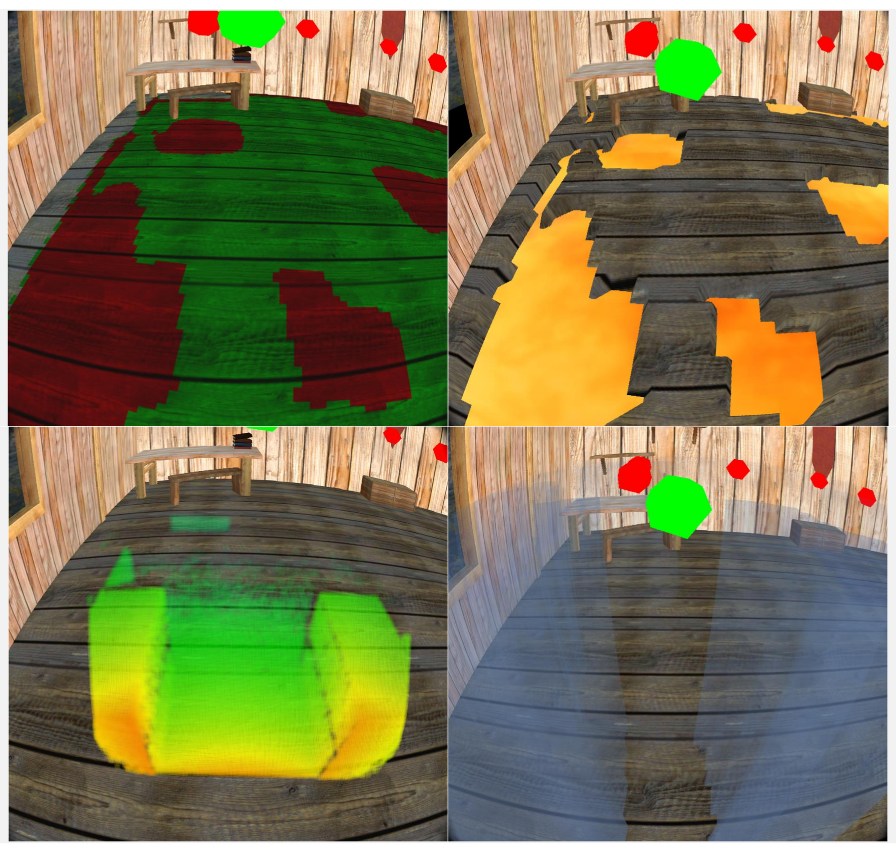
We evaluated four metaphors for representing physical obstacles in a virtual environment. Three of them are built from an occupancy map while the fourth is a dynamic point cloud.



Physical room

Occupancy map

Display the occupancy map on the scene floor with a colour code. The user should only walk in the green zone.



Lava lakes

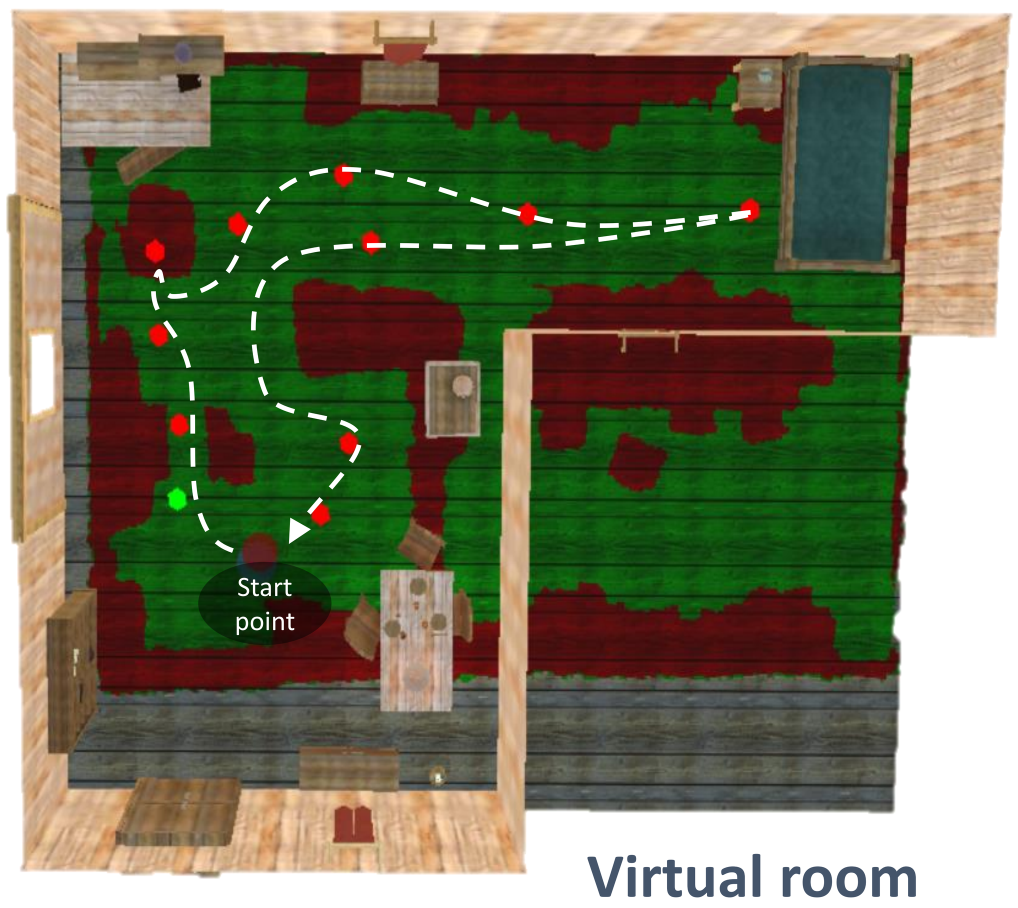
Create danger zones where the obstacles are.

Point cloud

Display the point cloud provided by Google Tango. The closer the points are, the more opaque and the redder.

Glass wall

Generate a transparent wall of height 1m50 along the limit of the free space. The closer, the more opaque.



Virtual room

Experiment

Task

- Follow a path (white dashed-line on the left figure) indicated by floating red balls in a virtual environment
- Cardboard boxes were placed to create obstacles along the path (red zones on the left figure)
- To pick up all the balls, the participants had to walk around those physical obstacles
- They walked two turns with each visualization mode in a balanced order, with a questionnaire in between

Participants

- 35 subjects
- Aged from 21 to 61
- 26 males, 9 females

Design

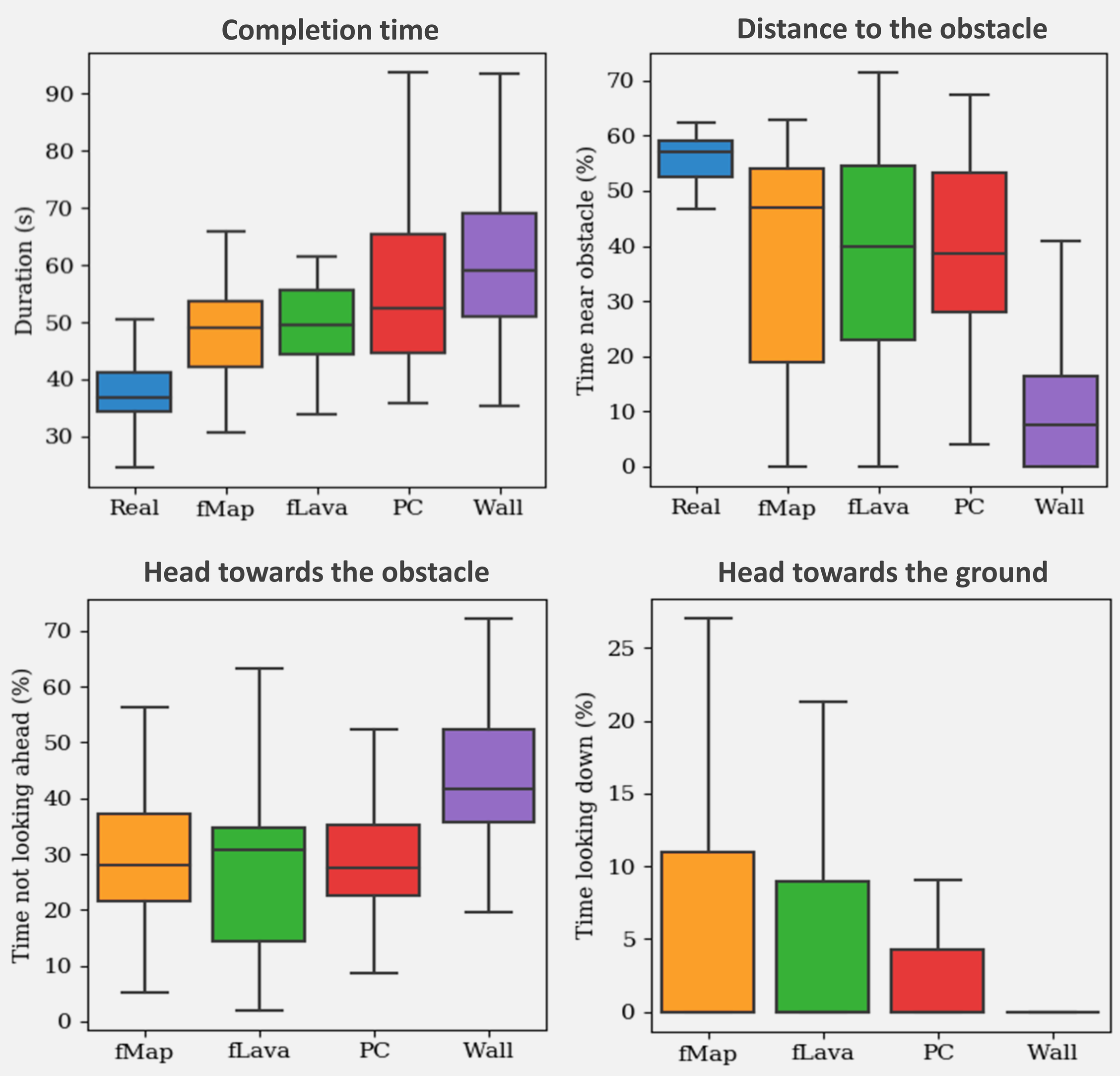
- We used a Google Tango smartphone as a Cardboard VR headset
- The physical room was scanned beforehand to create an occupancy map used to generate the visualization modes

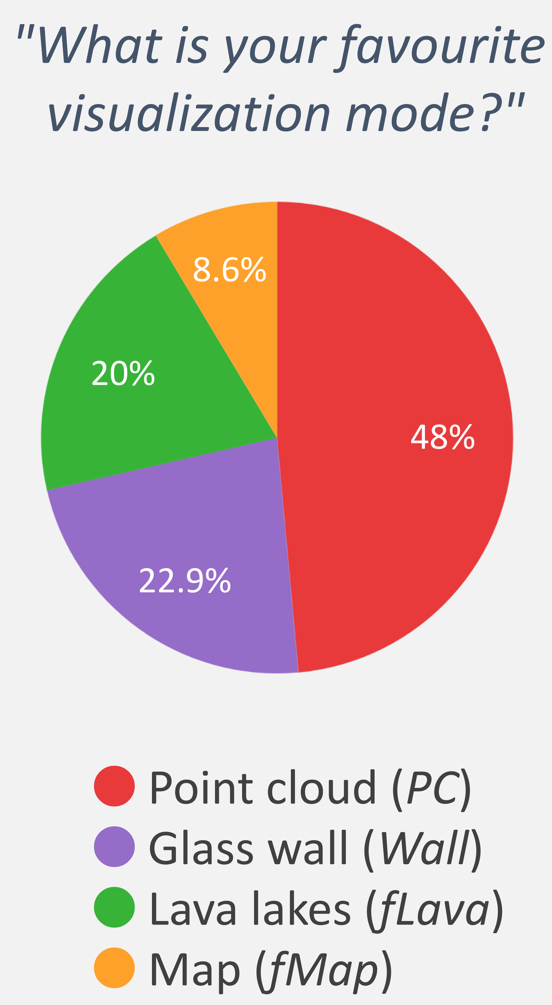
Results

A Friedman's chi-square showed significant differences for :

- Completion time ($\chi^2 = 52.13, p < 0.01$)
- Distance to the obstacles ($\chi^2 = 24.71, p < 0.001$)
  (Time spent closer than 0.4m to the closest obstacle)
- Time spent with the head towards the obstacle
  (Head pitch lower than $-50°$) ($\chi^2 = 8.03, p < 0.05$)
- Time spent with the head towards the floor
  (Head yaw higher than $30°$) ($\chi^2 = 44.11, p < 0.05$)

We found that with the map and the lava, the participants took significantly less time than with the wall but they spent more time with the head toward the floor and less with the head towards the obstacles. They also stay further away from the boundaries with the wall, which seems more dissuasive. In the end, the point cloud and the wall were preferred to the methods displayed on the floor.





Discussion

From the results we obtained, it seems that using 2D occupancy data to generate virtual obstacles introduces discomfort for the users compared to showing the obstacles as a point cloud.

In the case of the wall, even if it was "reassuring" for some participants, it was described as "oppressive" by others, which can explain that they walked more slowly and kept a larger distance to the obstacles with this visualization mode.

The methods displaying the occupancy map on the floor, made the participant walk faster than with the point cloud, probably because it enables better path planning by showing all the obstacles at once. However, it requires looking more towards the floor.

Overall, the point cloud was preferred by the users because it "adapts in real time" and "shows the precise boundaries of the obstacles".

In conclusion, using a 2D occupancy map for obstacle avoidance in VR could be used to gamify the physical space or be combined with the point cloud visualization to improve path planning while maintaining immersion.