A One-Handed Multi-Touch Mating Method for 3D Rotations

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Abstract

Rotating 3D objects is a difficult task. We present a new rotation technique based on collision-free "mating" to expedite 3D rotations. It is specifically designed for one-handed interaction on tablets or touchscreens. A user study found that our new technique decreased the time to rotate objects in 3D by more than 60% in situations where objects align. We found similar results when users translated and rotated objects in a 3D scene. Also, angle errors were 35% less with mating. In essence, our new rotation technique improves both the speed and accuracy of common 3D rotation tasks.

Author Keywords

3D rotation; 3D mating; 3D user interface; multi-touch

ACM Classification Keywords

H.5.2. [Information Interfaces and Presentation]: User Interfaces

General Terms

Design, Experimentation, Human Factors

Introduction

The most common interaction tasks in three-dimensional, 3D, virtual environments are navigation, object selection, and manipulation, such as translation and rotation. Object translation positions objects within the scene, whereas rotations orient objects. There is no standard for rotating 3D objects. One issue is that there is no “best” input device for 3D manipulation. Most users use two-dimensional, 2D, pointing devices, such as the mouse and touchscreens, as they offer good control of two degrees of freedom (DOF). However and in a 3D environment, control over 3 DOF is required for translations or rotations (*yaw*, *pitch*, and *roll*), or 6 DOF for both simultaneously. In many user interfaces this is handled through combinations of widgets or touch gestures, often through a combination of 2 DOF and 1 DOF controls. A mouse button is often assigned to control 2 DOF rotation. The third DOF is typically controlled via a modifier or the scroll wheel.

The computer-aided design program Solidworks recently introduced a simple form of object mating. There, clicking on a specific surface of an object followed by a click on another surface snaps these two together, so that the first surface “mates” onto the second. This simple mating technique may lead to interpenetration between objects. We were surprised to discover that there is no documented work on mating methods that avoid collision. This encouraged us to explore this idea for rotating objects on a touchscreen.

Previous Work

Relevant other work on 3D rotations uses either 2D or 3D input devices. An evaluation of four different methods, Bell’s [2] and Shoemake’s [3] virtual trackballs, and two variants of the Two-Axis Valuator [4], found the Two-Axis Valuator to be best [1] with a mouse. Another investigation of inspection tasks requiring 3D rotations found a similar result [8]. However, both of these studies investigated *only* 2DOF rotation control! Partala [7] found virtual trackballs to be superior on a subset of all 3D rotations. A recent study of full 3D rotation control with a mouse [5] did not identify significant differences between Bell’s and Shoemake’s trackballs and the Two-Axis Valuator.

Reisman et al. [9] presented a multi-touch method to control the position and rotation. The solver-based method aims to keep the object stable under the fingers. Yet, results are not always predictable and rotations may be limited to 90 degrees in two of three directions, e.g., when a cube is facing the viewer. Rotations then require clutching. Martinet et al. [11] used this method. “Sticky Tools” [10] permits 1 DOF rotation with a 2-finger “rotate” gesture and controls the other 2 DOF with a two-handed 2+1 finger gesture. Kin et al. [12] controls 2 DOF rotations with a single finger and the third DOF with a two-handed gesture.

3D rotations with 3D input devices have been examined in 6 DOF docking tasks [13][14]. A comparison of 3D rotation techniques with 2D and 3D input devices found that 3D input devices were about a third faster [6]. A recent system, where the orientation of a user’s hand controls 3D rotations, found a ~30% improvement in comparison with a virtual trackball [15].

A New Multi-Touch 3D Rotation Technique

When working with multi-touch tablets we noticed that one hand is frequently occupied with supporting or stabilizing the device. All previous touch-based 3D rotation methods require two hands and are thus not ideally suited for tablets. Hence, we designed our new technique explicitly for one-handed use. We also avoid the unpredictable nature and the limitations of Reisman’s [9] approach. Moreover, recent reflections on 3D user interfaces [16] inspired us. They point out

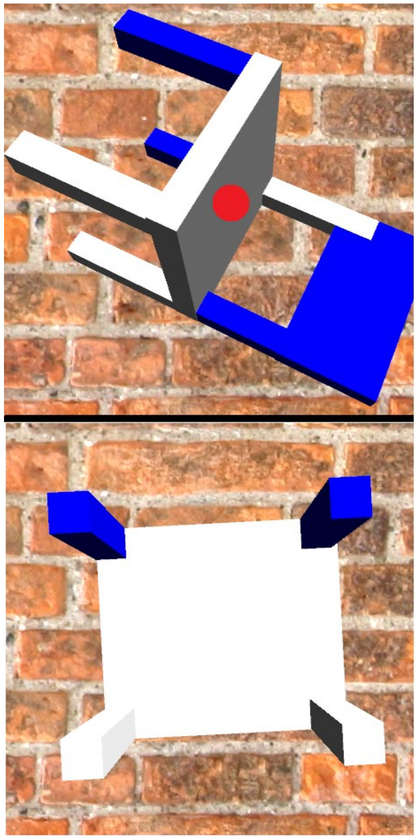

Figure 1. Illustration of mating for 3D rotation with method 1 in phase 1. Double tapping at the red dot will rotate the chair and match the orientation of the point of contact (i.e. the seat plane) with the back plane (i.e. the brick wall). Upper image is the initial position; the lower image the final position.

that in the real world the vast majority of objects are aligned with planes or other objects: (almost) all objects are in contact with others on our planet. "Floating" objects are a rare exception. Tables usually stand on floors; pictures are attached to walls; light fixtures to the ceiling. Many such objects have only a single free rotational DOF in their "normal" placement. In other words, truly random orientations are the exception in the real world. Therefore, we focus on user interfaces that are optimized for this pervasive case.

The idea of "mating" two surfaces fits the above-mentioned observation well, except that naïve mating may result in object interpenetration. Mating the seat of a chair "onto" the ground would put the backrest of the chair into the ground, which novices often find confusing [16]. Therefore we enhance basic mating by always putting the moved object into a position that avoids collisions, while still making the two mated surfaces parallel. As an added bonus mating also translates the object, which may lead to additional timesaving. Given that our enhanced form of mating also put objects into contact, we globally prevent objects from "floating" in our system. This limits the system to 2 DOF positioning, but also matches the capabilities of touchscreens better as fewer DOFs need to be controlled. This simplifies the user interface. Objects can still assume any 3D rotation.

Our Implementation

Given our focus on one-handed use of tablets, we designed our interaction scheme to minimize the number of fingers and motions required. For example, in the second method, a single finger controls all translations either by dragging the object around, or by first tapping the object then tapping the desired location and having the object mate to that location.

As discussed above, previous research did not identify any clearly superior 3D rotation technique. Hence, we base our multi-touch system on the Two-Axis Valuator to directly control 2 DOF rotations. For the third DOF, we use a different form of multi-touch gesture compared to previous work. We implemented two variations for this. One is designed for systems that permit only 3D rotations, the other for systems that support both positioning and rotation.

The first method targets 3D rotations. It interprets a single finger drag as Two-Axis Valuator manipulation. This is usually done with the index finger. A two-finger touch rotates around the view direction. Here we implement a new interaction technique: if one finger stays in place and a second "scrolls" horizontally below it, this is also interpreted as a rotation. Putting the index finger down and flicking the thumb left or right is a natural way to access this technique. Double tapping a point on the object will use the enhanced mate functionality to mate the specified surface of the object with the plane behind it, as illustrated in Figure 1.

In the second method, single finger movements control the (constrained) translation of an object along the surfaces of the scene using a variant of [17]. A two-finger drag gesture, typically with two fingers side-by-side, controls the rotation through the Two-Axis Valuator. A two-finger rotate gesture rotates the object around the view direction. Alternatively, users can touch with two fingers and flick the thumb to rotate around the view direction. A single finger tap on a surface of an object followed by a tap elsewhere in the

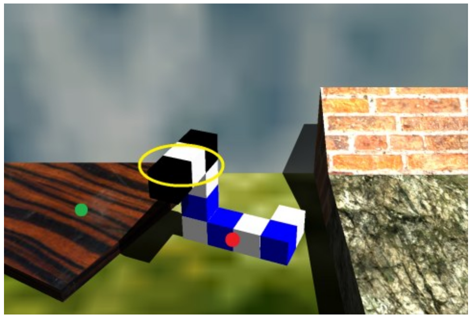

Figure 2a. Illustration of mating with method 2 in phase 2 of the user study. The aim is to mate the Shepard-Metzler object onto the left, wooden floor. The user first taps at the red dot and then at the green dot to mate the first location onto the second. A naïve mating operation would result in the circled yellow part of the object penetrating into the wood floor.

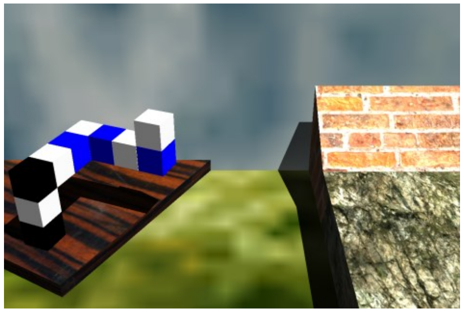

Figure 2b. Post mating pose of the object from Figure 2a. The object has been raised by the system to avoid interpenetration with the floor, while keeping the two selected surfaces parallel.

scene mates the two surfaces, i.e., puts them parallel at that location. If this results in a collision, the object is raised relative to the target surface until the object is only in contact. The final 3D movement is animated to help users understand the result. Moreover, a recently mated object is temporarily constrained, to permit the user to rotate the object in the local coordinate system of the target surface. This enables users to mate an object onto any surface and then to quickly adjust the remaining DOF using a two- or three-finger rotation.

Participants

Twelve paid volunteer participants were recruited from the local university campus. The age of the 6 male and 6 female participants ranged from 19 to 35 years (mean 26.17, SD 4.47). All had never participated in a 3D study before. All were right handed and preferred to use the tablet with their right hand. Mean 3D video game usage was 1.92 per week (SD 1.62).

Apparatus

We conducted the study on an 8” Android tablet. A desktop monitor was used in the second half of the study to display target scenes. We created a variety of common 3D objects, as well as several inspired by the Shepard-Metzler test [18]. After a pilot study we decided on a car, chair, dog, and one Shepard-Metzler object, see Figure 3. Colorings were introduced to disambiguate poses, as e.g., a view onto the bottom of the unenhanced chair would not reveal the full 3D rotation of the whole object. White parts of objects highlighted in different colors for feedback, see below.

Procedure

The study was conducted during the day in a quiet room with the participant in a seated pose. The software was first configured to the participant’s handedness. This affected the first part of the study where the rotating object was displayed on the user’s preferred side and the target on the other. Then the study was explained along with a demonstration. All participants acknowledged they understood how the system worked and had no questions. Participants were then permitted to play with the system up to a maximum of five minutes to get accustomed to the controls. No participant used the full five minutes. Participants filled a short questionnaire after the study.

Overall we used a 2x2 within subject design with 2 phases. The first phase targeted only 3D rotations, whereas the second investigated rotations with constrained translations. In each phase the conditions were mating enabled or not and surface aligned target orientations or not. Conditions were counterbalanced over all trials. In each set of 48 trials, subjects were asked to rotate 4 models 6 times with either mating enabled or not. Targets were aligned three of these six times, while the others had random target orientations. The order of each of these 24 trial blocks was determined using a Fisher-Yates shuffle. To generate the starting pose of the rotatable object we used two randomly shuffled copies of a list of 12 difference angles: 15, 30, 45, … , 165, 180 degrees. Each copy of the list matches to targets being aligned or not. To compute the starting 3D orientation we first defined a rotation axis by generating a random point on a unit sphere. The object was then rotated “back” from the target orientation about this axis by the angle chosen above. The participants’ task was to rotate the object to within a quaternion angle of 10 degrees from the target orientation. Users could not abort trials.

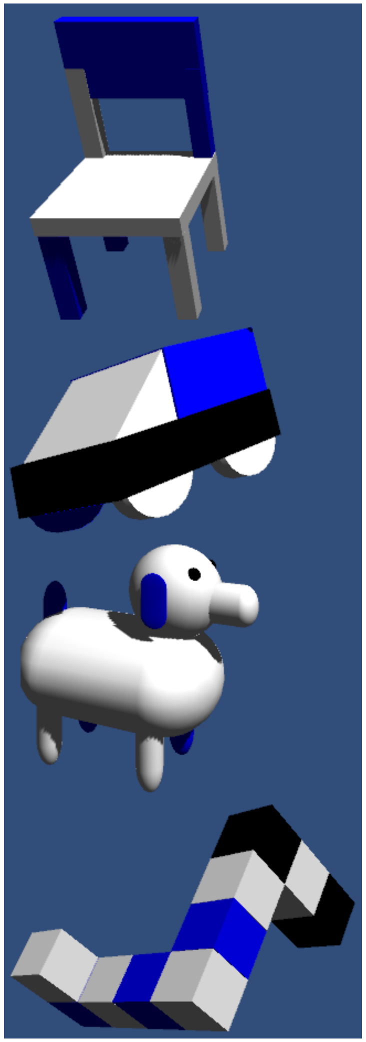

Figure 3. Objects for user study. The coloring was used to facilitate pose recognition.

Figure 1 illustrates the first phase (except that the two sides are shown above each other to preserve space). The target object on the left (or right) could not be manipulated and was the shown in the desired orientation. The object on the other side was rotatable. When the user touched the rotatable object the white segments turned magenta to indicate selection. When the object was within the 10 degree limit the white segments turned green to signal successful completion.

The task in the second phase shown in Figures 2a and 2b was to both translate and rotate the object into the target pose, a 5 DOF task. The desktop monitor showed the target pose. Participants were then able to use the entire tablet screen to match the scene. Here, objects highlighted in cyan when within 10 degrees of the correct orientation, in yellow when within 1/50th of size of the scene, and green when close to the correct pose.

Results

We found that using our mating system decreased rotation times substantially. According to a repeated measures ANOVA and in the 3D rotation task investigated in phase 1, there were significant effects of mating on completion time ($F_{1,11} = 23.06$, $p < .001$) and target alignment ($F_{1,11} = 100.92$, $p < .0001$). Both mating and aligned targets were significantly faster. There was also a significant interaction between the conditions. A Tukey-Kramer posthoc test shows that aligned scenarios with mating were ~65% faster than all other combinations. Figure 4 illustrates average completion times. The results for the error angles show a significant effect for mating ($F_{1,11} = 93.83$, $p < .001$) and also confirm that aligned targets were positioned significantly more accurately ($F_{1,11} = 63.75$, $p < .001$).

In the 3D translation and rotation task in phase 2 there was again a significant effect of mating ($F_{1,11} = 37.68$, $p < .0001$) and aligned targets ($F_{1,11} = 61.7$, $p < .0001$) on task completion time. There was also a significant interaction. Tukey-Kramer identifies that aligned scenarios with mating were completed ~64% faster than all other combinations. Figure 5 illustrates average completion times. There was a significant effect on error angles for both mating ($F_{1,11} = 108.75$, $p < .0001$) and aligned targets ($F_{1,11} = 24.71$, $p < .0005$), as well as a significant interaction between them. Tukey-Kramer reveals that aligned objects were oriented in the mating condition ~35% more accurately compared to all other combinations.

Discussion

Our new mating-based 3D rotation technique decreases the time required to match aligned target orientations by 64% or more, while significantly improving accuracy. Given that many objects are aligned to others in real world scenarios, this is substantial and exceeds all improvements found in previous work. Participants found the mating interface simple to use and all perceived it as faster according to our questionnaire. No one indicated discomfort or fatigue during the study. Participants generally found either the chair or the dog the easiest object to rotate. Unanimously, the Shepard-Metzler model was judged most difficult. Although our original design for the flick gesture was targeted at the thumb, about half the participants preferred to use the ring finger instead. Interestingly, the ring finger utilizes the limited space on the tablet better than anticipated by us. E.g., when rotating an object near the edge of the screen, where space is limited, flicking the ring finger vertically affords a greater range of rotation compared to the thumb.

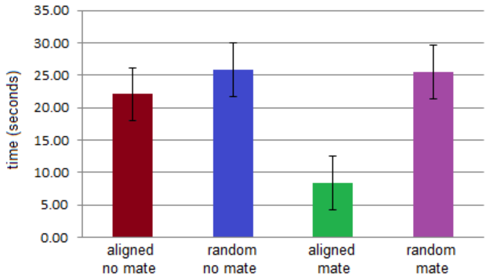

Figure 4. Mean trial times for study 1 with standard error.

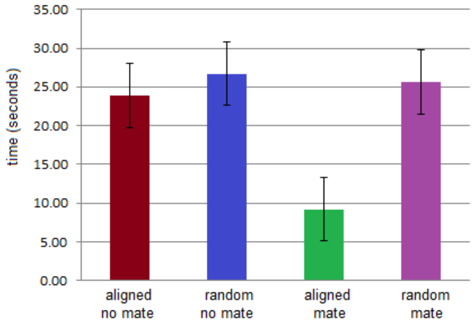

Figure 5. Mean trial times for study 2 with standard error.

Conclusion

We presented a new multi-touch 3D rotation technique based on mating to accelerate common tasks. It is targeted at one-handed touchscreen use, especially on tablets. Our user study revealed that the new technique improves manipulation times by more than 60% for common 3D rotation tasks. Rotation accuracy is significantly improved as well. In the future, we plan to investigate the performance of this mating technique for full 6 DOF manipulation tasks.

In future work we plan to investigate the "fat finger" problem. Specifically, we plan to develop a technique for quickly selecting (very) small objects in a 3D scene and then placing and orienting them in a very precise target pose. We will also investigate how navigation and manipulation can be combined so that one can easily move objects over larger distances.

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