Considerations for Targets in 3D Pointing Experiments

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Abstract
We identify various tradeoffs around 3D pointing experiments based on Fitts' law and the ISO9241-9 methodology. The advantages and disadvantages of each approach are analyzed and compared against each other. We present some recommendations for 3D pointing experiments and avenues of future work.

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Fitts' law; 3D pointing; ISO 9241-9

ACM Classification Keywords
H.5.2. User Interfaces: Evaluation/methodology.

Introduction
Pointing at three-dimensional objects to select them is a fundamental task in 3D user interfaces and is analogous to 2D pointing in graphical user interfaces. However, 3D selection is complicated by a number of issues not found in 2D systems. First, 3D graphics systems use perspective; much like reality, far objects appear smaller, which may influence pointing task difficulty. Second, 3D systems often use stereo display to enhance depth perception. Third, there is no universally accepted 3D pointing technique or device. Moreover, there are many different selection methods for 3D targets. Some of the most popular ones require that the users hand or finger intersects the target in

space, “laser pointer” techniques, where the user’s hand/finger or a device shoots a virtual ray into the scene and the system then selects the first object along that ray, or touch-through, where the user touches the 2D projection of the 3D object on a touch screen.

Previous Work

2D pointing has been investigated based on Fitts’ law [2] and the ISO 9241-9 standard [6]. The ISO standard contributes the measure of throughput, which permits comparisons across user strategies.

We acknowledge that many 3D pointing studies have been performed in the past. For brevity, we mention only a few recent studies that based on ISO 9241-9 here. A study of 3D pointing in a stereo display system [7] revealed that a 2D cursor based method was fastest, followed by a pen-based method and then a ray-based method. A recent investigation of cursor-based techniques for 3D pointing also found that methods that use a 2D cursor perform best [8]. Such techniques include the mouse as well as ray-casting with a cursor at the position where the ray hits the screen or the scene. One of the noteworthy findings of this work is a 2D model that accounts for perspective distortion describes cursor-based pointing at 3D targets quite well. Moreover, displaying the cursor only to the dominant eye was found to significantly improve performance in a stereo display system, even for classic ray casting. A recent comparison of touch-based methods on stereo surfaces revealed that 2D touch, i.e. touch-through, works well for objects within approximately 10cm of the surface, but that 3D touch is better for objects that further from the display [4].

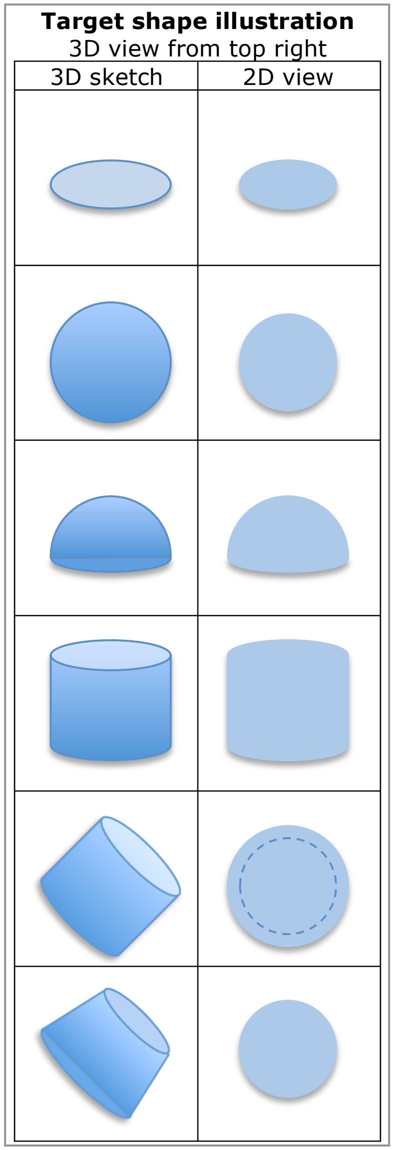
Issues in 3D Pointing Experiments

While it may seem straightforward to extend the ISO9241-9 methodology to 3D pointing, there are several issues in the domain of touch-based systems, but also relevant in other input methodologies. Here we review the most important ones.

Stereo viewing

One of the main issues is the stereo conflict inherent to any stereo 3D pointing system. Not only is the human visual system unable to focus simultaneously at objects at different visual depths (including a finger, but most stereo systems also suffer from the vergence-accomodation conflict. Consequently, when focusing on a 3D target displayed on the screen viewers will see a blurred finger or when focusing on the finger, they will see a blurred target [3]. This impacts particularly systems that use 2D touch for interaction. Note also that any issues in depth perception impact not only the initial ballistic phase of pointing motions (as the motor program may target the wrong location in space), but also the final correction phase (where visual cues are very important).

Cursor-based selection methods avoid the full 3D pointing problem, as they select objects visible from the viewer or along a ray. With this, a 2D manifold effectively describes everything that can be selected. Evidence confirms that a 2D model describes the performance of such techniques quite well [8]. Interestingly, displaying the cursor only to one eye cancels any negative effects of stereo conflicts. Yet, offset-based, i.e. cursor-based, methods do not work as well as direct touch methods for 3D pointing [5].



Non-spherical hit distribution
In some ways more worrisome is that the fact that the distribution of 3D "hit" points in a 3D mid-air pointing experiment is not spherical. The most likely cause for this is depth perception inaccuracies. This is best illustrated by a analysis of 3D touch on a tabletop, see Fig. 6 of [4]. The main issue is that the notion of throughput in ISO9241-9 *relies* on an (at least approximately) spherical hit distribution for the effective measures [6]. Strong deviations from that distribution may invalidate the underlying assumption(s) that enable the combination of speed and accuracy into a single measure.

Floating targets
Volumetric 3D targets are the natural extension of 2D ISO9241-9 targets. Displaying such targets as solid objects is not advisable, as the user can then not tell if the cursor is inside or behind the volume. Thus, most studies use semi-transparent volumetric targets. Yet, such transparent objects floating in space have few, if any, equivalents in the real world, i.e., they do not correspond to any real pointing task. The closest is popping soap bubbles. This reduces the external validity of volumetric targets. Note that Fitts' law [2] describes rapid aimed movements in the real world, so this is a concern. Based on this reflection, some research groups use other objects, such as cylinders, as bases or "pedestals" for the targets, to visually "anchor" the targets in 3D space.

Target shapes
Another important question concerns the shape of the target area or volume for a 3D pointing motion. Here are the most relevant options, see also the sidebar:

- disc
- sphere
- hemi-sphere
- cylinder
- oriented cylinder
- oriented truncated cone

The differences between these targets become apparent when one compares the 3D target volume with their visual appearance from the user's view.

The advantage of the disc is that it is equivalent to a 2D target, which enables direct comparisons between 2D and 3D pointing. Any of the other target types suffer from the problem that one is comparing a target area against a target volume. A disadvantage of disc targets is that they are view dependent, i.e., their visual profile depends on the viewing angle.

Spherical targets are the natural 3D equivalent of 2D disc ISO9241-9 targets. A disadvantage of spheres is that one cannot simply put a sphere on top of the display itself nor on "pedestals". In this situation, the user will then try to hit the sphere by touching the screen/surface (which is efficient), but fail to select the target as the sphere touches the screen/surface only at a single, infinitesimal small, point. One option is to use a hemi-sphere instead. Yet, this primitive has half the volume, which may distort the computation of various measures, including effective target widths.

Cylinders are the extrusion of a disc. A disadvantage is that the visible cross-section relative to the ideal is larger. To address this, one can rotate the cylinder towards the viewer to make the visual profile equal to a disc/sphere. The disadvantage of this approach is that an oriented cylinder close to the viewer will have a significantly smaller base relative to the top, which is closer to the viewer. To address this, one can use an oriented truncated cone, which appears as a disc when oriented towards the viewer.

Recommendations

Based on the reflections above, we recommend addressing the above-mentioned issues as follows:

As the accommodation-vergence conflict is inherent to current stereo displays, it cannot be directly addressed. Yet, stereo is not the strongest depth cue [1]. Thus, one strategy is to use head-tracking (i.e. motion cues), textures, pedestals, a surrounding environment, and other methods to improve depth perception. Then users do not have to rely on stereo alone.

To address the issue of the non-spherical hit distributions observed in 3D pointing experiments, we need appropriate 3D generalizations of Fitts' law, which take the depth dimension correctly into account.

Placing targets on (textured) pedestals aids users in their depth perception and makes targets easier to hit. Consequently, we recommend the usage of cylinders or other objects to visually anchor targets in space. How much improvement this yields in terms of pointing performance is an interesting avenue for further work.

Any generalization of Fitts' law to 3D should use semi-transparent spheres or oriented truncated cones as targets. Yet, comparisons with 2D techniques require disc (or maybe hemi-spherical) targets. This calls for the development of methodologies that can compare 2D and 3D targets in one framework.

Beyond this, we also recommend including a 2D pointing technique with any 3D study to increase external validity. Ideally, this should be a "best practice" comparison for 2D *and* 3D techniques.

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