Tangible Spin Cube for 3D Ring Menu in Real Space

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Abstract
In this paper, we introduce a novel interface, the Tangible Spin Cube, for experiencing a 3D ring menu in real space. It enables a tangible object-referenced 3D ring menu and its items' placement by using multi-marker tracking. Also, it supports spin interaction using hall sensor-based spin detection for natural menu browsing. Finally, we evaluate the performance of the current prototype's spin detection and show an example of a 3D ring menu application.

Keywords
3D ring menu, tangible UI, augmented reality

ACM Classification Keywords
H5.2. Information interfaces and presentation (e.g., HCI): User Interface.

General Terms
Design, Experimentation

Introduction
In a menu application for system control, the user explores the presented menu using a given interface and finally selects the desired item. The 3-dimensional (3D) menu, a part of the graphical menu, puts more spatial information to practical use than does a 2D

menu [2]. Therefore, use of a 3D menu can save space for displaying many more items. In addition, it could reduce the time for learning, and it attracts users' interest by applying intuitive menu navigating interaction. The ring-type menu is a basic and popular style in various computing fields [5].

The existing problems of 3D ring menus are as follows: From a placement point of view, the desktop and mobile devices provide display-referenced menus so users cannot change the view without additional input (keyboard, mouse, button, touch-and-drag, etc.). Also, they present some restrictions in drawing items because of the static size of the monitor or display region. In the case of a 3D menu in virtual space, we could partially solve the mentioned limitations, but it needs expensive tracking devices and does not perform very well in real space.

The goal of the Tangible Spin Cube that we propose in this paper is to explore a novel interface presenting a realistic ring menu in real space and navigating the menu items intuitively. First, we design the tangible object tracked by a multi-marker system and augment the 3D ring menu around the tangible object. Second, for natural menu exploration, we suggest two input methods, including a fast wireless button input and a hall sensor-based spin detection input. Especially in spin detection, we evaluate our hall-sensor detection by comparison with the marker-based spin detection.

Related work

Collapsible Cylindrical Trees [4] is display-referenced ring menus for fast hierarchical navigation in web-based desktop applications. It presents several different rings at once and expands the selected menus according to its hierarchy. TUISTER [3] is a tangible user interface that applies the 3D ring menu style for hierarchical structures. This is very similar to menu browsing techniques that use a two-handed spin interaction metaphor, but it has limitations in its menu presentation because of the fixed display device. In Visual Hints [9], using a tangible augmented reality technique, Ghosted hints showed a kind of single-handed 3D ring style. However, it was not designed for a menu function.

Design of the Tangible Spin Cube

The Tangible Spin Cube targets manipulation of a 3D ring menu that is usable by a novice in real space. To realize this in real space, Tangible Augmented Reality takes good advantage in terms of a metaphor that combines tangible input with augmented reality techniques [7]. However, although many tangible augmented reality interfaces have been proposed, they have not paid much attention to the system control category. Therefore, we focus on the menu application in system control; Figure 1 shows the concept of the TSC.

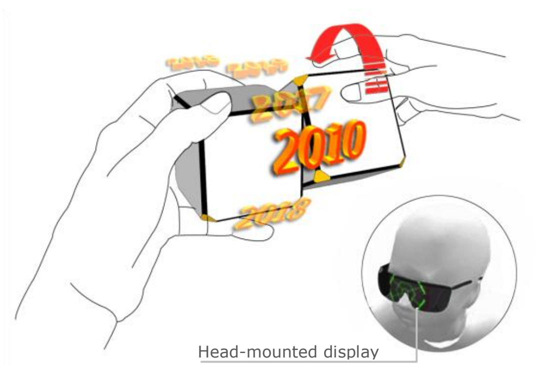


figure 1: The concept of the Tangible Spin Cube

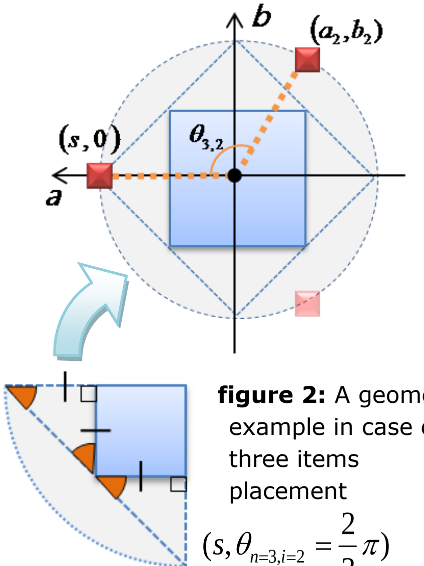


figure 2: A geometric example in case of three items placement

$$(s, \theta_{n=3,i=2} = \frac{2}{3}\pi)$$

Robust Marker-based Tangible Object Tracking

We are targeting a tangible object-referenced menu that can be used freely to change the users' view. In other words, it can translate and rotate toward any direction in 3D space. Therefore, the tangible objects composing TSC must be robustly tracked by camera or a head-mounted display. However, a single marker could be occluded by an inexperienced user's hand or over-rotated so that the capturing device can no long see it. Therefore, we plan the cubical shape for applying multi-marker, which could provide more robustness in the object tracking.

Supporting Natural Two-handed Interaction

Using two-handed tools supports a bimanual asymmetric interaction. This means that while the actions of both hands are different, they are closely coordinated to achieve the same task. In order to support the right and left hands together, the two cubes have an attachable property via built-in magnets. Based on these concepts, we think users' spin gestures using the two cubes is a proper interaction metaphor for navigating a ring menu for the TSC. The main cube is grasped by the non-dominant hand for stable menu display, and the subsidiary cube is handled by the dominant hand. Then the augmented ring menus might rotate clockwise or counter-clockwise according to the spin direction.

Fast and Stable Wireless Input

Menu applications require more frequent input events than do other applications. Usually, tangible AR interfaces have used marker-based input, using a time delay for the selection event, because of easy implementation. However, this method of input does not guarantee speed and stability at the same time. Therefore, we use a wireless button, which has the additional benefit of force feedback from its physical presence.

Ring Menu and Items Placement

Our approach to menu placement is to augment a virtual ring realistically around the tangible cube. In order to do this, we track the cube using a multi-marker tracking approach [6]. In a multi-marker system, one coordinate frame is generated from relative information posed by a set of six different markers. In the TSC, we use the two multi-marker coordinate frames for the main and sub cubes. They partially solve the occlusion problem and make menu tracking more robust with regard to diverse view angles.

Besides the location of the ring menu, the position of the items constructing the ring menu is important for a realistic 3D menu. In the case of a TSC, the size of the tangible cube and the number of items changed by the depth of the menu hierarchy are variable factors, so they should be considered. Also, an overlap case between the dominant hand for grasping the cube and the rendered menu could occur. We can find a sensible *i*-th rendering center point of *n* items using Equation 1. Figure 2 shows the geometric example of three items in one ring.

$$\begin{pmatrix} a_i & b_i \end{pmatrix} = \begin{pmatrix} s & 0 \end{pmatrix} \cdot \begin{pmatrix} \cos\theta_{n,i} & -\sin\theta_{n,i} \\ \sin\theta_{n,i} & \cos\theta_{n,i} \end{pmatrix} \qquad (1)$$

$$\theta_{n,i} = \frac{2\pi \cdot (i-1)}{n}$$

s: length of the side of the tangible cube
n: total number of items at current hierarchy
i: index of the items (i=1,2,...,n)

Ring Menu Browsing using Spin Detection

We suggest the two-handed spin gesture for natural ring menu navigation. We already have two marker coordinates, so we can calculate their relative rotation information for detecting rotation. However, the performance of this marker-based spin detection depends on the captured image. Therefore, we propose the hall sensor-based spin detection method for two-handed natural ring menu navigation.

Usually, the hall sensor is a transducer that responds to changes in a magnetic field and that can be used for proximity-sensing applications [8]. In order to sense the rotation of a cube, a single sensor is enough. Our purpose is to detect the spin direction for menu applications; thus at least two hall sensors are required. The hall sensors installed on the main cube detect the movement of the identically built-in magnets of the sub cube (see figure 3). If we add the hall-sensor, the TSC could support more subdivided detection as well.

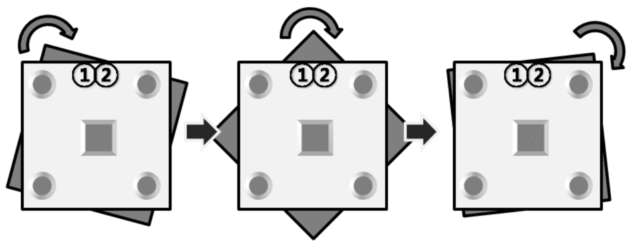


figure 3: The consecutive sequences using two hall-sensors for counter-clockwise (left) spin detection

Implementation

Our first prototype of the TSC is shown in figure 4. The cube was made of acrylic material and the length of each side was 70 (mm). On the surface, 6 different markers [1] on every face and 8 buttons were attached at every corner. On the inside of the cube, we constructed a Bluetooth module for a wireless network, one powerful magnet for a strong cube coupling, and 4 corner magnets for force feedback from every 90-degree on spin interaction. In addition, a circuit for 2 hall sensors was composed in the main cube for spin detection so it senses the corner magnets of the sub cube.

figure 4: A prototype of TSC: multi-markers (left), 5 built-in magnets inside the cube (center), a circuit for 2 hall sensors (right)

Experiments and Results

An experiment was conducted to compare our hall sensor-based spin detection (HSD) and marker-based spin detection (MSD). Through the comparison, we evaluate that the proposed method is more suitable in practice than MSD. The HSD detects the spin when the cube rotates over 45 degrees at each state. Therefore, we implemented the comparative MSD method, which has a similar detection idea. As shown in table 1, each

Calculated Relative Rotation (CRR)	*Dividing Section*
$-45 < CRR \le 45$	0
$45 < CRR \le 135$	90
$135 < CRR \le 225$	180
$225 < CRR \le 315$	-90

table 1: adjustment from continuous to discrete value in MSD

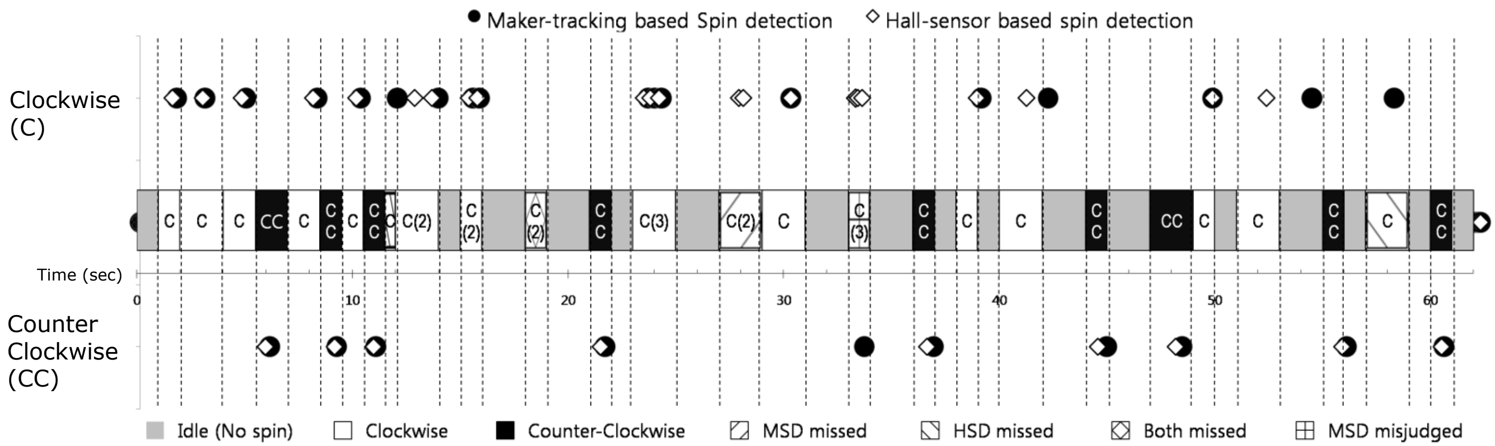


figure 5: Spin simulation result (The width of centered boxes describes the permissible detection boundary for real-time spin interaction)

We simulated 35 free spins over 1 minute. The HSD detected the spins and the MSD also detected the markers via the web camera at the same time. Therefore, we could operate the spin simulation with identical experimental spins. Buttons were used at the beginning and the end as an input in this experiment. Figure 5 shows the result of all 35 spins. The centered box sequences, including spin directions, demonstrate the solution of the spin simulation, and each boundary was determined by a recorded video observation.

Basically, the HSD does not have obstructed signal acquisition, whereas MSD has a high possibility of blurred image generation according to users' spin action. In this context, we know the detection ratio of each method. The result showed that the MSD detected 77% (27 detects) of the spins correctly, and the HSD detected 89% (31 detects) correctly in the given experiment.

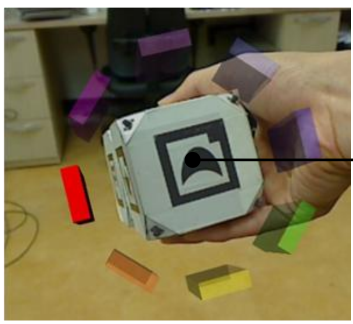
Now, we examine the limitations of the MSD approach from the graph and indicate the trouble with the current HSD also.

We divide the limitations of the MSD into two categories. The first category is related to a blurred image from the user's quick spin action, and the second is serious occlusion by the user's hands. The two consecutive spins (*C(2)* with the forward slashes) were too fast to capture detectable interim section images, so the MSD could not judge the direction of rotation and it led the detection astray. On the other hand, in the fast three consecutive spins (*C(3)* with the cross line), the system judged the opposition direction with the original spin. This misjudgment could be critical in menu browsing and stressful for the user. The long delayed spin by hand occlusion, as in the case of the 32th spin, is not critical in menu browsing, but it might not be sufficient for performance in real-time response.

Against the MSD, our current HSD method did not misjudge the spin direction but it still lost 4 spins. In order to find the reason we examined the recorded sequence again carefully. Our conclusion is that small magnets in the sub-cube got out of the standard route during the user's spin gesture. This problem could be solved by using a different size magnet or a more powerful one.

Application

We exploited an example of the 3D ring menu application using the current prototype of the TSC (see figure 6). It presented a ring menu with multiple hexagonal model items around the cube. Also, it supports simple menu browsing with spin gesture input.



An algorithm of item placement worked well in our prototype case, and it reserved a little room for the user's hand.

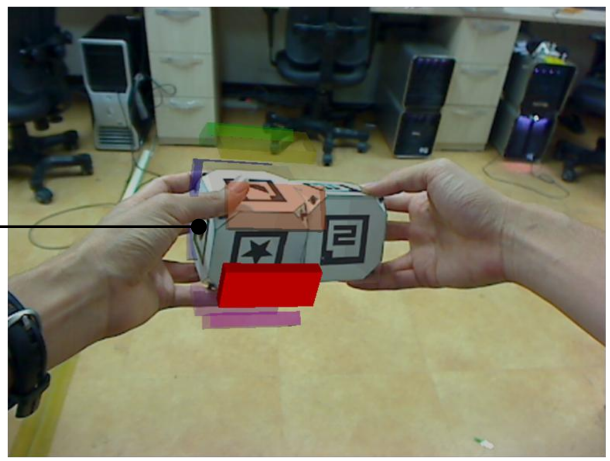


figure 6: A simple 3D ring menu application that has 8 items around the TSC

Conclusion & Future work

In this paper, we proposed a Tangible Spin Cube that supports 3D tracking and spin detection for a realistic 3D ring menu. It was implemented by a multi-marker cube tracking for 3D menus and for partially solving occlusion problems. Also, a robust spin detection using cheap hall sensors was designed and its performance evaluated. Finally, we showed an initial prototype of the 3D ring menu as well. In future work, we will enhance the sensing reliability of the TSC. With better performance, we could expect to build a TSC-based hierarchical 3D ring menu system. In this context, a system evaluation including qualitative and quantitative measures will be carried out.

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