3D Object Rotation Using Virtual Trackball with Fixed Reference Axis

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1. Introduction

Among the 3D interaction techniques designed in the last decades to examine virtual objects using the mouse, virtual trackballs are especially suitable for overall examination of 3D objects. This experimental study focuses on a specific type among the various virtual trackball techniques: Two-Axis Valuator (TAV) with fixed axis. The classical TAV considers rotations around global X- and Y-axis, but for many applications, like 3D modelling, and many web-based 3D viewers, a special variation of the TAV is implemented, where horizontal displacements of the mouse are mapped to rotation around the fixed vertical axis. This technique is known as TAV with fixed up-vector (Bade, 2005) or just fixed trackball (Rybicki, 2016), and achieves transitive rotations.

However, for some objects, there can be another intrinsic axis. For instance, objects like the rotor of a turbine have an intrinsic rotation axis, often horizontal (González-Toledo, 2017). In order to work with these objects, we propose to use a TAV with a generic fixed axis, which is not necessarily vertical. The hypothesis of this study is that the consistency between the object's intrinsic axis and the fixed axis in a TAV interaction will make interaction more natural, as the user's mental model will be a better fit to the interaction technique or, in other words, the level of stimulus-response compatibility will be higher.

2. Method

16 people, 12 male and 4 female, participated in the experiment. A TAV technique with fixed axis was implemented, being the fixed axis configurable as vertical or horizontal. The rotation controller is operated by holding down the right mouse button and tracking mouse movement. The left mouse button is reserved for selection. The 3D object used for the experiment is a sphere with twenty small protrusions distributed over its surface, referred to as targets. This sphere is covered by a texture indicating meridians and parallels. In this way we are suggesting an intrinsic axis by texture, on a geometry (a sphere) without any intrinsic axis.

Each participant had to perform an inspection tasks in four conditions (four trials), presented in a random order, counterbalanced using Latin squares: (1) consistent-vertical, defined as vertical fixed axis in TAV and vertical intrinsic axis in the object; (2) inconsistent-vertical, defined as vertical fixed axis in TAV and horizontal intrinsic axis in the object; (3) consistent-horizontal, defined as horizontal fixed axis in TAV and horizontal intrinsic axis in the object; (4) inconsistent-horizontal, defined as horizontal fixed axis in TAV and vertical intrinsic axis in the object.

The inspection task consists in rotating the sphere, looking for one of the targets which is highlighted in red. Once it is located, it has to be placed inside a circular viewfinder at the centre of the screen and selected using the left button of the mouse. The selection of the first target is used to start the trial. Once the highlighted target has been clicked, a new one is highlighted and the process repeats until all of the remaining nineteen targets are selected. The time taken to select each target is recorded. Parallel to the performance measure, we also obtained a usability score by asking two questions at the end of each trial using a Likert scale from 1 (strongly disagree) to 5 (strongly agree).

- Q1: The rotation system is easy to use.
- Q2: The movements correspond to what I expect from my actions.

3. Results

A two-way analysis of variance (ANOVA) has been carried out on the average selection time. We found a significant effect of consistency ($F(1,15)=8{,}822$, $p=0.01$), being the consistent conditions the ones requiring less time. The fixed axis has not significant influence ($F(1,15)=3.586$, $p=0.078$). The most relevant effect of consistency is produced when the fixed axis is horizontal (See Fig. 1). In fact, a post-hoc analysis revealed significant differences between consistent and inconsistent conditions only for the horizontal case ($T(15)=3.339$; $p=0{,}004$), but not for the vertical case. This is true even considering Bonferroni correction
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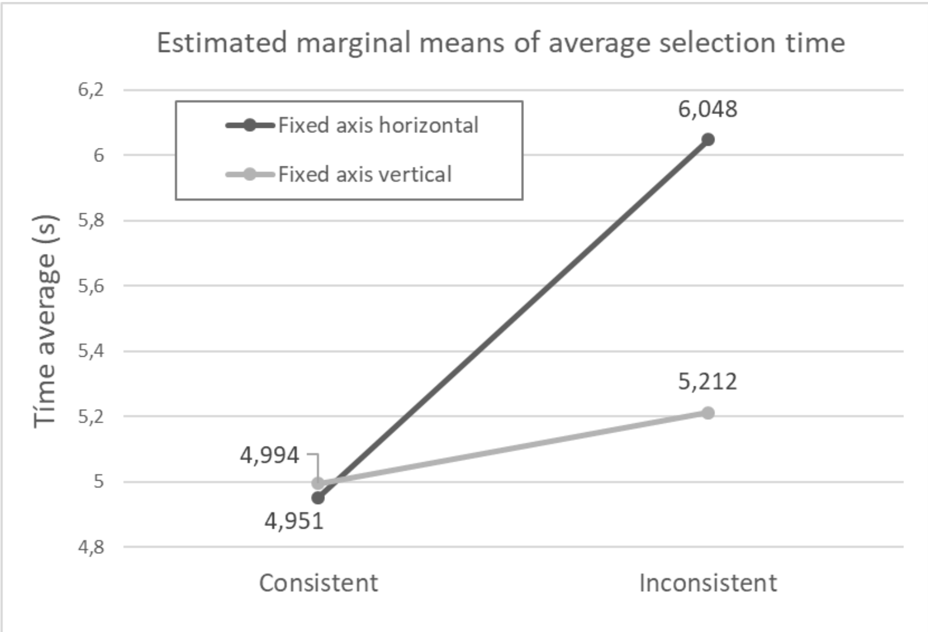

Figure 1. Estimated marginal means of average selection time.

Regarding usability scores, for Q1, Wilcoxon Signed-Ranks tests indicated that the consistent conditions were rated significantly more favourably than the inconsistent conditions for both horizontal ($Z = -2.858$, $p = 0.004$) and vertical situations ($Z = -2.658$, $p = 0.008$). The same effect was found for Q2 in both horizontal ($Z = -2.961$, $p < 0.003$) and vertical cases ($Z = -2.627$, $p < 0.009$).

4. Discussion

Our results confirm that the object's intrinsic axis is significantly relevant and should be considered when choosing a TAV with generic fixed axis. Regarding performance, consistence between an object's intrinsic axis and a TAV fixed axis is significant only when the latter is horizontal. However, scores in usability show it is significant for both horizontal and vertical situations. Experience with 3D tools could explain this result, as these tools usually implement TAV with fixed vertical axis and this could mask the negative effect of the inconsistency. This should be explored in further studies. However, the conflict between the technique and user's mental model is still there, as the scores in usability revealed. Therefore, the use of 3D rotation techniques that take into account the intrinsic axis of the object seems, in any case, a good option.

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