Obstacles Awareness Methods from Occupancy Map for Free Walking in VR

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ABSTRACT

With Head Mounted Displays (HMD) equipped with extended tracking features, users can now walk in a room scale space while being immersed in a virtual world. However, to fully exploit this feature and enable free-walking, these devices still require a large physical space, cleared of obstacles. This is an essential requirement that not any user can meet, especially at home, thus this constraint limits the use of free-walking in Virtual Reality (VR) applications.

In this poster, we propose ways of representing the physical obstacles surrounding the user. There are generated from an occupancy map and compared to the representation as a point cloud. We propose three visualisation modes: integrating an occupancy map into the virtual floor, generating lava lakes where obstacles are and building a semi-transparent wall along the obstacles boundaries. We found that although showing the obstacles on the floor only impacts lightly the navigation, the preferred visualization mode remains the point cloud.

Index Terms: Human-centered computing—Visualization—Visualization techniques; Human-centered computing—Visualization—Empirical studies in visualization

1 INTRODUCTION

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. Therefore, there is a need for metaphors to represent obstacles in a virtual world.

In recent works, [3] showed that replacing some physical objects by similar virtual object gave better spatial information than superimposing the surrounding environment as a 3D point cloud to the virtual scene. However, this substitution would be computationally expensive since it requires to get the shape of real objects. 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 walking space. We compare those visualisation methods to the existing representation as a point cloud by measuring the walking speed, the distance to obstacles and the head direction in the different cases. Thus we aim to compare the impact on each method on navigation.

2 VISUALISATION MODES

We evaluated four metaphors for representing physical obstacles in a virtual environment, whose three are built from an occupancy map. They were developed on a Google Tango smartphone since it includes software for Simultaneous Localisation and Mapping which provides extended position tracking. Moreover, it features Area Learning, which enables the phone to relocate in a room that was scanned beforehand. It also features a depth camera returning a point cloud.

The occupancy map is built by projecting on a plane the points whose height is higher than the floor $h_{min} = 0$ and lower than $h_{max} = 2m$, thus suspended objects are also represented as obstacles.

Occupancy map on the floor The first visualisation method that we propose (*fMap*) consists in displaying the occupancy map on the scene floor with a colour code (Fig. 1b). The user can walk in the greenish zones but has to avoid the reddish ones. We build the occupancy map and update it each frame from the captured point cloud as described by Keller et Exposito [2].

Lava lakes The second, *fLava*, consists in creating danger zones on the floor where the obstacle are (Fig. 1d).

Point cloud For this third method (*PC*), we use the point cloud provided by Google Tango and display it as done by Kohei et al. [3]. We base the point cloud colour on the radial distance of the points to the user, the closer, the more opaque and the redder (Fig. 1c).

Glass walls This forth metaphor, *Wall*, is similar to the one used to delimit the walking space in the Virtual Cabin [1] or Chaperone. We adapted it for cluttered spaces by generating a transparent wall of height $1m50$ along the limit of the free space. The wall opacity is decreasing proportionally to the user distance to it (Fig. 1e).

3 EXPERIMENT

In order to compare the performance on navigation with those different methods, we conducted an experiment on 35 subjects aged from 21 to 61. There were 26 males and 9 females. We asked the participants to complete a path following task in a virtual environment with the different visualisation modes, in a random order. The path was indicated by floating balls to pick up by walking toward them. The balls were placed such that the user can see easily the next ball to pick up, which appears in green. We placed some cardboard boxes with different heights in the room to play the role of physical obstacles. The task we asked the participants to complete was to go through the obstacles without stopping to pick up all the balls.

We used the Google Tango smartphone Lenovo Phab 2 Pro as a Cardboard VR headset that the users had to hold on their eyes while walking. The displayed virtual scene was a shack that can be walked around by walking wearing the headset and the physical obstacles could be displayed with each of the four visualisation methods. To create those obstacles visualizations, we scanned the physical room to generate an occupancy map.

4 RESULTS

In order to compare the four visualisation methods, we measured the following parameters during the trajectory. We used a Friedman's chi-square test to find significant differences between conditions, then we performed pairwise comparisons using a Conover post hoc analysis with Bonferroni correction for adjusting p values with a threshold of 0.05 for significance.

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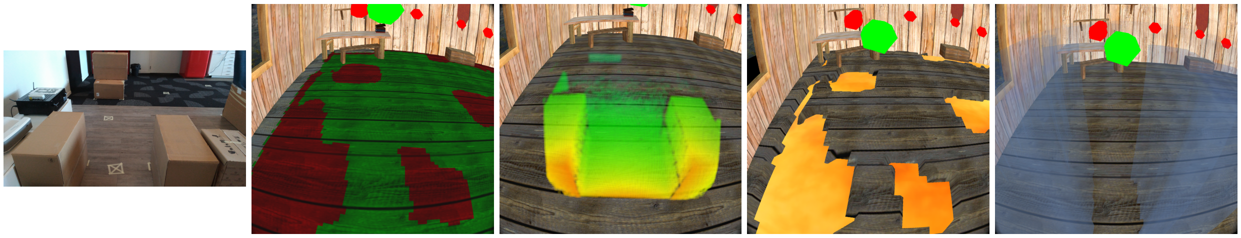

(a) Real room (*Real*) (b) *fMap* (c) *PC* (d) *fLava* (e) *Wall*

Figure 1: The different visualisation modes we evaluated.

Completion time First, we compared the completion time of the task to evaluate the user performances and found a significant difference between visualisation methods ($\chi^2 = 52.13, p < 0.01$). The users took significantly more time with the walls than with the point clouds and more time with point cloud than with the map on the floor or the lava (Fig. 2a).

Head orientation By measuring the head orientation, we want to know how each visualisation mode influences the way the user looks around.

While the user was walking around a physical obstacle to get the next ball, we measured the time proportion during which the user's head pitch is lower than $p_{min} = -50°$ and the yaw higher than $y_{max} = 30°$. Given the field of view of the HMD, $p < p_{min}$ corresponds to looking at one's feet. $y > y_{max}$ was set empirically and corresponds to looking slightly toward the obstacle instead of looking right ahead.

The time spent looking down and looking at the obstacle differed across the four visualisation modes ($\chi^2_{pitch} = 8.03, p < 0.05$), (${\chi_{yaw}}^2 = 44.11, p < 0.05$). The post hoc analysis showed that with the walls, people looked significantly less at the floor than with the point cloud ($p < 0.001$). Likewise, they looked significantly more at the floor with fMap than with the point cloud or the other methods ($p < 0.05$). They also looked significantly more towards the obstacle with the walls ($p < 0.001$). However, we found no significant difference between the fMap and fLava conditions.

Distance to obstacle Thanks to the occupancy map, we measured how much time the user spent closer than $0.4m$ to the obstacles when walking around it and found that the user remained further away from the obstacles with the walls than with other methods ($p < 0.001$).

Global appreciation About half of the participants preferred the point cloud method. The wall was preferred by 22.9% and the lava lake by 20% of the participants, mainly for the fun aspect.

We also asked the participant to rate on a 7 Likert scale how much they feared to hit a real obstacle with each of the methods but found no significant results on the answers between the visualisation modes.

5 Conclusion

In conclusion, 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 most of them, and the measure of the distance to the obstacles and the trajectory duration confirms this. The methods displaying the occupancy map on the floor, however, enables the user to walk faster than with the point cloud, probably because it enables better path planning by showing all the obstacles at once, but it requires looking more towards the floor. The point cloud was still preferred by the users because it "adapts in real time" and "shows the precise boundaries of the obstacles".

Generating VR obstacles from 2D occupancy map could then be interesting in order to gamify the available space in an obstacle avoidance use case.

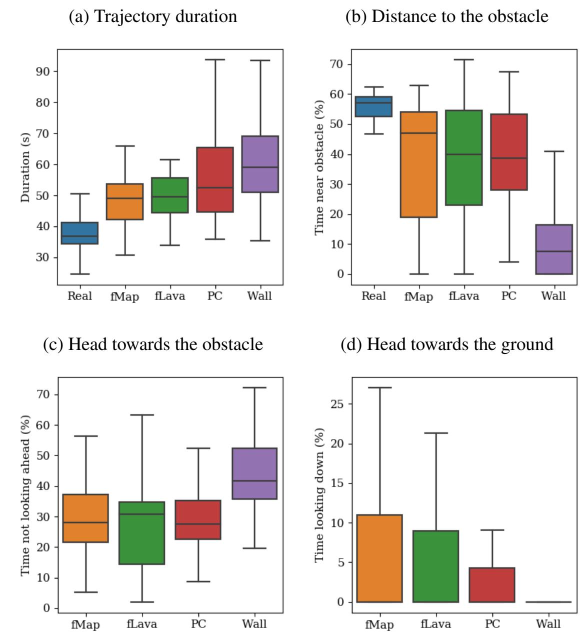

Figure 2: Impact of the visualisation mode on the navigation. b, c and d were measured on the same portion of the trajectory where the user has to walk around a physical obstacle to reach the next ball. The *Real* case corresponds to the trajectory with the headset on the forehead instead of looking through it.

References

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