

Tangible AR interaction based on fingertip touch using small-sized non-square markers

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Abstract

Although big-sized markers are good for accurate marker recognition and tracking, they are easily occluded by other objects and deteriorate natural visualization and level of immersion during user interaction in AR environments. In this paper, we propose an approach to exploiting the use of rectangular markers to support tangible AR interaction based on fingertip touch using small-sized markers. It basically adjusts the length, width, and interior area of rectangular markers to make them more suitably fit to longish objects like fingers. It also utilizes convex polygons to resolve the partial occlusion of a marker and properly enlarges the pattern area of a marker while adjusting its size without deteriorating the quality of marker detection. We obtained encouraging results from users that the approach can provide better natural visualization and higher level of immersion, and be accurate and tangible enough to support a pseudo feeling of touching virtual products with human hands or fingertips during design evaluation of digital handheld products.

Keywords: Augmented reality; Tangible interaction; Fingertip touch; Small-sized markers; Rectangular markers

1. Introduction

In tangible augmented reality (AR), each virtual object is registered to a physical object and the user interacts with virtual objects by manipulating the corresponding physical objects [1-5]. The use of simple objects with markers has been exploited to support accurate and tangible interaction in AR environments. Big-sized markers are good for accurate marker recognition and tracking, but they are easily occluded by other objects and deteriorate natural visualization and level of immersion during user interaction.

In this paper, we propose an approach to exploiting the use of rectangular markers to support tangible AR interaction based on fingertip touch using small-sized markers. The approach uses rectangular markers whose length, width, and interior area can be adjusted to make them more suitably fit to longish objects like fingers. It also utilizes convex polygons to recover the quadrilateral boundaries of markers which are partially occluded, and properly enlarges the pattern area of each marker while adjusting its size without deteriorating the quality of marker detection.

2. Related work

Various interaction techniques have been studied for improving immersion and providing the feeling of touch in AR environments. Park et al. [4] have studied approaches to AR-based user interaction which uses simple physical objects to provide tangible interaction without any hardwired connections in a simple and cheap AR environment. In their approach, the user creates input events by touching specified regions of the product-type object with the pointer-type object, and the virtual product reacts to the events by rendering its visual and auditory contents on the output devices. In their subsequent works [5-7], Park and his graduate students presented ideas of resolving hand occlusion and replacing the pointer-type object by a finger fixture for achieving better visual immersion and more tangible interaction with sense of touch.

Recently, Park and his students proposed tangible AR interaction using product- and ring-types of paper models which are fabricated by paper crafting [8]. More recently, they presented the work on tangible AR interaction in which the ring-type paper model is replaced by a small sticker-type object made of thick paper [9]. These approaches are very attractive since they are available at very low cost without hardwire connections, and accessible without restriction on location.

The work presented in this paper was originally presented at the 2013 Asian Conference on Digital Design and Engineering (ACDDE 2013) [9]. In this paper, we extended the

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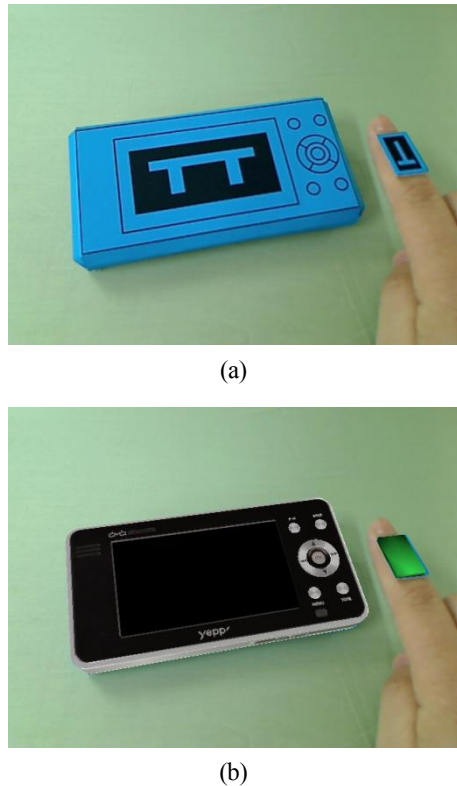


Figure 1. Tangible objects: (a) paper models, (b) augmented virtual objects.

work further to investigate the accuracy and the usefulness of the proposed tangible interaction approach by experiments and user studies. The experiments on button selection tasks are included to assess the accuracy of the proposed interaction approach and to compare it with previous interaction approaches. The user studies are added to investigate the usefulness of the proposed approach in design evaluation of digital handheld product.

3. Proposed approach

We basically follow the user interaction mechanism described in Park et al. [5, 8]. As shown in Figure 1, we use two types (product-type and sticker-type) of tangible objects for interaction between the user and the product in an AR environment. The product-type object representing a digital handheld product can be either an RP mockup [4, 7] or a paper model [8]. In the figure, we used a paper model representing a portable multimedia player. The sticker-type object made of thick paper is a small-sized rectangular marker itself. In this work, tangible objects are made blue in order to make the real image of the tangible objects not only create good contrast to skin color but also include the rendered region of the virtual objects properly.

The user attaches the sticker-type object around his or her fingertip. The product-type object is used to acquire the position and orientation of the product, and the sticker-type object is used to recognize the position of a fingertip.

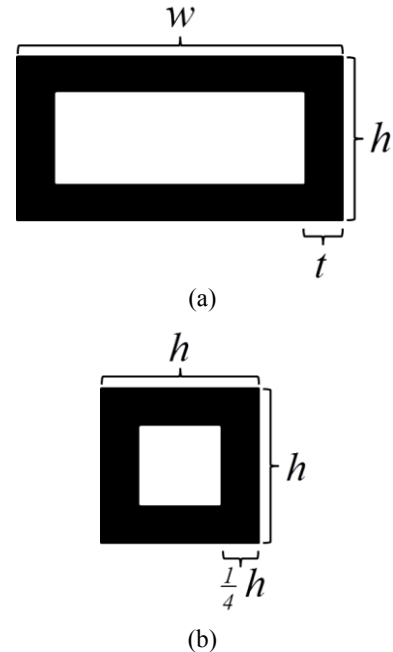


Figure 2. Marker dimensions: (a) rectangular marker, (b) square marker used in ARToolKit.

In the previous works [4–8], as the size of the pointer-type or ring-type object is pretty large, it is frequently hindered to get a wider view of virtual products during user interaction in an AR environment. Thus, it is required to decrease the size of markers while keeping their accuracy of recognition and tracking.

In order to overcome the shortcomings of using big-sized markers in AR applications, various solutions including markerless tracking have been developed [10]. Markerless tracking is attractive in that it does not need any artificial markers to calculate the position and orientation of virtual objects in the real environment, but it is not so good in tracking accuracy and computational efficiency as fiducial marker tracking.

For rapid and accurate user interaction in design evaluation of digital handheld products, we facilitate the efficient use of fiducial markers. In marker tracking such as the one used in ARToolKit [11], quadrilateral contours are detected from real images, and their inside regions are analyzed for identifying square markers (for example by template matching). In the proposed approach, we exploit the use of markers and present solutions to satisfy the following requirements. Firstly, the width and height of a marker can be adjusted to fit it to a target object. Secondly, the pattern area of the marker can be enlarged for better marker identification without sacrificing the quality of tracking. Thirdly, the marker can be recognized and tracked when it is partially occluded.

3.1 Enlarging pattern area

To resolve the first and second requirements, we devise to use rectangular markers shown in Figure 2. Parameters of a

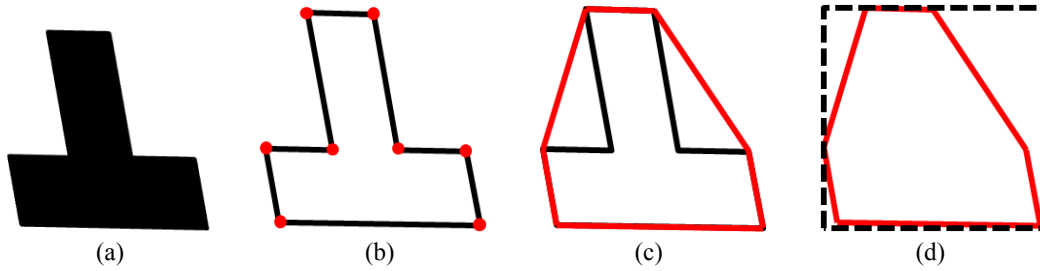


Figure 3. Convex polygon and minimum enclosing rectangle: (a) binary image, (b) extracted polygon, (c) convex polygon in red, (d) minimum enclosing rectangle.

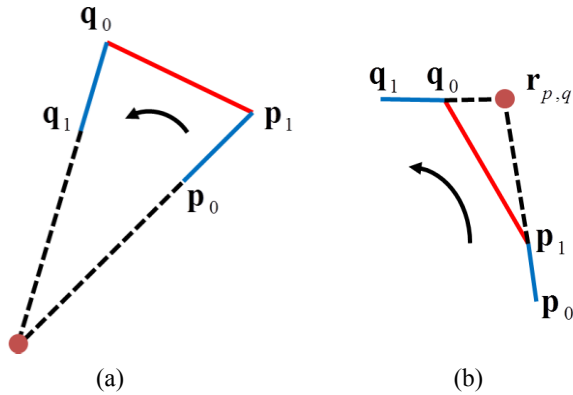


Figure 4. Computation of an intersection point: (a) invalid point, (b) valid point.

rectangular marker are width (w), height (h), and thickness (t). Note that $w = h$ and $t = 1/4h$ for a square marker used in AR-ToolKit. By using rectangular markers is that their length, width, and interior area can be adjusted to make them fit to the shape of target objects (for example, longish objects like fingers).

The inside pattern area of a marker is used for marker identification. For a square marker used in ARToolKit, its pattern area (A_s) of its inside pattern used for marker identification is given as $A_s = 1/4h^2$. For a rectangular marker, its pattern area (A_r) is given as $A_r = (w - 2t)(h - 2t)$. For a rectangular marker with $w = 2h$ and $t = 1/8h$, its pattern area is $A_r = 21/16h^2$.

When width (w) and height (h) are fixed, small thickness increases pattern area and the accuracy of marker identification. However, too small thickness is very likely to cause the failure of quadrilateral contours detection and marker tracking. From our experimental experience, we found that thick-

ness (t) in $[1/4h, 1/10h]$ is suitable for our applications.

With the flexibility in adjusting the width, height, and thickness of rectangular markers, we can properly enlarge the pattern area of a marker with fixed size without deteriorating the quality of marker detection. This makes it possible to support tangible AR interaction using small-sized markers.

3.2 Resolving partial occlusion of a marker

Based on an assumption that a marker attached to a tangible object is occluded either by a user’s hands or by other tangible objects, the basic idea for resolving the partial occlusion of a marker is to reconstruct quadrilaterals using the convex polygons of contours extracted from a real world image. Its detailed steps are described as follows:

- (1) Compute a binary image from a real world image by applying an adaptive thresholding technique, and obtain contours from the binary image. For each contour \mathbf{P} whose area is greater than a specified value, do Steps (2) to (6).
- (2) Obtain line segments on \mathbf{P} and compute the convex polygon \mathbf{P}_{conv} from the line segments.
- (3) If the number of points of \mathbf{P}_{conv} is 3 (i.e., \mathbf{P}_{conv} is triangle), go to Step (2). If the number is 4, store \mathbf{P}_{conv} as one of quadrilateral contours and go to Step (2). If the number is greater than 4, go to Step (4).
- (4) Compute the minimum enclosing rectangle \mathbf{R}_{mer} from \mathbf{P}_{conv} . See Figure 3.
- (5) For four line segments of \mathbf{P}_{conv} , compute four valid intersections between two neighboring line segments $\mathbf{p}_0\mathbf{p}_1$ and $\mathbf{q}_0\mathbf{q}_1$, and construct a candidate quadrilateral with the four valid intersections. An intersection is valid if it is in the right side of the line $\mathbf{p}_1\mathbf{q}_0$. See Figure 4.
- (6) Among the candidate quadrilaterals, select the one with the minimum difference in area from the rectangle \mathbf{R}_{mer} , and

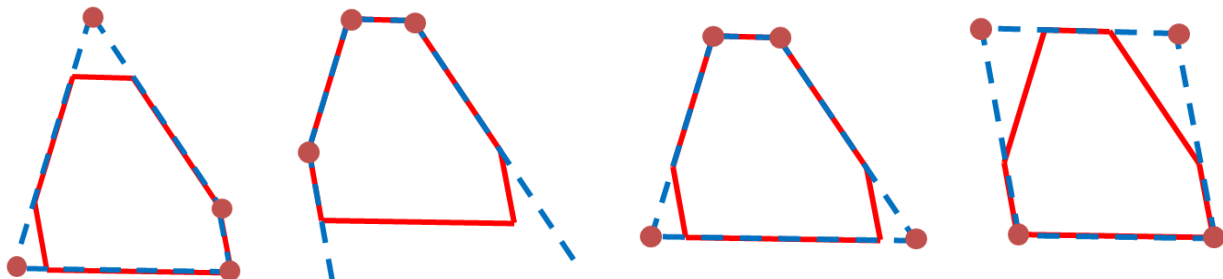


Figure 5. Candidate quadrilaterals of an AR marker.

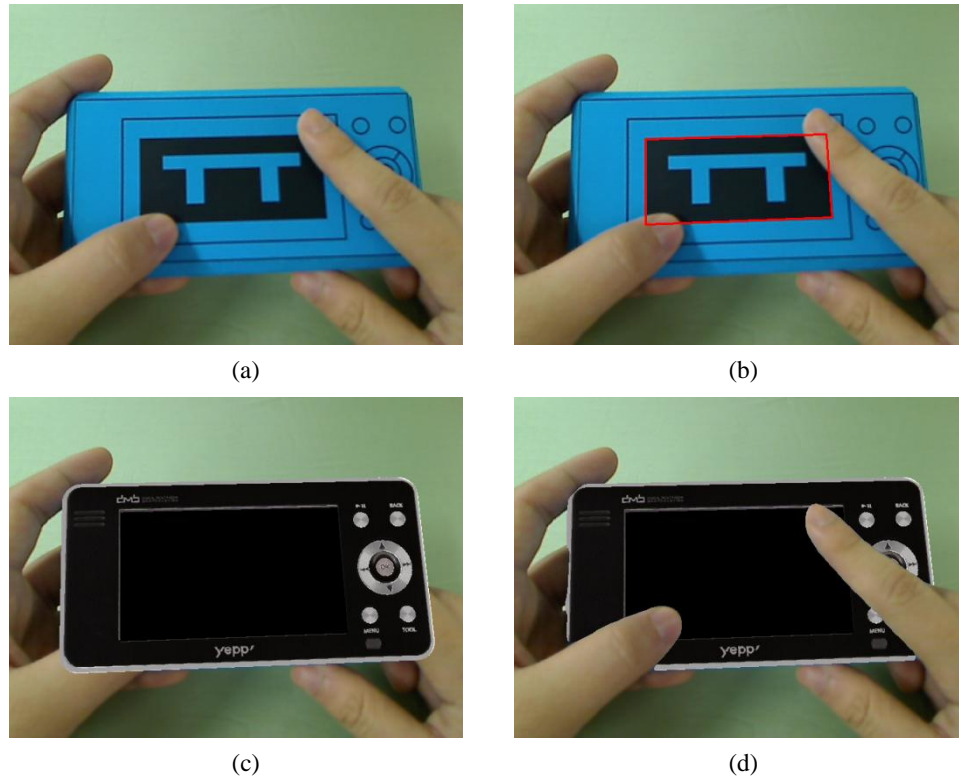


Figure 6. Example of resolving partial occlusion of a marker: (a) real world image, (b) reconstructed quadrilateral, (c) augmented image, (d) augmented image without hand occlusion.

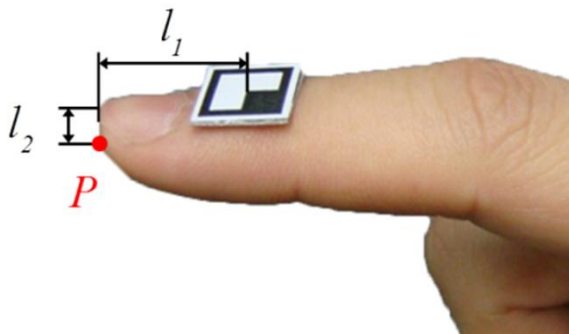


Figure 7. Fingertip location with respect to a small-sized marker.

use the quadrilateral for marker identification. See Figure 5.

Figure 6 shows the result of resolving partial occlusion of a marker which is attached to the paper model of the portable multimedia player. The hand occlusion solver was applied in Figure 6(d).

3.3 User interaction mechanism

For digital handheld products having buttons or sliders, we assume that input events are created either by pushing buttons or by moving sliders. We consider that an input event occurs if the following conditions are satisfied: (i) The distance from the fingertip to the button (or slider) is the shortest among the distances from the fingertip to the other buttons



Figure 8. AR environment used in this work.

and sliders, and (ii) the distance is kept smaller than a tolerance during a specified time period.

For distance computation between two points defined in different coordinate frames, we transform the points into a reference coordinate frame. Using the camera calibration information, we can acquire coordinate transformations between the camera and the AR markers associated with their

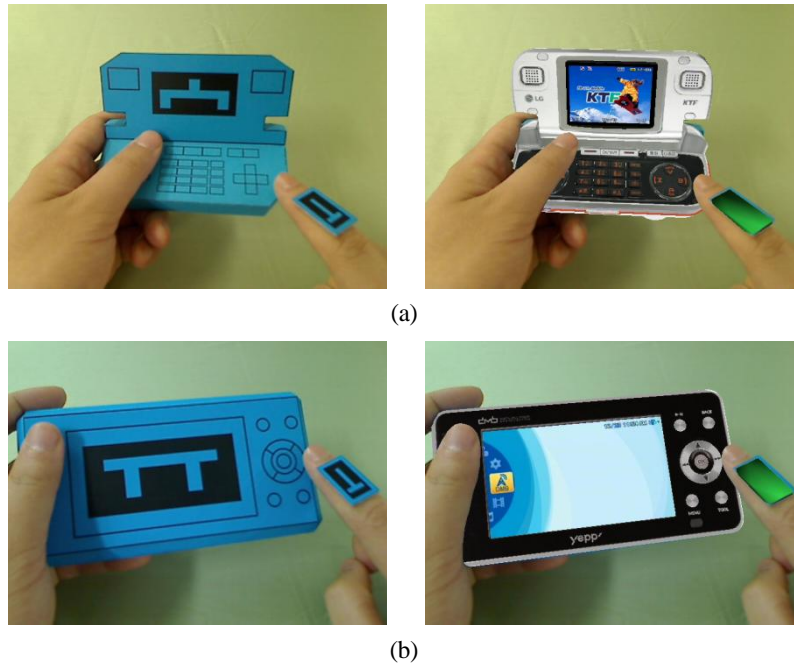


Figure 9. Virtual design evaluation using the proposed tangible interaction: (a) the game phone, (b) the portable multimedia player.

tangible objects.

To determine the fingertip location, we need to know the lengths l_1 and l_2 in Figure 7. Given the lengths, the fingertip location \mathbf{p} with respect to the local coordinate frame of the AR marker can be determined as follows: $\mathbf{p} = \mathbf{0}_m + l_1\mathbf{y}_m - l_2\mathbf{z}_m$ where $\mathbf{0}_m$, \mathbf{y}_m , and \mathbf{z}_m are the origin, y -axis, and z -axis of the marker coordinate system, respectively. For accurate tangible interaction, it is necessary to make the fingertip location the same with respect to the AR marker. Thus, we need to estimate or measure the lengths l_1 and l_2 as exactly as possible.

4. Implementation and application

We implemented the proposed tangible interaction approach by using C and C++ languages with open sources ARToolKit, OpenCV, OpenGL, and GLUT on a windows-based desktop personal computer (Intel Core i5-2400 3.1GHz processor, 4 GB SDRAM and ATI Rade on HD 4870 X2 2 GB graphic card). As shown in Figure 8, we used a PC cam-

era of resolution up to 800×600 and tangible objects as input devices. A pair of speakers (not shown in the figure) and a small 10 inch LCD monitor with resolution 1024×640 are used as output devices. To imitate a video see-through display, we mounted the LCD monitor and a reading stand on a small tripod stand, and attached the camera to the backside of the reading stand.

We have integrated the proposed approach into virtual design evaluation of digital handheld products such as MP3 players, game phones, portable multimedia players, and smart phones. Its scheme is very similar to the one described in Park et al. [4, 5, 7, 8]. Figure 9 shows virtual design evaluation of two digital handheld products. The visualization of virtual objects in the AR environment is accomplished by overlaying the rendered image of the objects (free of hand occlusion) on the real world image in real time. The hand occlusion solver presented by Park and Moon can be employed to improve the visualization without hand occlusion during user interaction [6, 7].

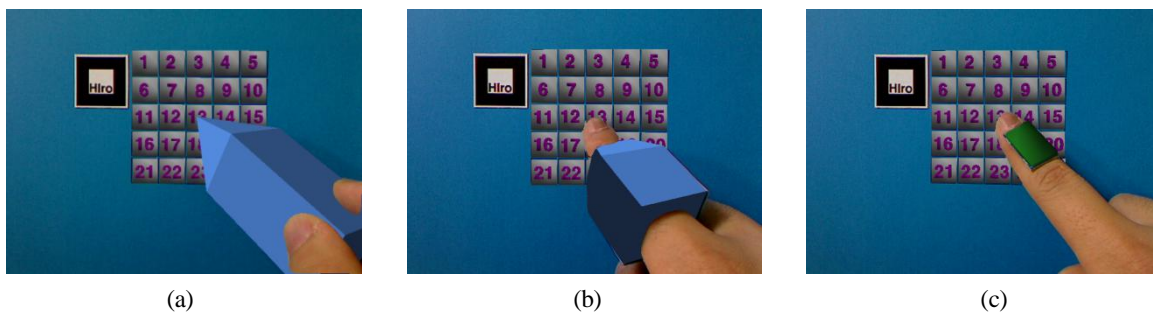


Figure 10. Task of button selection (12 mm): (a) using a pen-style object, (b) using a ring-style object, (c) using a sticker with a small-sized marker.

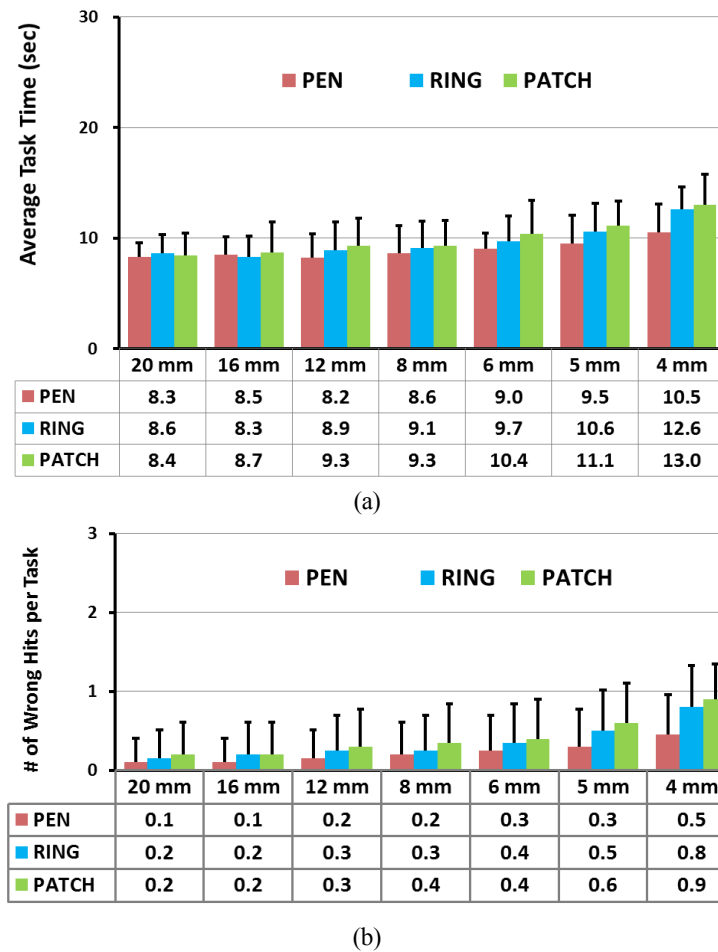


Figure 11. Accuracy of tangible AR interaction: (a) time required for each button selection task, (b) number of mistakes for each button selection.

Let PATCH denote the proposed approach which uses the sticker-type object for tangible interaction. Let PEN be the approach which uses the pen-type object [4]. Let RING be the approach which uses the ring-type object [8]. To compare the accuracy of the PATCH approach with the PEN and RING approaches, we conducted button selection experiments in a setup similar to the one in Figure 8. In the setup, instead of a product-type object, a thin plate (size: $150 \times 130 \text{ mm}^2$) is positioned in a fixed location. 20 university students voluntarily participated as the subjects of the experiments. The subjects consist of 17 males and 3 females and their ages range from 21 to 25 years (mean = 23). They all have basic knowledge of 3D geometric modelling and Computer Aided Design (CAD), and most of them are familiar with the concept of AR.

Each subject was informed how to do button selection tasks with the three approaches. As shown in Figure 10, the subject was then asked to complete a set of button selection tasks using each approach. Square buttons with an AR maker (size: $28 \times 28 \text{ mm}^2$) are put on the plate. The button length decreases from 20, 16, 12, 8, 6, 5, 4, 3 mm. Given a sequence of 4 random numbers in each selection task, the subject has to

touch the inside regions of the given numbers with the index fingertip (holding the ring- or sticker-type objects) or the tip of the pen-type object. Different sounds are given to differentiate between right and wrong selections of each number. We herein consider that a button is selected if it is closer to the fingertip (or the tip of the pen-type object) than the others and its distance is kept smaller than half the length of the button for 0.5 second. Each task is not completed until the subject selects the 4 numbers correctly. After each selection task, we recorded the time required and the number of wrong selections. The order of the approaches was counterbalanced between subjects to remove order effects.

Figure 11 depicts the accuracy assessment of the three approaches in the time required and the number of wrong selection per each task. In the figure, average values with standard deviations are plotted. The gap between the fingertip and its computed location is usually bigger than the gap between the pen tip and its computed location, implying that the PEN approach is more accurate than the RING and PATCH approaches. However, we found that there are no significant differences both in the average task time and in the number of wrong selections for button sizes greater than 5 mm. Our

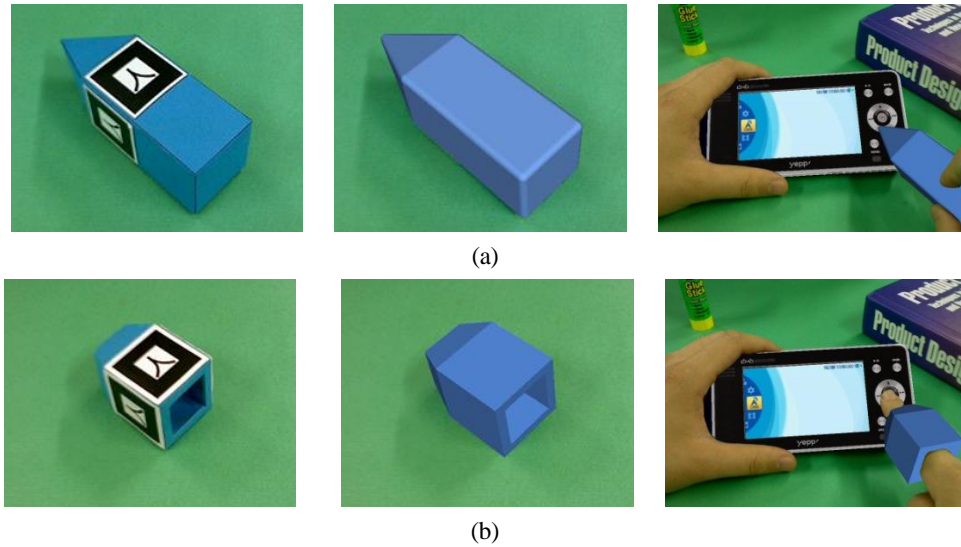


Figure 12. PEN and RING approaches applied for design evaluation: (a) the PEN approach using pointer- and product-types of paper models, (b) the RING approach using ring- and product-types of paper models.

experimental experience is that the task time and the error frequency are tolerable if the button size is not less than 5 mm, which means that the interaction using the sticker-type object can be applied to a wide variety of information appliances.

To investigate the usefulness of the proposed tangible in-

teraction approach in design evaluation of digital handheld products, we carried out a user study with the same of group of 20 subjects in the AR environment shown in Figure 8. Task performance measures and questionnaires were used to compare the proposed approach (PATCH) with the two approaches (PEN and RING) using the pointer- and the ring-

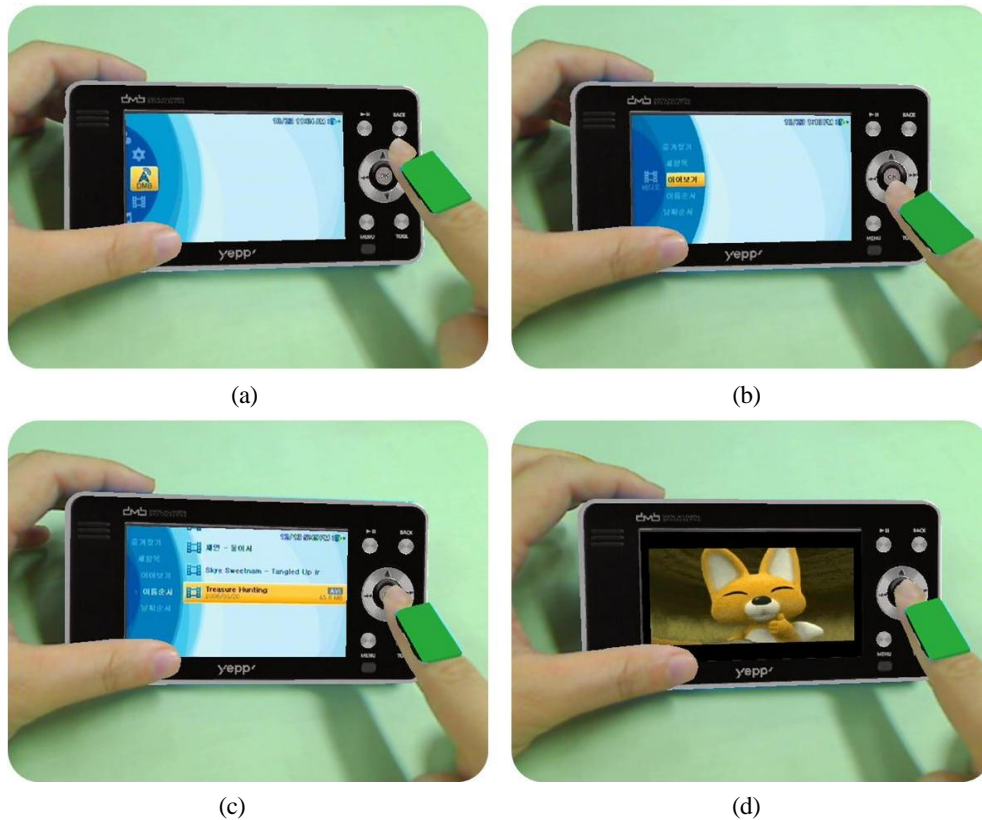


Figure 13. Task used in the user study: (a) move to main menu, (b) select submenu for animation play, (c) move to the 4th animation file, (d) play the animation.

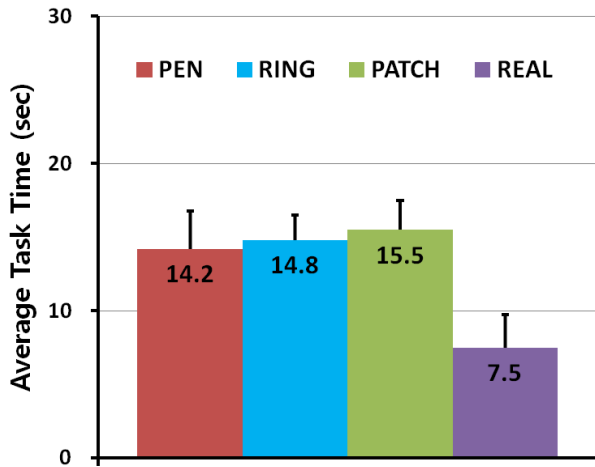


Figure 14. Graphical result of task performance measures.

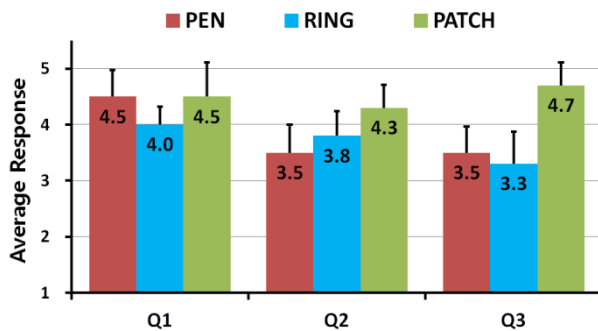


Figure 15. Graphical result of questionnaire results.

type paper models as shown in Figure 12. As we have built the virtual prototypes from commercial products based on reverse engineering, we included the use of real products (hereafter called REAL) as the target reference of the three approaches. In this user study, a portable multimedia player was chosen as a test product, and a paper model was used as its product-type object.

Each subject was introduced about the design evaluation using real products and informed how to manipulate virtual products (i.e., how to click buttons or to move/scale/rotate the virtual products by using the tangible objects) using the three approaches (PATCH, PEN, and RING). When the subject felt familiar with all the approaches, the subject was asked to complete a task using each approach and the time required to complete the task was measured. Before performing the task, the subject was allowed to have access to a simple graphical manual describing the task steps, which are shown in Figure 13. The order of the approaches (PATCH, PEN, and RING) was counterbalanced between subjects to remove any order effects. The results of the performance measures (i.e., average task times) are plotted in Figure 14.

From the results of task performance, we found that the task performance of using real products (REAL) is the best among the four, but that the other three approaches (PATCH, PEN, and RING) are comparable each other. As shown in

Table 1. Questionnaire contents.

| | |
|----|--|
| Q1 | Is it easy to click buttons during user interaction? |
| Q2 | Is it comfortable to use during user interaction? |
| Q3 | Does it provide good visibility during user interaction? |

Figure 11, the interaction accuracy of the PEN approach is slightly better than those of the RING and PATCH approaches. This trend was also reflected in the results of task performance, but the difference in task performance between the three was not so significant.

After completing all the tasks, each subject was asked to fill questionnaires in order to capture the qualitative aspects (i.e., ease to click buttons, degree of comfort, level of visibility) about his or her experience of using the three approaches (PATCH, PEN, and RING). The questions asked are summarized in Table 1. All responses were scored on a 5-point scale. The results of the questionnaires (i.e., average scores) are plotted in Figure 15. From the results, we found that the PATCH approach earned higher scores in all the three aspects than the others.

Most of the subjects commented that the RING and PATCH approaches are better to provide a feeling like manipulating products with human hands. They felt that it was nice to click buttons with their fingertips not with the pen-type object. They also commented that the PATCH approach is very good to provide a wider view of virtual products during AR interaction than the PEN and RING approaches.

By analysing feedbacks from users, we found that the proposed user interaction is accurate enough to be applied to virtual design evaluation of digital handheld products, and tangible enough to provide a feeling like manipulating products with human hands. Moreover, it can improve the level of visual immersion during user interaction due to the use of a small sticker-type object.

5. Conclusions

In this paper, we have addressed how to exploit the use of rectangular markers to support tangible AR interaction based on fingertip touch using small-sized rectangular markers. The approach proposed in this paper can improve level of visual immersion while manipulating virtual objects, and support tangible AR interaction with a pseudo sense of touch at very low cost without hardware connections.

There may be some patterns which support the good robustness of marker tracking used in the proposed approach. It needs future research to find some rules of thumb which are well used to generate marker patterns which guarantee robust marker tracking. The users still have difficulty in the interaction based on marker-based objects when some AR markers fail to be recognized due to bad illumination conditions or the severe occlusion of markers by tangible objects or the user's hands. We considered resolving the partial occlusion of a marker in the paper. In case that corners or edges of a marker are occluded, its quadrilateral (i.e., rectangular boundary) is

reconstructed and its interior pattern area is used for template matching. However, if the interior pattern area is severely occluded, the marker is likely to be wrongly recognized. For future works, we need to address how much occlusion the proposed approach can handle. We also need to develop more robust tracking techniques using simple polygonal patterns and prior information obtained in previous frames.

Acknowledgements

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