

# Two-handed tangible interaction techniques for composing augmented blocks

Hyeongmook Lee · Mark Billingham ·  
Woontack Woo

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**Abstract** Modeling tools typically have their own interaction methods for combining virtual objects. For realistic composition in 3D space, many researchers from the fields of virtual and augmented reality have been trying to develop intuitive interactive techniques using novel interfaces. However, many modeling applications require a long learning time for novice users because of unmanageable interfaces. In this paper, we propose two-handed tangible augmented reality interaction techniques that provide an easy-to-learn and natural combination method using simple augmented blocks. We have designed a novel interface called the cubical user interface, which has two tangible cubes that are tracked by marker tracking. Using the interface, we suggest two types of interactions based on familiar metaphors from real object assembly. The first, the screw-driving method, recognizes the user's rotation gestures and allows them to screw virtual objects together. The second, the block-assembly method, adds objects based on their direction and position relative to predefined structures. We evaluate the proposed methods in detail with a user experiment that compares the different methods.

**Keywords** Two-handed interaction ·  
Tangible interaction · Augmented reality ·  
3D model assembly · Multi-modal feedback

## 1 Introduction

Although augmented reality (AR) has been studied for a long time, there is still a need for new interaction techniques in AR applications. In particular, there has been little work done on interaction methods for AR modeling applications. In the real world, small physical objects are often combined to form a large object or scene. For instance, tiny toy blocks can be easily combined together to make an original creation using two-handed interaction. However, the limited number of real blocks or space for construction may make it impossible to build very large objects. In a virtual environment (VE), there is no limit on the virtual blocks or construction space, but the object manipulation may be more difficult. In our work, we are trying to bridge the gap between the real and virtual world and develop an interaction technique that is as easy to use as moving real blocks, with the flexibility of virtual content.

In this paper, we propose a two-handed tangible AR interaction method for combining augmented toy blocks into new virtual objects. We are only focusing on simple virtual toy block composition that is based on familiar interaction metaphors from the real toy assembly and so should be easy to learn. We present a novel manipulation interface called the cubical user interface (CUI), which has two tangible cubes that are tracked by a marker tracking method. The CUI supports physical object combination through a screwing operation using built-in magnets and button input by wireless communication modules. Using

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H. Lee · W. Woo (✉)  
GIST U-VR Lab, Gwangju 500-712, South Korea  
e-mail: wwoo@gist.ac.kr

H. Lee  
e-mail: hmooklee@gist.ac.kr

M. Billingham  
The HIT Lab NZ, University of Canterbury,  
Christchurch, New Zealand  
e-mail: mark.billinghurst@hitlabnz.org

the CUI, we have designed two types of tangible interactions. The first, the screw-driving (SD) method, recognizes the users' rotating gestures and allows them to screw virtual objects together. The second, the block-assembly (BA) method, adds objects based on their direction and position relative to predefined structures.

The proposed interaction techniques have the following advantages. Two-handed operations can give better performance than using a single hand in 3D object composition (Gribnau and Hennessey 1998). Through the SD method, the user can freely position a virtual block for combining objects in 3D space. The BA method supports a fast composition strategy and effective visual guidance using information about the virtual blocks. Finally, the tangible cubes provide natural force feedback in the composing operation.

The remainder of this paper is organized as follows. In Sect. 2, we review related work from immersive virtual reality (VR) and tangible AR interactions for virtual object composition. Then in Sect. 3, we describe the proposed two-handed CUI tangible interface and the SD method and the BA method. Next, we show the implementation aspects and results for an augmented toy block composition task. In Sect. 5, we present a usability study that evaluates the proposed interactions by comparing different input methods. Finally, we end the paper with a discussion of some directions for future research and conclusions.

## 2 Related work

### 2.1 Virtual object composition in immersive VR

Many VR researchers have attempted to transfer effective GUI-based modeling and object composition tools into immersive 3D space. Industrial researchers have tried to develop modeling and planning systems for engineers (Jayaram et al. 1997; De Sa and Zachmann 1999). For example, VADE (Connacher et al. 1995) is an immersive 3D modeling environment for the engineer, which supports 3D space modeling with a glove interface. Research like this has found that accuracy in collision detection and avoidance and intuitive interactions are critical problems that need to be addressed.

There is relevant earlier research related to the virtual object modeling and object composing techniques. "3DM" (Butterworth et al. 1992) is an immersive 3D surface modeling application that allows model manipulation from both CAD- and GUI-based drawing program. A head mounted display (HMD) device shows the virtual space, and the system supports one-handed modeling interaction with a wired six degree of freedom two button mouse. "VLEGO" (Kiyokawa et al. 1996) is an immersive two-handed 3D

modeler, which uses virtual toy block assembly and flexible two-handed interaction for object composition. The user can manipulate virtual blocks by holding two wired 3D input devices, providing various bimanual interactions such as parallel block selection, composition, separation, and cooperative orientation. The system also automatically supports collision detection and avoidance between object primitives and adjusts their positions. ArcheoTUI (Reuter et al. 2007) is a two-handed and foot-based tangible user interface for assembling fragments of fractured archeological objects in VR environment. In this system, a handheld prop tracked by an optical tracker allows the user to translate and rotate the virtual fragments, and foot pedal input is used to clutch the movements of the hands.

In general, immersive VR approaches enable free positioning in 3D space thanks to using HMDs and input devices such as gloves, and 3D mice. However, the user has to rely on virtual control points in the immersive space, which means a lack of real-world spatial context for providing depth perception in the composition task. Therefore, user experience or gender differences could cause a big difference in performance (Gaulin 1992). Furthermore, the virtual input device may not provide any natural force feedback related to the composition interaction during the operation.

### 2.2 Virtual object composition in tangible AR

In AR interfaces, there is an opportunity to use real objects to interact with virtual content. In this context, Ishii and Ullmer (1997) have developed the concept of tangible user interface (TUI) where real-world objects are used as the computer input and output devices. Many researchers have explored how to use TUI techniques for object composition (Camarata et al. 2002; Lersithichai and Seegmiller 2002). For example, the "Active Cube" (Watanabe et al. 2004) is a multimodal tangible user interface that allows users to construct 3D graphics on a monitor using physical cubes. Multiple cubes can be used for real-time 3D modeling by networking between the cubes when they are physically connected.

However, TUI-based virtual object composition has some disadvantages. In case of one-to-one mapping between the physical and virtual object (Watanabe et al. 2004), the weight of the real objects and space they take up are going to increase for each additional tangible object. When the user is manipulating real objects and seeing the output on a screen, then there is a separation between the input and output space that may be confusing.

Tangible AR is a metaphor that combines TUI input techniques with AR output to overcome some of these limitations (Kato et al. 2001). This has been used in a number of AR applications. For example, in the "Tiles" system (Poupyrev et al. 2002), multiple planar magnetic

tiles have single fiducial markers attached to them and the user composes virtual objects when the tiles are move close together. Zhou et al. (2008) also uses a tangible AR technique based on a cube to support virtual data composition for interactive storytelling.

Various tangible AR modeling applications have been developed. “TARM” (Park and Lee 2004) is a tangible AR modeling system that allows the user to generate a new 3D model using physical block manipulation. In the main modeling process of TARM, four real blocks represent four virtual primitives such as cube, cone, cylinder, and sphere. One virtual primitive block is overlaid onto a single marker attached to a physical block. A collision detection method is also provided between a marker and the target virtual object for object combination. Therefore, this interface is an intuitive way for a novice user to perform object composition. However, the use of a single marker means that it does not support free orientation of the virtual block. Another tangible AR modeling system, “ARpm” (Fiala and Adamo-Villani 2005), used the 3D Studio Max modeling functions in the real world with a fiducial marker-attached wireless pointer device. ARpm enables users to use the complex 3D polygonal modeling provided by 3D Studio Max. However, the selection of a small spot where the user wants to do the modeling is still hard work in AR space, and the adjustment of the movement volume is also difficult in 3D space. In the engineering field, Wang et al. (2005) have shown natural tangible interaction in assembly between virtual objects in augmented environment. However, this required heavy installation and preparation for execution including 3D model creation using laser scanners and setting up a color marker system.

For effective virtual object composition in tangible AR, the system has to provide special interaction techniques for composition such as familiar assembly metaphors from the real world. However, most AR applications use similar interaction techniques with selection or manipulation (Irawati et al. 2006; Kato et al. 2003; Yonemoto et al. 2007). Effective input methods are a critical issue for the fast overall performance. Furthermore, user studies for evaluating the input methods should be conducted. Unfortunately, there are few virtual object compositing interaction techniques so far and almost no examples of user studies with such systems.

### 3 CUI-based tangible interactions

#### 3.1 Cubical user interface

We consider the design of a novel interface for virtual block composition usable by a novice. Most other tangible AR interfaces use tools such as paddles, props, and cups

which have been designed by considering external properties such as shape, size, and weight (Kato et al. 2003; Irawati et al. 2006; Lee and Kim 2009). However, they have less attention paid to the internal properties for natural user interaction by novices, such as robust manipulator tracking, two-handed tool-based inter-operation, and fast wireless input methods.

*Robust manipulator tracking.* In general, a manipulator that has tracking markers on it could be occluded by an inexperienced users’ hand or be over-rotated so that the camera can no long see it. This shows that the tracking manipulator is an important factor in interaction and single marker-based interaction may not be so useful. In a multi-marker approach, one coordinate frame is created from relative pose information from a set of different markers making the tracking more robust.

*Two-handed tools-based inter-operation.* Using two-handed tools supports two types of bimanual interactions: symmetric and asymmetric (Guiard 1987). Bimanual symmetric means each hand performs identical actions either synchronously or asynchronously. Bimanual asymmetric indicates that the actions of both hands are different but closely coordinated to achieve the same task. In a selection of two virtual blocks which are going to be combined together, a bimanual symmetric approach using two tools could save time. A bimanual asymmetric approach enables a practical two-handed-based composing strategy (e.g., hammering, screw-driving, gluing, assembling) which could be more useful in virtual composition.

*Wireless fast and stable input.* Various tangible AR interaction methods have used marker-based input using a time delay for selection techniques. This input method has an inverse relationship between speed and stability. For instance, it can create erroneous input events by unexpected marker occlusions with a short time delay. If a long time delay is specified, stable input is guaranteed but each event takes more time and can cause a large delay due to repeated input like in an assembly task. In order to support both speed and stability in user input, we use a wireless button which has the additional benefit of providing force feedback.

After considering possible external and internal properties, we arrived at the design requirements for a two-handed tangible tool for composing augmented blocks shown in Table 1. The first three characteristics are concerned with external properties. In the tangible user interface design process, the most relevant shape to achieve the user task has different answers according to the application domain of the target system (Depaulis et al. 2005). We decided on a cube shape because it is a primitive that supports multiple combinations and simple assembly structure. Using a multi-marker approach with one tracking marker on each face, a cube provides robust tracking and

**Table 1** Five issues of designing guideline in two-handed tangible tool

Characteristic	Description	Related property
Familiarity	A shape which is easy to handle to general user	Shape, size, weight
Rotatability	A non-planar shape detected at least one marker from every direction; possible to rotate freely with augmented blocks	Shape, size, tracking
Combinability	A shape that satisfies toy block-assembly policy; possible to assembly at six sides (top / bottom / left / right / front / back) on existing block	Shape, inter-operation
Continuity	Not much delayed input in continuous composition operation	Input method
Accessibility	Easy input to reach whenever user want to select or decide	Input method

free rotation of augmented blocks. In addition, the six perpendicular sides of the cube meet the requirements of using a simple block for composing virtual objects. The remaining two characteristics are related to providing an input mechanism for when a user makes any selection or decision situation. In order to guarantee continuity, we used multiple wireless buttons. These give a faster and more stable response than the traditional occlusion-based input. In our case, we place a button on every cube corner for easy accessibility. Our approach is similar to Couture et al. (2008) who have introduced the ESKUA cube-shaped tool and TUI for CAD object assembling; however, their system is not designed for AR interaction and does not satisfy the same internal (fast and stable input) and external (accessibility) design requirements.

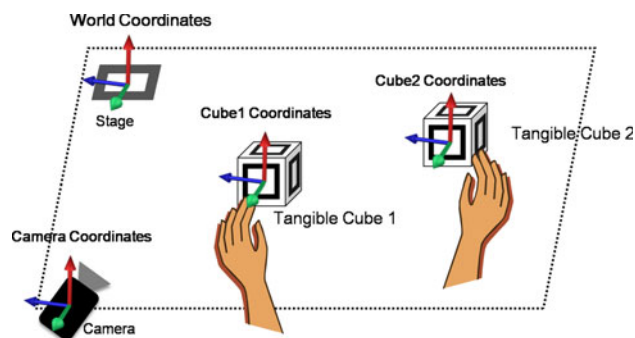
In order to conduct two-handed composing interactions in an AR environment, we built up an interface based on using two tangible cubes and defined it as the cubical user interface (CUI). The CUI is targeted at construction of AR scene where users are able to easily create virtual block combinations using a simplified tangible configuration with natural interaction. The CUI consists of three main components: (1) a camera, (2) a stage, and (3) tangible cubes. Figure 1 shows the configuration of the CUI, based on a fiducial marker tracking method. The first component is a camera for capturing the real scene. The stage is for placing available virtual blocks and putting the interim and final results on. Finally, two tangible cubes are used to select

virtual blocks from the stage and handle them in the real world. In CUI, the camera and other components each have a coordinate frame generated from a fiducial pattern. Those independent coordinates are used to calculate relative information such as distance, position, and rotation between objects.

### 3.2 The screw-driving method

In addition to defining objects in the interface, we need to specify how objects are able to interact with one another. Rather than allowing users to combine objects in any manner, we provide nature combination points on each virtual object where they can be joined. Then, we use a screw-driving (SD) technique to connect objects at these points. This is based on the real-world condition where two or more real objects are joined together using a screw and screwdriver. If a person turns the screwdriver clockwise, the two target objects are fastened, while a counterclockwise rotation loosens two targets that are already screwed together. The screw-driving (SD) method uses this same metaphor to join virtual objects. The screw-driving technique can also support axis change by the help of additional button input so 3D positioning is also possible.

Figure 2 shows the flowchart of the SD method. We divide the two tangible cubes into the main cube which is held in the non-dominant hand and the subsidiary cube which is held in the dominant hand. In advance, the initial position between tangible cubes (including the selected virtual block) is set by user using the push buttons on the cubes. This preliminary connection makes a total of 36 ( $6 \times 6$ ) cases which have slightly different formations between the two selected blocks. After that, the augmented 3D model is moved along the axis of the main cube according to rotating gesture of subsidiary cube. Using this movement, the amount of the change in position is scaled depending on the size of moving block. When the cube is rotated clockwise, the virtual object toward the main cube and when it is counterclockwise the object moves away from the main cube. The faster the rotation speed is, the faster the cube moves.

**Fig. 1** The configuration of the cubical user interface

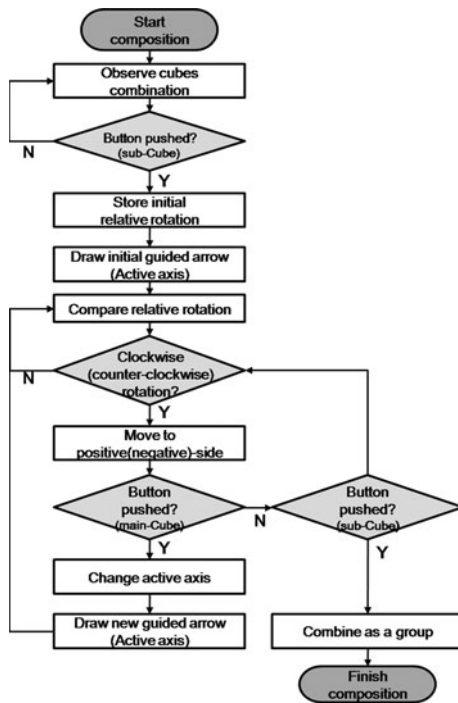


Fig. 2 A flowchart of the screw-driving method

To detect the users’ rotation gesture, the relative pose between multi-markers is compared. After storing the relative rotation of initial position following a button press, the SD method checks the difference between the stored and the current relative rotation. Equation 1 shows how we find the initial rotation from the start position by matrix multiplication and  $R_t$  function.  $M_{marker\ i}$  is the pose matrix of one of the tangible cubes and  $R_t$  is the rotation value only from pose matrix. Here, we use quaternions not Euler angles to represent the rotation between two markers and so avoid the problem of gimbal lock. In Eq. 2, we obtain the combined rotation between the initial and current rotation by multiplication of the two quaternions. The difference in outcome between Eqs. 1 and 2 shows the variation in rotation. In order to reduce the accumulated error, a round off method around the activated angle is required in the rotation measurement. Clockwise or right rotation, which acts as fastening a screw, defines the positive direction and counterclockwise or left rotation, which acts as loosening, defines the negative direction. Based on this principle, the moving virtual block event is activated according to the rotation direction of the users’ hand.

$$\mathit{initRot}_{t-1} = R_{t-1} (M_{\mathit{marker}2} \cdot M_{\mathit{marker}1}^{-1}) \tag{1}$$

$$\mathit{combRot}_t = \mathit{initRot}_{t-1} * R_t (M_{\mathit{marker}1} \cdot M_{\mathit{marker}2}^{-1}). \tag{2}$$

In order to allow positioning in 3D space, the SD method can change the rotation axis using active button

input. We designate the three axes ( $X$ ,  $Y$ , and  $Z$ ) with blue, green, and red colors, and the default combinable axis is initially set to the  $X$ -axis. In this context, the left two axes are preserved and the applicable arrow is superimposed on the buttons as well. By pushing the augmented button that matches the defined axes color, the moving axis is changed and the previous axes and color are saved to the pushed button. This process is appropriate for working with the non-dominant hand and supporting fast composition. In addition, in the middle of the composition, the guide arrow indicating the active axis changes according to the situation of augmented buttons and users’ input at that time. This helps to keep the user informed about the direction used for 3D positioning with the various axis changes.

### 3.3 The block-assembly method

If we know about the model structure of the component model objects, we can anticipate the product of the composition process, and so we do not expect to spend much time in combining virtual blocks. For instance, when we assemble real toy blocks, the connection points are often already fixed, so we just need to look at the coupling position and direction between blocks and fit them together. In addition, thanks to pre-existing knowledge of given models, the user may get a manual showing how the blocks should be assembled. The block-assembly (BA) method is an attempt to apply these ideas to the composing interaction.

Figure 3 shows the flowchart of the BA method. As with the SD method, the BA method is used on the two virtual objects that are selected by the tangible objects. In this context, if the selected objects are not in the combinable set, it does not allow the user to progress to the next assembly step. So user has the chance to choose different blocks that are part of the feasible set.

To confirm the feasibility condition, a predefined structure is required. This structure table is given from the assembly system, and it includes the hierarchical, relative position, and relative rotation information among the virtual blocks. Figure 4a shows examples of the predefined structure. Each model has one id and six directional pointers representing the combinable spots with static rotation and translation values. In Fig. 4b, we depict the tree view using partial models of a virtual toy car. The tree is generated from the set of bold lines in Fig. 4a. A connected line means that two models satisfy the feasible condition, and a directed line describes the hierarchy. In addition, every connected model has relative rotation and translation values as well. In case of  $M_3$ , the wheel model could have two rotation and translation sets, so it is the users’ decision as to how to use the tangible cube for combining the wheel with the body part. Based on this

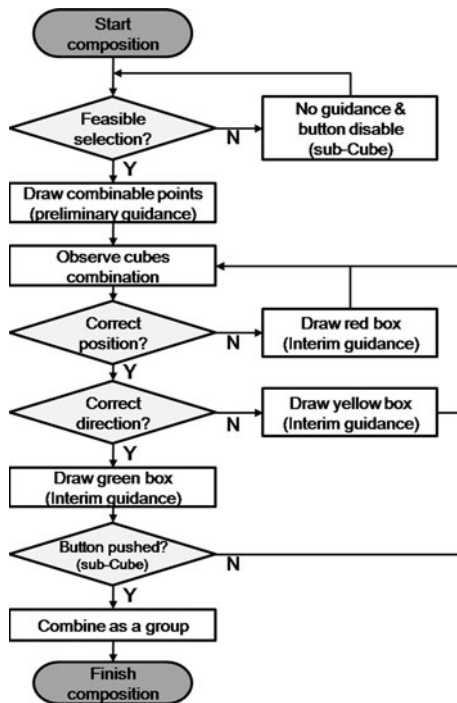


Fig. 3 A flowchart of the block-assembly method

strategy, the BA method creates a runtime tree structure when the selected block set are feasible and updates it during the composition process.

Based on the predefined structure, the BA method provides two types of additional guidance for the user: preliminary guidance and interim guidance. The preliminary guidance draws a virtual animated arrow toward the combinable side (see Fig. 5). When a new block is selected, the BA method traverses the runtime tree structure and then finds the available combinable sides of objects. In contrast, the interim guidance returns a color sign as the visual feedback. In the toy block composition case, three conditions are possible when an initial composition happens. One is a correct position and orientation, another is a correct position but an incorrect orientation, and the other is an incorrect position. The color sign feedback shows

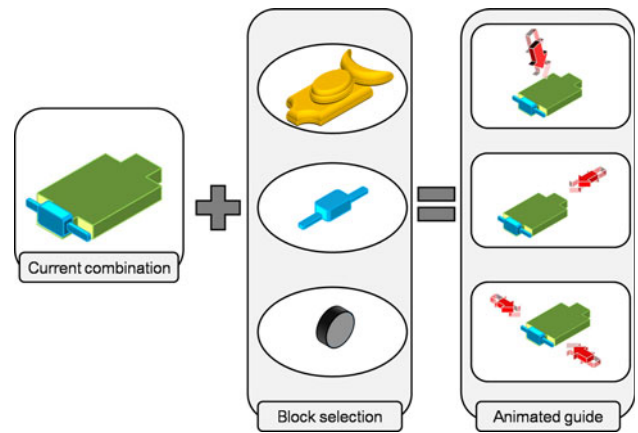


Fig. 5 An example of the preliminary guidance for the combinable points

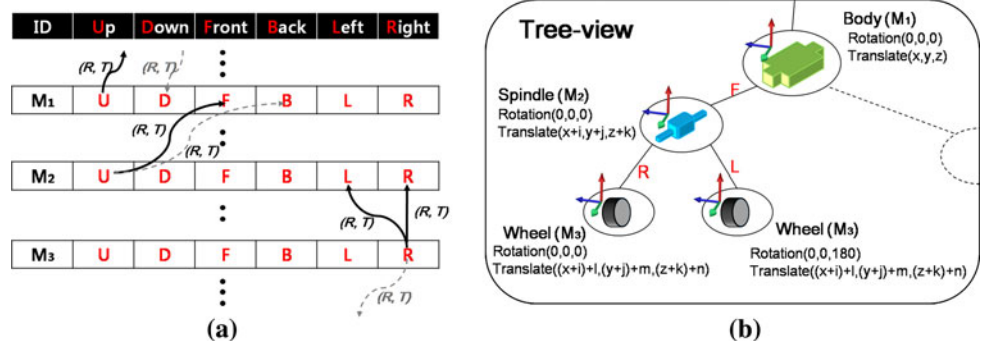
Table 2 Linking policy for interim guidance of BA method

Color sign	Impression	Composition status
Green	Safety	Correct position
		Correct direction
Yellow	Caution	Correct position
		Incorrect direction
Red	Danger	Incorrect position

which condition the combined object is in. From a composition point of view, the position is a more important factor than orientation. Table 2 shows the linking policy between the color sign system and the combined status of virtual objects.

In order to judge the position and orientation of the subsidiary cube relative to the main cube, we calculate the relative translation vector ( $\text{Vec}(\mathbf{T}_x, \mathbf{T}_y, \mathbf{T}_z)$ ) from Eq. 3.  $\mathbf{T}()$  denotes the translation value from the pose matrix. By a combination of three elements in the relative translation vector, six combination cases of the subsidiary cube have to be defined by the system in advance. Then, the system knows which side of the main cube the subsidiary cube is approaching from. For the

Fig. 4 The representation of the predefined structure (a) and tree view in partial model of virtual toy car (b)



users' decision, the button input is used but it is activated on the green sign only.

$$Vec(\mathbf{T}_x, \mathbf{T}_y, \mathbf{T}_z) = T(\mathbf{M}_{\text{marker1}} \cdot \mathbf{M}_{\text{marker2}}^{-1}). \quad (3)$$

### 4 Implementation

#### 4.1 Tangible cube

Figure 6 shows one prototype of the constructed tangible cube. It was made in acrylic and is 70 × 70 × 70 mm in size. To enable physical connection, five magnets were attached on each inner surface of the cube. One strong magnet was located at the center of the surface and four sub-magnets at the corners, which supports rotating gestures with force feedback, and provides additional magnetic connection for each 90 degree rotation. According to the placement of the sub-magnets (numbers, power, distance, etc), the system can provide the different magnetic force feedback but this is required to be synchronized with the spin recognition process by the marker tracking. For wireless input, we designed a

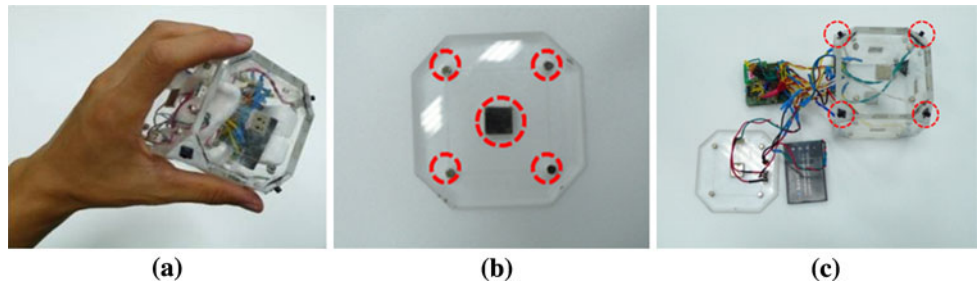
simple circuit with a Bluetooth module and buttons on the microprocessor chipboard and then put it into the tangible cube with a charging battery. Buttons were attached to every corner for fast input and easy accessibility. Each button has assigned to the individual port on the chipboard so it allows the developer to use them for various purposes.

For visual tracking of the cube and overlay of the virtual model, we attached multiple markers of 4 × 4 cm on each face and used a multi-marker method which has one base origin. In addition, we let the center of the cube correspond to the center of virtual model as shown in Fig. 7. We added a semi-transparent virtual cube of identical size over the tangible cube for better depth perception. In this implementation, we used the ARToolkit tracking library to track the marker (ARToolKit).

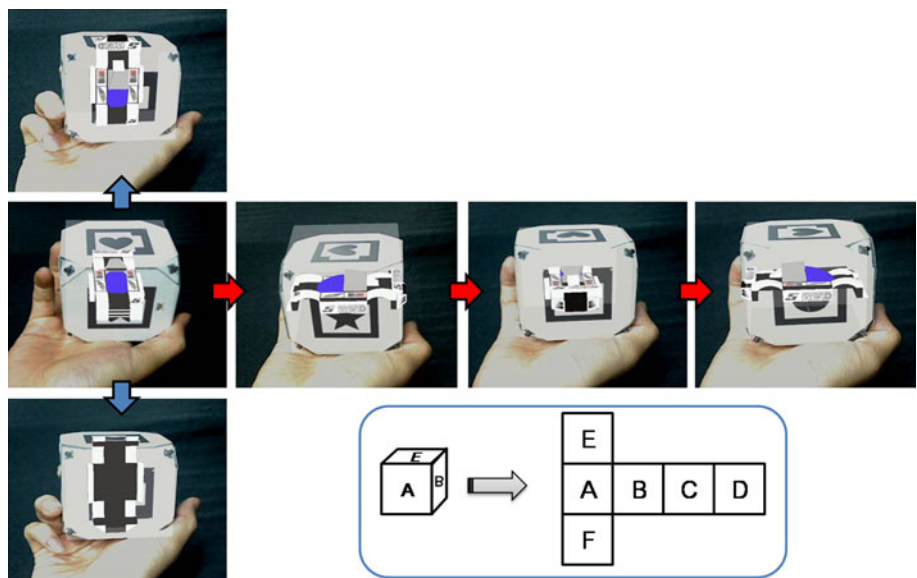
#### 4.2 The SD method in the augmented block composition

In implemented SD method, the moving augmented block event is activated when the relative rotation between the

**Fig. 6** Description of tangible cube: **a** handy size, **b** multiple magnets, **c** multiple buttons



**Fig. 7** An augmented car model covering the tangible cube



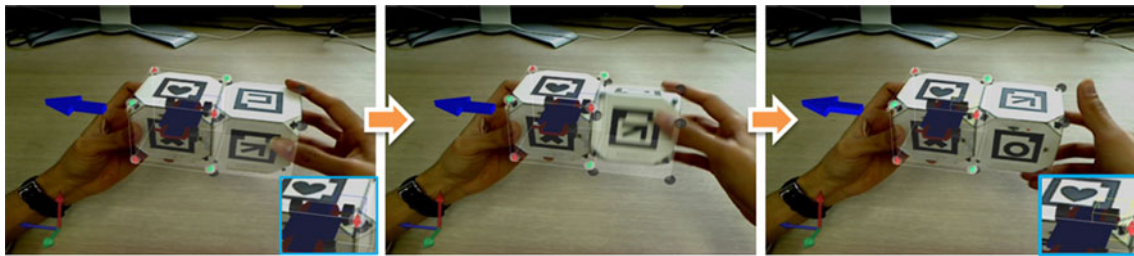
tangible cubes is more than 90 degrees. Figure 8 shows successive images of model movement for the composition between an augmented spindle and wheel. The default direction of movement was set toward the  $X$ -axis, the blue arrow shown at the left in the images. These static axes are displayed all the time with the direction of arrow pointing toward the positive direction. Therefore, the wheel is screwed onto the spindle by clockwise (or positive directional) rotations of the subsidiary cube. If a counterclockwise rotation is repeated, the wheel is moved further away from the spindle in this context.

There are three visual hints about the current target object and the moving axis. First is the superimposed animated arrow of active axis around the main cube. Second is virtual buttons with directional arrow at the corner. The last is the active color of the bounding box of the 3D model. Figure 9 shows an example of an axis change to the

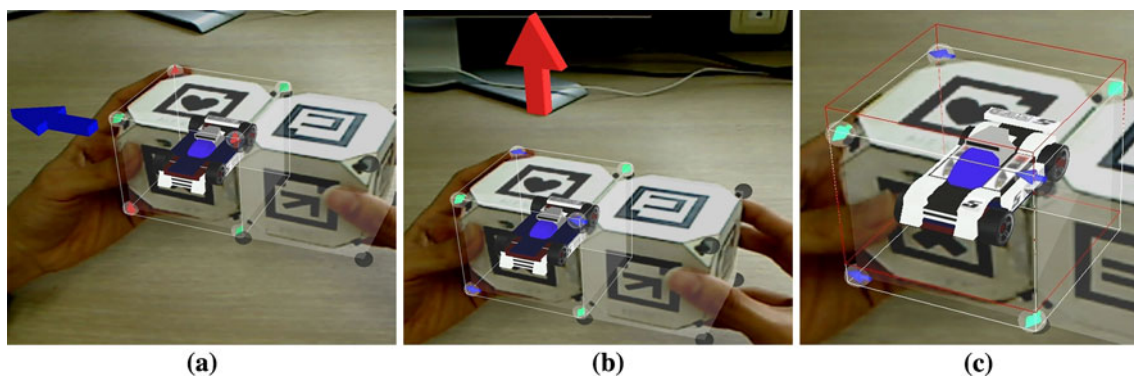
$Z$ -axis with visual hints. In Fig. 9a, we know at a glance that the present target block is a separated wheel and the moving axis is the  $X$ -axis. In order to change the composition axis to the  $Z$ -axis, the user pushes the corner button which is the most accessible. When this happens, the previous  $X$ -axis is stored to the pushed button with a blue arrow and the color of bounding box is changed to the desired axis as shown in Fig. 9b. Using the direction policy of the static axes shown at the lower left in Fig. 9c, a positive directional rotation moves the car cover block up and a negative directional rotation moves the block down.

#### 4.3 The BA method in augmented block composition

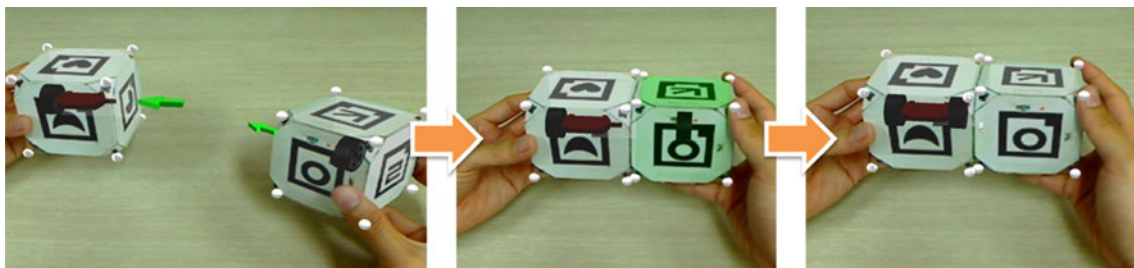
Figure 10 shows the implemented BA method based on the predefined structure of Fig. 4. The user attaches the wheel block to the subsidiary cube and combines it with a spindle



**Fig. 8** 3D model movement by clockwise rotation



**Fig. 9** The moving axis changed from the  $x$ -axis to the  $z$ -axis by pushing a button with visual hints (a–c)



**Fig. 10** Sequential steps for the block-assembly method

on the main cube because the spindle is higher in the object hierarchy than wheel. The two augmented blocks on the tangible cubes satisfy the feasibility condition so the BA method checks the relative position and orientation in real time. When the correct position and orientation is found, pushing a white button is enough to complete the composition on the main cube and runtime scene tree structure is updated.

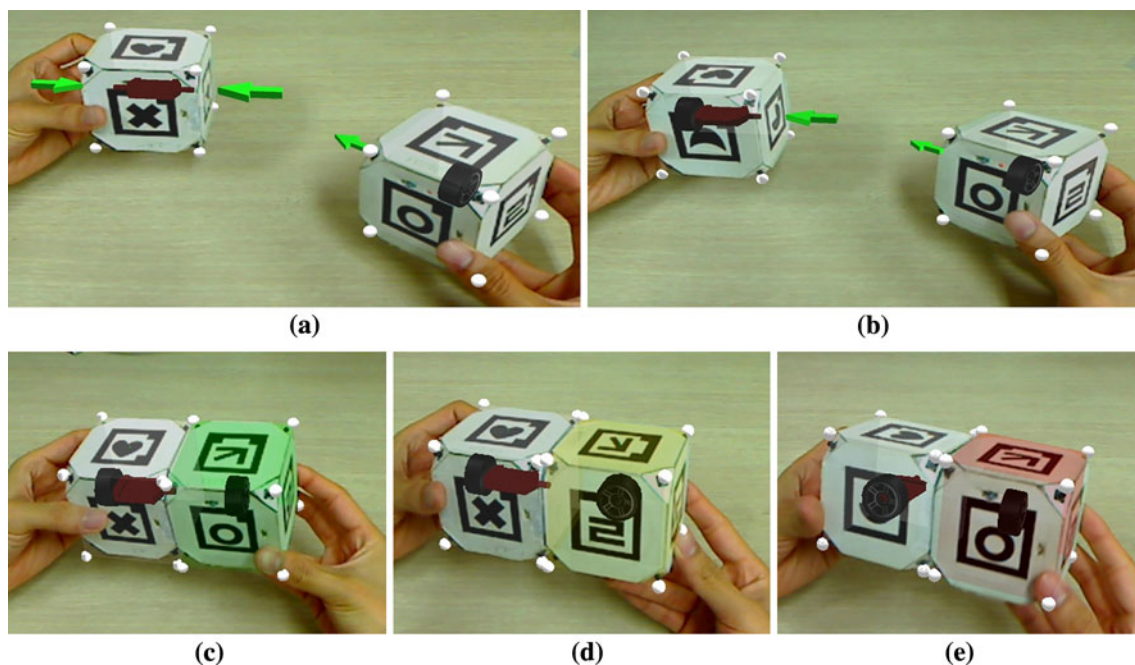
Figure 11 shows preliminary guidance using an animated virtual arrow and interim guidance with a virtual color sign box. The guidance is related to the runtime tree structure. As shown in Fig. 11a, a spindle has two possible cases for wheel composition but there is only one case existing in Fig. 11b. The main cube has the role as the stored stage so the direction of the arrows faces inside. On the other hand, the subsidiary cube has an opposite directional arrow which faces outside. Therefore, if the two kinds of arrows are shown at the same time, it shows all the possible connections between selected blocks to user. In spite of the preliminary guidance, when the users neglect the policy of block hierarchy in the middle of the composition, the interim guidance directly notices the users' mistake and provides the appropriate color feedback on the block (Fig. 11c–e). It provides position and direction feedback using semi-transparent color cubes but it is not so useful when the combinable position is hard for the user to guess. So in the implemented BA method, the preliminary and interim guidance strategies work in cooperation with each other.

## 5 Experimental results

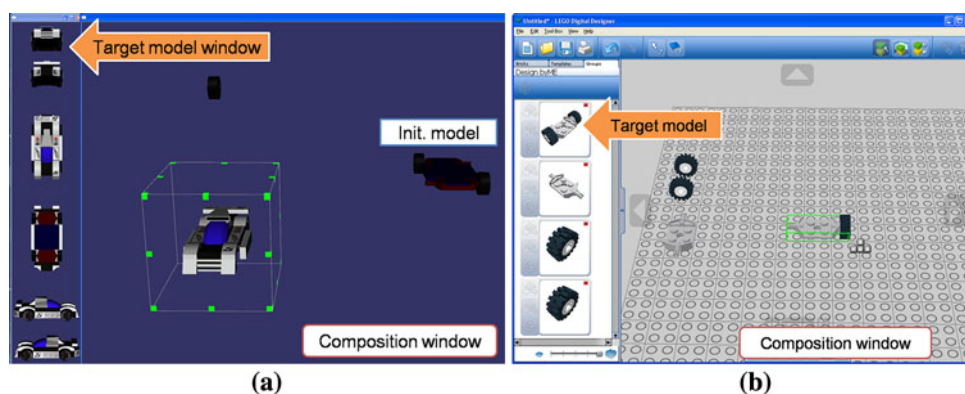
### 5.1 Pilot study with comparison task

In this section, we report on a pilot user study to evaluate our two tangible AR composition techniques and the CUI. In this study, we ask users to assemble virtual toy blocks using the CUI- and GUI-based modeling approaches. We chose two different targets to compare with the SD and BA methods. The SD method mainly offers selection and connection steps of virtual objects so we tried to find the proper comparative modeling tool. However, most existing GUI-based tools including commercial software were designed with a different purpose and so comparison with one of them did not seem to be suitable. Therefore, we developed our own GUI-based composition tool using Open Scene Graph (OSG). Using a rotation and translation manipulator, a user can select and position virtual objects in virtual 3D space using keyboard input and mouse events (see Fig. 12a). For the BA method, we compared performance against the Lego Digital Designer (LDD) because the LDD knows information about model constraints and supports composition based on fixed combinable points and not free positioning by the user. The LDD also provides a wireframe box-based guide like the interim guidance used in the BA method (see Fig. 12b).

The OSG-based tool and LDD software were installed on a standard desktop PC, and the two tangible AR methods were set up with a front USB camera and a large



**Fig. 11** Visual guidance: **a, b** preliminary guidance, **c–e** interim guidance



**Fig. 12** GUI-based assembly tools: **a** OSG-based positioning tool, **b** block-assembly tool (LDD)

display as shown in Fig. 13. Eleven subjects (8 men, 3 women) participated in the pilot study, ranging in age from 24 to 31 years old. Of the subjects, nine had previous experience with VR/AR technology. However, only two of them had relevant experience with object composition task in some 3D modeling tools.

The experimental task for the subjects was to combine a set of virtual blocks. We considered the characteristics of each interaction method on the choice of the target model. Particularly, we are not focusing on the completed assembly system but introducing tangible interactions based on AR tracking technology. Therefore, the experimental task was not very complex, and we arranged each scenario to check that the interaction properties would work well and to explore the possibility of each interaction method. Therefore, to compare between the SD (CUI)- and OSG-based tools (GUI), the goal of task was to conduct the assembly of a virtual car (two wheels and cover model addition to the unfinished initial block) by positioning with axis change. To comparison between the BA (CUI) and LDD tools, the setup included the use of multiple combinable points and the assembly goal was to generate the cars wheel using a spindle and two wheel blocks.



**Fig. 13** Experimental setup of CUI composition pilot study

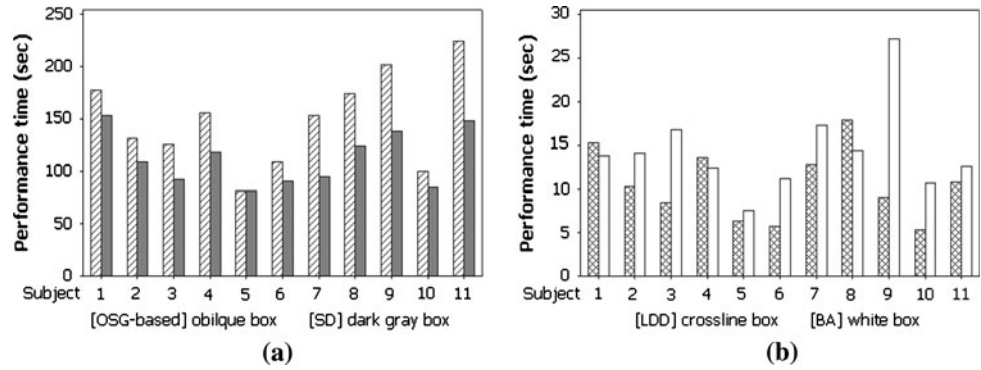
The experimental procedure had four steps (1) preliminary information gathering about the subjects, (2) training on how to use the interfaces, (3) task execution with the model assembly, (4) post-interview and subjective surveys. Subjects were trained on the four composing methods until they felt comfortable with the techniques and then they were told to complete the assembly tasks as quickly as possible. During the task execution, the subject's performance time was measured. In the case of comparing the OSG-based and SD methods, we added the visual feedback for when a selected block is arranged at the right position, indicating that the user can stop moving the block. We performed the experiment in two parts: comparing the OSG-based and SD methods and then comparing the LDD and BA methods. In each part, the subjects performed the task twice in a counterbalanced order, once with the GUI-based tool (either OSG-based or LDD) and once with the CUI. After the completion of each part, we interviewed the subjects and collected their opinions about the ease of use of the interface and their performance.

## 5.2 Performance analysis

Figure 14 shows the measured execution time of the participants across the different composing methods. Significant performance time differences were tested for using two sample  $t$  tests with the two-sided alternative. Before the  $t$  test was conducted, the normality was examined using the Anderson–Darling test (Anderson and Darling 1952) and then Levene's test (Olkin et al. 1960) was used to check if the data sets had equal variance. The mean performance time for each of the two comparison groups is shown in Table 3.

In the G1 group, subjects spent approximately one and a quarter times longer completing the given task with the GUI interface than with the CUI method. Using a  $t$  test analysis, we find that the difference is statistically significant ( $t = 2.36$ ,  $df = 20$ ,  $p = 0.03 < 0.05$ ), so the SD

**Fig. 14** The measured performance time of participants: **a** OSG-based versus SD **b** LDD versus BA



**Table 3** Task performance of four composing methods

Group	Comparison group description	Methods	Mean (s)	Standard Dev.
G1	Three axes-based free positioning	OSG-based	148.5	44.1
		SD	112.1	25.9
G2	Pre-knowledge-based combination	LDD	10.5	4.1
		BA	14.3	5.1

method is faster than the GUI interface in 3D positioning for this particular virtual toy block composition task.

When we observed the subjects during the execution, the input modes of the two methods were not very different because they both used similar button input to start and end the virtual block selection and composition steps. However, subjects did show differences in the composing process. Our OSG-based tool, like many traditional GUI interfaces, provides a virtual camera that enables the user to change viewpoint. However, through the block composition task in virtual 3D space, we observed that most users had trouble in moving the camera to provide a suitable object view. This caused uncertain view changes and positioning so it led to delays in the task execution. In contrast, the CUI interface provided 3D translation and rotation of the block with users' seamless cube movements by multi-marker tracking. Therefore, most of subjects had

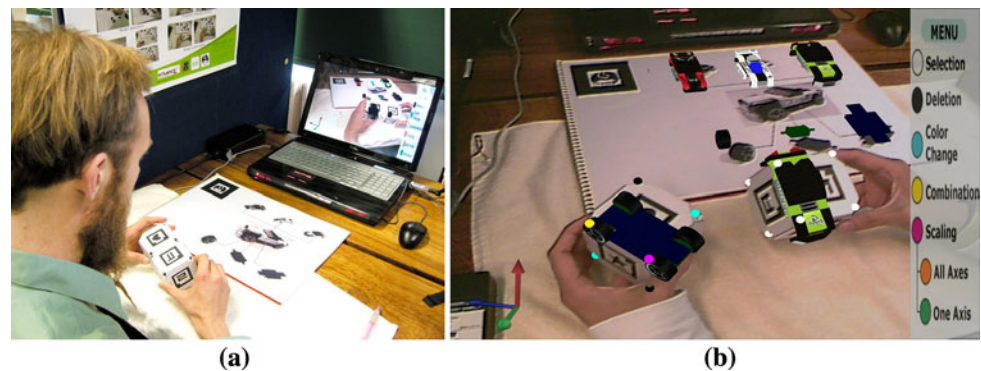
no trouble to find the initial combination position. Also, with the augmented active axis arrow, the SD method allowed a virtual block to be easily and comfortably translated in one dimension at a time while screw-driving.

In case of G2, a *t* test showed that the performance times were not statistically significantly different ( $t = -1.96$ ,  $df = 20$ ,  $p = 0.06 > 0.05$ ). By looking at the G2 group execution, we observed that most participants exhibited a tendency to depend on the supporting guidance rather than just combining the virtual blocks.

### 5.3 Lessons learnt from the pilot study and public demonstrations

In addition to the performance data described earlier, we have collected qualitative evaluation data on two-handed tangible interaction techniques for augmented blocks through the pilot study and public demonstrations of the technology (see Fig. 15). After the comparison experiments, we collected valuable comments about the proposed techniques from post-experiment interviews of the pilot study. We also obtained additional informal comments at several demonstrations through the person who had experiences of our two techniques at the same time. Furthermore, we demonstrated a prototype of SD method-based AR block-assembly system for applicable use and listened carefully to user opinions related to composing method

**Fig. 15** The toy block-assembly system demonstration on International Symposium on Mixed and Augmented Reality 2008: **a** the experience by a participant **b** an assembly for a virtual car



(see Fig. 15). Based on this feedback, we summarize what we have learned for enhancing our CUI-based composing interaction techniques.

*Two-handed cubical interface.* Our composing environment uses two cube interface objects which enable that virtual block selection using a single cube and virtual block combination using interaction between both hands. In addition, the support for free cube rotation can be used to check the shape or interim composition step of the virtual objects. At this point, users said that using the environment was truly similar to real block assembly so it was familiar and easy to use. Every corner button facilitates accurate and fast input and steps through the suitable modes for the sequential assembly process. Finally, the built-in magnets offer realistic force feedback in combination, separation, and rotation gestures. Most of the users were satisfied with the force feedback system and agreed that it was necessary for AR applications to have realistic force feedback in interactive AR assembly applications. However, some users said that the solid acrylic material was not so good and that cubes were too big for small hands. Therefore, we may need to conduct further work to find a better esthetic design to satisfy users.

*Composing interaction.* This paper uses familiar composing interactions of screw-driving and a block-assembly metaphor for natural 3D object composition. After an explanation, most of the users who were well acquainted with the screw-driving principle learned the SD method without difficulty and they were able to easily complete the augmented block composition. In case of the BA method, people were familiar with how toy blocks are assembled and so every user finished the composition task quickly. In order to improve the users' satisfaction in the final AR block-assembly application, it would be good to combine characteristics of the two methods. For instance, using the BA and SD methods in consecutive order enables an application with fast composition and free object placement. This mixed method will be possible to apply to the decision method in case of multiple connection points in one surface.

*Robust tracking.* In our tangible object-based AR interaction, the tracking patterns on the cube were often occluded by the users' fingers causing the tracking to fail. So a more robust tracking manner is required. For example, we could use 3D object tracking methods (Park et al. 2008) and obtain more stable cube tracking results. In addition, when the user performs a fast continuous screw-driving gesture, then a blurred image may be generated and the SD method can fail to recognize the rotation. One way to overcome this would be to add an inertial tracker to the system to provide results that are independent of the computer vision and improve the stability of the rotation gesture recognition.

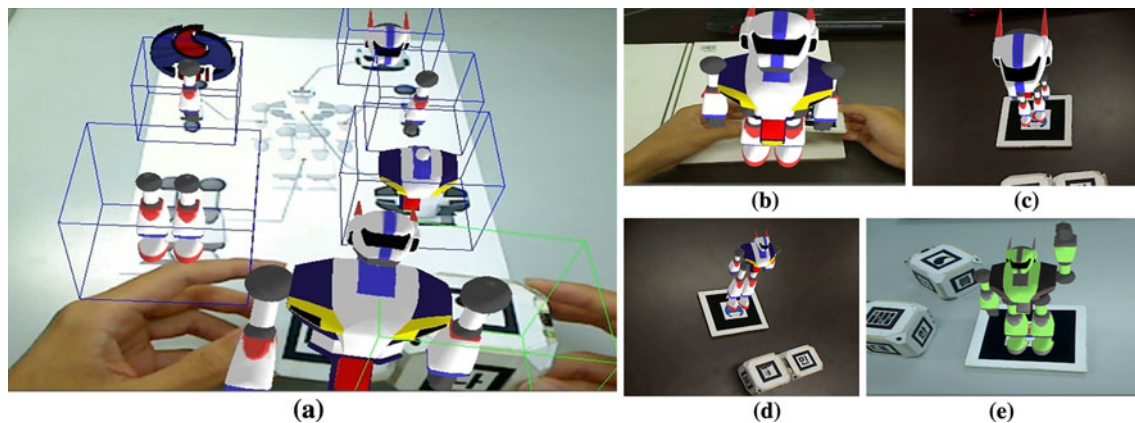
*Visual assembly guidance.* Each technique provided different visual guidance for virtual block composition, and most of users said that the visual guidance methods were very useful for completing the combination task. However, some participants said that in order to use the moving axis guide in the SD method they had to recall the axis color and so it took more concentration. In the BA method, the preliminary guidance pointed out the reasonable combinable candidates and the interim guidance gave significant help when assembling confusing blocks like bisymmetric models (e.g., wheel, robot arm). This shows that good visual assembly guidance tools should help reducing users' confusion in the assembly process.

#### 5.4 A feasible application for the user-generated character creation

Based on proposed tangible AR-based composing concept, one possible new application is for the creation of various virtual characters for a novice user. Figure 16 shows the example of user-generated characters from component objects. Besides the composing interaction, several tangible interactions can be implemented using the relative distance between cube, button input, and cube rotation. In addition, cubes can support a variety of property changes such as scale, color, orientation for creating a user-generated character.

## 6 Conclusions and future work

In this paper, we explored two-handed tangible interaction techniques for composing augmented reality blocks. We developed the cubical user interface (CUI) to provide a familiar composing environment for general users and to enable block unit composition using both hands. The CUI are a pair of real cubes with magnets and switches inside and AR tracking markers on their surface. Based on this interface, we designed and implemented two types of natural composing interactions using a real assembly metaphor. First, the SD method recognizes the users' rotating gestures and allows them to screw virtual objects together. The user can also freely position a virtual block for combining objects in 3D space. Second, the BA method adds objects based on their direction and position relative to predefined structures. It supports a fast composition strategy and effective visual guidance using information about the virtual blocks. In a pilot study, we analyzed the performance of each method and then verified that they are effective when compared to GUI-based methods for simple virtual block composition tasks. In addition, we summarized user feedback including the strengths and weaknesses of the methods and areas for improvement.



**Fig. 16** An example of the various user-generated characters by the tangible block interactions: **a** the source blocks for the robot **b** big body robot **c** a big head robot **d** a long head robot **e** a robot raising a hand

In the future, we will aim to develop an effective virtual block-assembly system together with extended assembly functions for the general user and conduct a more rigorous user evaluation. We developed a first prototype of the assembly system and gave various users the chance to experience it as shown in Fig. 15. Although a systematic evaluation was not performed, participants were able to create their own product using two cubes and a limited number of source blocks, and they immersed themselves in the assembly task (see Fig. 16). These user-generated objects are typical of those used in AR applications and show how the system could be extended to create a tangible AR character authoring system for a novice user.

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