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LotusMenu: a 3D menu using wrist and elbow rotation inspired by Chinese traditional symbol

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Three-dimensional rotation, including pitching, yawing and rolling, is an important gesture in 3D interaction, with the potential to extend the selection capability in large screen interaction system. For 3D rotation interaction, researchers indicated the design space of pen tilt [1] and wrist tilt as input modality [2,3]. However, the combination of freehand 3D rotation gesture has not been fully utilized for menu control.

Menu selection in 3D user interface has long been a challenging task. At present, many 3D user interfaces still use linear menu as their selection technology, which is reported to have defects in time performance and user fatigue [3]. The reason is that most in-air freehand gestures involve the movement of shoulder joint and require a larger range of motion. Rotation information in 3D space has not been fully explored, although studies have indicated that these kinds of information could potentially extend the selection capability [2, 4].

In this article, we present a 3D LotusMenu based on the metaphor of Chinese traditional symbol lotus. As shown in Figure 1, this menu is controlled by three-dimensional rotation of user's wrist and elbow. The proprioceptive design of the menu allows the user to interact intuitively and effectively [5]. We compared user performances in 3D LotusMenu and traditional three-level linear menu. Results show that the LotusMenu is significantly faster than the traditional linear menu, and there is no significant difference in error rate between the two. In addition, our subjective assessment suggests that LotusMenu technique can significantly reduce users' fatigue.

LotusMenu technique. In order to improve the ability of interactive selection and efficiency of the 3D interactive space, as well as to achieve better user performance, we designed the LotusMenu technique based on a metaphor of mapping user's hand motion with a lotus. The reasons of choosing such a metaphor come from two aspects. On one hand, the lotus petals are distributed in the circumferential direction around the central axis with a multi-layered structure, which fits consistently with the rotation gesture. This makes the menu intuitive and easy to use. On the other hand, the lotus image is one of the most important plant decorative pattern in the history of Chinese ornaments. This well-known ancient pattern naturally has a high degree of acceptance. Therefore, we believe that this metaphor is affordable for the 3D rotation interaction and familiar to users.

LotusMenu technique corresponds the lotus shape to the 3D rotation interaction. We map the selection of circular petal groups to the rolling gesture of elbow (Figure 1(a)), the selection of layered petals to the pitching gesture of wrist (Figure 1(b)), and the selection of circular lotus seeds to the yawing gesture of wrist (Figure 1(c)). Since the range of motion of the wrist rolling gesture is limited [6], and it poses a higher risk of injury and more discomfort than forearm rolling [7], we chose to use the forearm instead of the wrist in the rolling gesture. On this basis, we merge the rolling gesture of elbow and the pitching gesture of wrist to select items in first and second level, which corresponds to the selecting of petals in LotusMenu. In this way, there is almost no shoulder movement in this gesture. So the gesture can be easily performed within a small range of motion. In addition, because the rotation of the wrist and arm is merged as much as possible, the fatigue caused by gestures is further reduced.

To use the technique, the user first needs to wake up the LotusMenu, and then directly present a gesture with certain elbow rolling and wrist pitching angles to select the first and second level menu item. Finally, the user selects the third level menu items by yawing his/her wrist. The design of interaction is within user's natural working range as well as direct mapping between hand motion and items. These allow the user to operate with a natural rhythm without adding significant cognitive over-head [5]. The interaction sequence and visual feedback of the LotusMenu are shown in Figure S1.

Recognition algorithm. The gesture recognition is based on Leap Motion's hand tracking technique. We will use three

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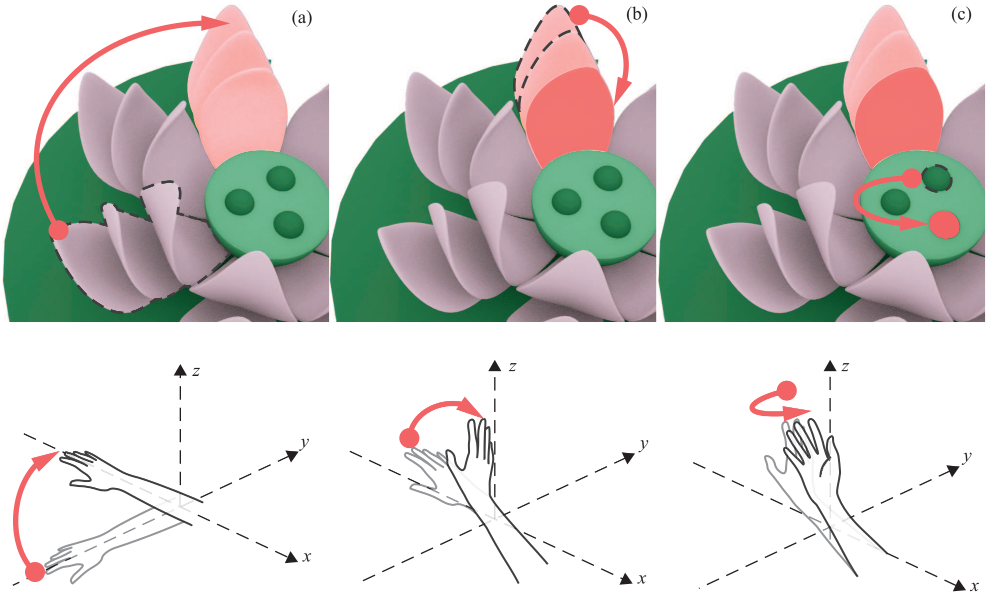

Figure 1 LoutsMenu. (a) Rolling gesture; (b) pitching gesture; (c) yawing gesture.

vectors detected by the detection space of Leap Motion in the calculation of the recognition algorithm, which are the arm direction vector (V_{arm}), the five-finger vector (V_{fingers}), and the palm normal vector ($V_{p_{\text{nor}}}$). The 3D rotation interaction is calculated by the following algorithm.

- Rolling recognition. In the first level of the menu selection task, user performs the arm movement parallel to desktop with elbow as axis. We calculate the angle A_{Roll} between projection vector of direction vector of arm (V_{arm}) on the XY-plane, which is noted as ($x_{\text{arm}}, y_{\text{arm}}$), and the left direction (-1, 0):

$$A_{\text{Roll}} = \arccos\frac{x_{\text{arm}} \cdot (-1)}{\sqrt{x_{\text{arm}}^2 + y_{\text{arm}}^2}}. \quad (1)$$

In the initial state (St), if A_{Roll} is detected within 10 and dwelling for 0.8 s, the selection is activated. Then the user can roll his/her arm to select an item in the first level. We then calculate A_{Roll} every 1/60 s (1 Hz) to linearly map the value to the actual item in the first level.

- Pitching recognition. In the second level, the user performs the pitching movement with wrist as pivot point on the position of arm in previous level. We collect the direction vector of five fingers (V_{fingers}). We calculate the angle A_{Pitch} between the vector of the user's finger in detection space of Leap Motion and the projection of it on XY-plane, which noted as ($x_{\text{fingers}}, y_{\text{fingers}}$):

$$A_{\text{Pitch}} = \arctan\frac{|z_{\text{fingers}}|}{\sqrt{(x_{\text{fingers}})^2 + (y_{\text{fingers}})^2}}, \quad (2)$$

where z_{fingers} is the altitude of finger tips above XY-plane. We then calculate A_{Pitch} every 1/60 s (1 Hz) to linearly map the value to the actual item in the second level.

- Yawing recognition. In the third level, the user performs the yawing movement when fingers point upward with wrist as pivot point. We collect the normal vector from the palm outward ($V_{p_{\text{nor}}}$). We calculate the angle A_{Yaw} between the projection of normal vector on XY-plane, which noted as ($x_{p_{\text{nor}}}, y_{p_{\text{nor}}}$), and the forward vector (0, 1):

$$A_{\text{Yaw}} = \arccos\frac{x_{p_{\text{nor}}}}{\sqrt{x_{p_{\text{nor}}}^2 + y_{p_{\text{nor}}}^2}}. \quad (3)$$

We then calculate A_{Yaw} every 1/60 s (1 Hz) to linearly map the value to the actual item in the third level.

Experiment. In order to explore the user performance of LotusMenu, we conducted an experiment to compare LotusMenu with traditional linear menu. We decided to choose linear menu as experimental comparison because of its high efficiency and wide acceptance.

- Participants and apparatus. Ten subjects with right-handedness, 5 females and 5 males, aged between 21 and 24 participated in the experiment. We used a laptop with a 12.5-inch LED display at 1366 × 768 resolution. We also used the desktop mode of Leap Motion v2.0 to detect the movement of the hand and arm.

- Design. A within-subject design was adopted in the experiment. Participants were required to complete 3×3×3 selection tasks in two menu techniques respectively, with the Latin squares method to counterbalance the technique order (Figure S2). Before the formal experiment, the participants were asked to fully practice until they make themselves master of the two techniques.

For each technique of the formal experiment, the participants were requested to complete 3 blocks, with 27 random shown target items in each block, which covered all items of the 3×3×3 hierarchical menu items. Participants were asked to perform all trials as quickly and accurately as possible. They can take breaks between blocks. It took each participant about 20 min to complete all trials.

In total, we collected data from 1620 trials (2 techniques×3 blocks×27 menu items×10 participants). For each trial, we collected task completion time and task error data under each condition. After completing all trials, the participants were asked to complete a questionnaire, which compare the two techniques from four aspects: error-proneness, speed, fatigue, and easy to learn on a Likert scale, from 1 (least) to 7 (most).

- Result. Paired-T test shows that there is no significant difference between the two techniques in terms of error rate ($p = 0.487$, $T = -0.725$). But the completion time of LotusMenu is significantly shorter than the linear menu ($p < 0.001$, $T = -28.208$ (Figure S3)).

We also compare the subjective perception of the two menu techniques (Figure S4). Results from the Paired-T test reveal that users feel that LotusMenu technique can significantly reduce operating fatigue ($p = 0.041,\ T = -2.377$). The LotusMenu is also perceived more error prone ($p = 0.014,\ T = 3.051$) and less easy to learn than the linear menu ($p = 0.007,\ T = -3.473$). Differences in the other aspects are not significantly.

Discussion and future work. Not surprisingly, as a new technique, it is perceived that LotusMenu needs more time to get familiar than traditional linear menu. But when users become experts, they can operate LotusMenu more quickly than the traditional one, without sacrificing error rate. This is because when using the linear menu, the users, even the expert users, need to complete each menu level with the corresponding selection and confirmation. In contrast, when using the LotusMenu technology, the expert users can merge the 3D rotation gestures to some extent.

Interestingly, although LotusMenu can significantly reduce the completion time without sacrificing error rate, the participants did not feel this benefit. That may be due to the underestimation of themselves when they face with new technology [1, 8].

Besides, LotusMenu was perceived less fatigue than traditional linear menu. This is because the LotusMenu requires less mid-air arm movements, which has been proved to be one of the main causes of user fatigue in 3D interaction [3].

In the future, we will study user behaviors under different parameters of LotusMenu. In addition, we will try to design more 3D rotation widgets in different application environment, and explore how these widgets work.

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Supporting information Videos and other supplemental documents. The supporting information is available online at info.scichina.com and link.springer.com. The supporting materials are published as submitted, without typesetting or editing. The responsibility for scientific accuracy and content remains entirely with the authors.

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