Exploring virtual environment with immersive metaphor is still largely unexplored, with the costly CAVE exception. This question takes importance in lots of fields, such as fluid mechanics, where space and time resolved dataset become more and more common. For that reason, we present an interaction design study of an window exploration metaphor, for large 3D virtual environment. The metaphor is based on the use of a tablet as a tangible and movable window on a virtual environment. Rotations in the environment are tracker-less mapped on the rotations of the tablet. Our design is inspired by fluid mechanics issues, but is build keeping generalizability in mind. The study shows that mapping three degrees of freedom onto corresponding real three degrees of freedom of space raises the transparency, the efficiency of data exploration and the space awareness of users.
mapped onto the natural three degrees of freedom of the
users. The complexity of the interaction interface is then
expected to be minimized [11].

Another advantage is, as the metaphor is natural, better
reactivity and shorter training phase are expected.

Mapping rotations allows an extra side effect. Due to per-
manent small rotations, parallax effect will occur at every
moment and will give a strong depth perception. The 2D
scene representation appears to be in 3D. We therefore ex-
pect an improvement of the spatial perception of users. Only
one dimension of displacement is proposed, in the camera di-
rection. As exploration was our objective, adding a strafing
metaphor was discarded.

3. DESIGN

Exploring a virtual reality environment may have numer-
ous applications, such as fluid mechanics, astronomy, or sim-
ply visiting a house for sale. We make up an environment
to test the proposed metaphor, with keeping in mind the
generalizability of the design.

The scene is composed by a few hundreds of sphere (500).
The position, the color and the diameter of spheres were
random in the scene. The light is strengthen at the center of
the view, as if the subject is holding a flashlight. The reason
is to incitate the subject to explore the scene by given partial
awareness of the environment. As targets, a few eggs (3) are
hidden in the scene, with, as for spheres, random diameter
and color. Seeking for eggs force subjects to explore a large
part of the scene. The choice of eggs was driven by the
difficulty to discriminate an egg from a sphere under some
point of view. When found, eggs are highlighted with a
circle. A typical view of the software in use can be seen in
figure 2.

4. EXPERIMENTAL STUDY

4.1 Hypothesis

Our main assumptions are:
-H1: Subjects explore a larger space with the window
method
-H2: Finding a target takes less time with the window
method
-H3: Subjects prefer the window method

4.2 Conditions

The scenario is to find any of the eggs, though participants
were allowed to continue the exploration until the time out.

Condition C1 is with the use of the window metaphor. For
the comparison condition C2, the rotations have been
replace by familiar gestures for angular movement, named as
“game pad controller”. Practically, the derivated of the two
main angles were mapped on a joystick widget. We integrate
a slider to allow the displacement in the camera orientation,
both forward and backward. Obviously, spatial properties
are isotropic.

4.3 Hardware and Software setup

The experiment was run on a Nexus 7 tablet. It weights
340g. The experimental software was a custom made OpenGL
ES 1.1 renderer. The tracking of rotations was done with
the internal gyroscopes. Source code is available on request.

4.4 Participants

Fourteen participants (only men) recruited at the LIMSI
lab (University of Paris-Sud), aged between 20 and 27 years
old completed the experiment. The mean age was 24 years
old (standard deviation $\sigma = 2$).

4.4.1 Measures

The following measures were collected for each run of any
condition:
-MO1: Number of eggs found over time
-MO2: Displacement over time
-MO3: Angular displacement over time

In addition to these measures, we present to participants
a short questionnaire on a 5 point Likert scale for the subjec-
tive evaluation of each metaphor, investigating participants’
fondness between the two approaches:
-MS1: Moving forward and backward
-MS2: Rotating in the scene
-MS3: Finding eggs – Difficulty of the task
-MS4: Finding their way – Difficulty to self-localization

4.4.2 Procedure

Subjects sit on a desk chair and are free to hold the tablet
how they feel at ease. No payment was offered.

Before the experiment, we describe briefly both metaphors.
The experiment begins with a short training case. For each
5. RESULTS

In the following, statistical tests use the Wilcoxon signed-ranked test, since populations do not respect Gaussian laws.

The completion time (when $MO_1 = 1$), in mean ($t = 70.3s$), is 23.4% inferior with the window method. It is a tendency, comparatively to the condition $C_2$ (mean time of $t = 86.8s$), with a p-value of $p = 0.091$.

As finding eggs involve exploring the scene, it indicates the window method is more suited for exploring tasks. Moreover, the displacement $M_02$ (see figure 3) surprisingly indicates that participants have travel along a significantly larger distance when using the window method (the mean difference is 40.0% at the final time, with a p-value $p \ll 0.01$). As expected for a supposedly more intuitive metaphor on rotations, the seen angle $MO_3$ (see figure 4) is also significantly larger with the proposed method (the mean difference is 29.0% at the final time, with a p-value $p \ll 0.01$). The hypothesis $H_1$ is therefore true.

We consider the fraction of participants having found an egg over time (see figure 5) extracted from $MO_1$. It shows three main times in the exploration. Until $t \approx 40s$, curves are similar. Participants randomly found an egg close to their initial position. Next, until $t \approx 70s$, the gap between the conditions $C_1$ and $C_2$ is increasing. This is where the influence of the proposed metaphor is the strongest. Then, the gap is very slowly decreasing. Lots of participants have already found the egg in $C_1$, therefore participants in $C_2$ are catching up. At reference time $t = 70.3s$, when participants have found the egg in condition $C_1$, participants in condition $C_2$ have still not found one (high significant, p-value $p = 0.0088$ according to the McNemar’s test). It strongly confirms the above statement, the tendency that subjects founds an egg with shorter time when exploring the scene with the window-based method. The hypothesis $H_2$ is then verified.

The $MS_2$ measures show that subjects significantly prefer the window metaphor ($p = 0.012$) which validates $H_3$. It is empowered by the fact that $MS_4$ is significantly better for the window metaphor ($p = 0.037$).

Table 1: Activity during experiments, in percentage of the total time.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Condition C1</th>
<th>Condition C2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotation</td>
<td>47.2%</td>
<td>30.7%</td>
</tr>
<tr>
<td>Translation</td>
<td>12.8%</td>
<td>24.0%</td>
</tr>
<tr>
<td>Rotation + Translation</td>
<td>11.2%</td>
<td>4.80%</td>
</tr>
</tbody>
</table>

The fact that participants travel a larger distance in the window metaphor was not expected. The displacement was mapped on the same slider widget in both conditions. As a matter of facts, subjects do not feel any difference in the displacement – as it can be seen in figure 6, the box for displacements are comparable. Still they travel more. Surprisingly, subjects use 96% more the displacement widget in the window metaphor (a mean of 17.1 activations per minute for first scenario, to be compared to 8.6 activations per minute in the game pad controller based scenario) but for a total amount of time almost twice inferior. Consequently, their mean velocity is also higher (32.2% higher). As stated above, $MS_4$ is significantly better for the window metaphor, subjects have less difficulty to self-localized themselves. It means that subjects know where to move for exploring new areas of the scene, so they do it straightly. It is empowered...
by the fact that, in condition C1, subjects spend only 28.8% of the total time doing nothing when subjects in condition C2 spend 40.5% of the time doing nothing. This difference is highly significant (p-value p ≪ 0.01), and can be found in table 1. Then, the proposed metaphor allows to control simultaneously more degrees of freedom than the game pad controller based scenario. The proposed interface is actually more transparent that the tactile one, which explains H3 trueness.

Overall, subjects think of the task of finding eggs as hard to complete in both conditions (the median of MS3- is 2 with small dispersion on the Likert scale for both C1 and C2), which was important to force subjects to explore the scene.

6. CONCLUSION AND FUTURE WORK

In this paper, we have presented a concept: using a tablet as a motional window on a virtual environment. Mapping users’ degrees of freedom of rotations directly on the displacement in the virtual world has been implemented. We design a scene and rigorously experimented the proposed metaphor. We showed that the window metaphor is suited for the exploration of virtual environment. Moreover, using the tablet as a motional window is also faster for seeking targets. We explained, based on objective measurements, why participants prefer the proposed metaphor, as an indirect proof of the augmentation of transparency. Initial project was to map the six degree of freedom of movement of the tablet onto the six degree of freedom of movement in the virtual space. It is regretful that the accelerometer sensors give nosey response. With data analysis, a tendency of the translation of the tablet is computable, but a strong drift is appearing quickly due to integration errors. Self-localizing rapidly become impossible. Nevertheless, the augmentation of transparency showed by the experiments leads to an improvement of the use of others well-known metaphors such as a slider. The development was done keeping in mind generalization, especially for scientific visualization from one dimensional-three components fields like pressure field to high dimensional-three components fields, or serious game interface, for instance visiting house-for-sale. The proposed metaphor is natural. We assume it has better reactivity and shorter training phase and it will be rigorously experimented in future works.

7. ACKNOWLEDGEMENTS

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8. REFERENCES