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ORIGINAL ARTICLE

Hand gesture-based tangible interactions for manipulating virtual objects in a mixed reality environment

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Abstract In the environment of mixed reality (MR) or augmented reality (AR), there have been several previous works dealing with user interfaces for manipulating and interacting with virtual objects aimed at improving immersive feeling and natural interaction. However, it is still considered that there must be much progress in supporting human behavior-like interactions for providing control efficiency and natural feeling in MR/AR environments. This paper proposes a tangible interaction method by combining the advantages of soft interactions such as hand gesture and MR and hard interactions such as vibro-tactile feedback. One of the main goals is to provide more natural interaction interfaces similar to the manipulation task in the real world by utilizing hand gesture-based tangible interactions. It also provides multimodal interfaces by adopting the vibro-tactile feedback and tangible interaction for the virtual object manipulation. Thus, it can make users get more immersive and natural feeling in the manipulation and interaction with virtual objects. Furthermore, it provides an alternative instruction guideline based on the analysis of the previous interaction while manipulating virtual objects, which makes it possible for the user to minimize manipulation errors during the interaction phase and the learning process, which guides the user to the right direction. We will show the effectiveness and advantage of the proposed approach by demonstrating several implementation results.

Keywords Augmented reality · Hand gesture · Human–computer interface · Mixed reality · Pinch glove · Tangible interface · Vibro-tactile feedback

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1 Introduction

Mixed reality (MR) or augmented reality (AR), another type of virtual reality (VR), is considered as an excellent user interface for ubiquitous computing applications [1–4]. Interactions with these entities occur in real-time providing convincing feedback to the user and giving the impression of natural feeling. Thus, MR is considered to complement ubiquitous computing by providing more natural and intuitive interface to a three-dimensional information space embedded within physical reality. For this reason, many previous works related with MR have proven advantageous in a variety of real-world application scenarios such as manufacturing [5], collaborative urban design [6], distributed design review [7], AR-based ubiquitous car service [8], and context-aware AR service [9].

However, MR is limited in providing graspable or tangible feelings of physical models, although the rendering on the physical models results in a realistic appearance. An attempt to provide tangible interfaces between the physical space and virtual space is the tangible user interface (TUI) that couples digital information to physical objects and their ambient space [10]. However, it is still difficult to dynamically change an object's physical properties in TUI. Thus, tangible MR is considered to be a candidate to remove the limitations of the MR and TUI approaches while maintaining their original benefits. The tangible MR can combine the intuitiveness of TUI with the realistic rendering capabilities of MR [11–14]. Park et al. proposed a tangible AR approach to prototyping digital handheld products [11]. Lee et al. proposed a tangible interaction method using augmented reality and rapid prototyping for supporting collaborative design evaluation of digital products [12]. Terry et al. introduced *Jump* an AR-based system that transformed paper-based architectural documents into tangible query interfaces [13]. Hong et al. proposed a sensor-based interaction for ubiquitous VR/MR systems that were able to interact implicitly or explicitly with through a sensor [14]. These previous works showed that tangible MR made it possible for physical objects to be equally important as virtual ones.

Furthermore, it is necessary that MR interfaces should allow for additional interactions with virtual objects, which should not only enable natural and intuitive interaction with them, but also it should help to provide seamless interactions between real and virtual objects at the same time. In this regard, several previous works have started to apply haptic interaction, multimodal interaction, and gesture-based interaction in tangible AR/MR environments [15–17]. A big advantage of adopting gesture or hand-based interaction is the intuitive use of gestures such as pointing, grabbing, or stretching. One of the most popular implementations is based on light-weight pinch gloves which trigger actions by hand gestures. Buchmann et al. presented a technique for natural, fingertip-based interaction with virtual objects in AR environments [15]. They used image processing software and finger- and hand-based fiducial markers to track gestures from the user, stencil buffering to enable the user to see their fingers at all times, and fingertip-based haptic feedback devices to enable the user to feel virtual objects. In real life, we rely heavily on the multimodal interaction when we manipulate objects with our hands. However, virtual objects cannot provide such feedback interaction [16], especially if the user only relies on visual objects [17]. In this respect, a vibro-tactile feedback was proposed as a kind of multimodal interaction, which provides feedback to various parts of the body using a set of sensors. The vibro-tactile sensors can be attached at different points on the body and controlled from a microprocessor. Thomas et al. proposed a set of glove-based user interface tools for an outdoor wearable augmented reality computer system [18]. The main form of user interaction was the use of hand and head gestures. Robert et al. addressed the issue of improving the perception of contact that users made with purely virtual objects in virtual environments [19]. They described a prototype system for delivering vibro-tactile feedback to the user, which could provide a distributed, portable solution for incorporating vibro-tactile feedback into various types of systems. Viegl et al. proposed two hand direct interactions in a mobile environment [20]. Recently, Yi et al. proposed a method for rapidly generating 3D architectural models based on hand motion and design gestures captured by a motion capture system [21].

Although there has been much progress in providing tangible and interactive interfaces in MR-based applications, a more sophisticated research is still needed since there are limitations and drawbacks in providing immersion, natural feeling, and convenience in providing augmentation and interaction interfaces. Most MR tools have mainly focused on how to manipulate 3D models such as selection, position, and rotation of them just with fiducial markers. However, they are not enough to support natural and intuitive user interactions in real environment. Therefore, one of the important issues is how to effectively combine graspable or touchable interactions with visual information to provide human-like manipulation in the real world, although the user interacts with even virtual objects. Another is to provide multimodal, acoustic, vibro-tactile feedback to users for complementing visual feedback.

This paper proposes a tangible interaction method by combining the advantages of soft interactions such as hand gesture and MR and hard interactions such as vibro-tactile feedback. The main goal is to provide natural and intuitive interactions similar to the manipulation task in the real world by utilizing hand gesture-based tangible interactions in the MR environment. It also provides a multimodal interface by adopting the vibro-tactile feedback and tangible interaction for object manipulation. Thus, it can make users get more immersive and natural feeling in manipulating the virtual object. Moreover, it provides an alternative instruction guideline based on the analysis of the previous interaction while manipulating virtual objects, which makes it possible for the user to minimize manipulation errors during the interaction phase and the learning process, which guides the user to the right direction. We will show the effectiveness and advantage of the proposed approach by demonstrating several implementation results. Section 2 overviews the proposed approach and explains tangible interfaces using software and hardware interfaces for the pinch glove. Section 3 discusses a set of hand configurations for the hand gesture and MR-based tangible interface. Furthermore, it explains how to provide alternative hand gestures during the object manipulation. Section 4 shows implementation results. Section 5 concludes with some remarks.

2 System overview

The proposed tangible interface is based on the combination of a gesture-based interaction using a pinch glove and a

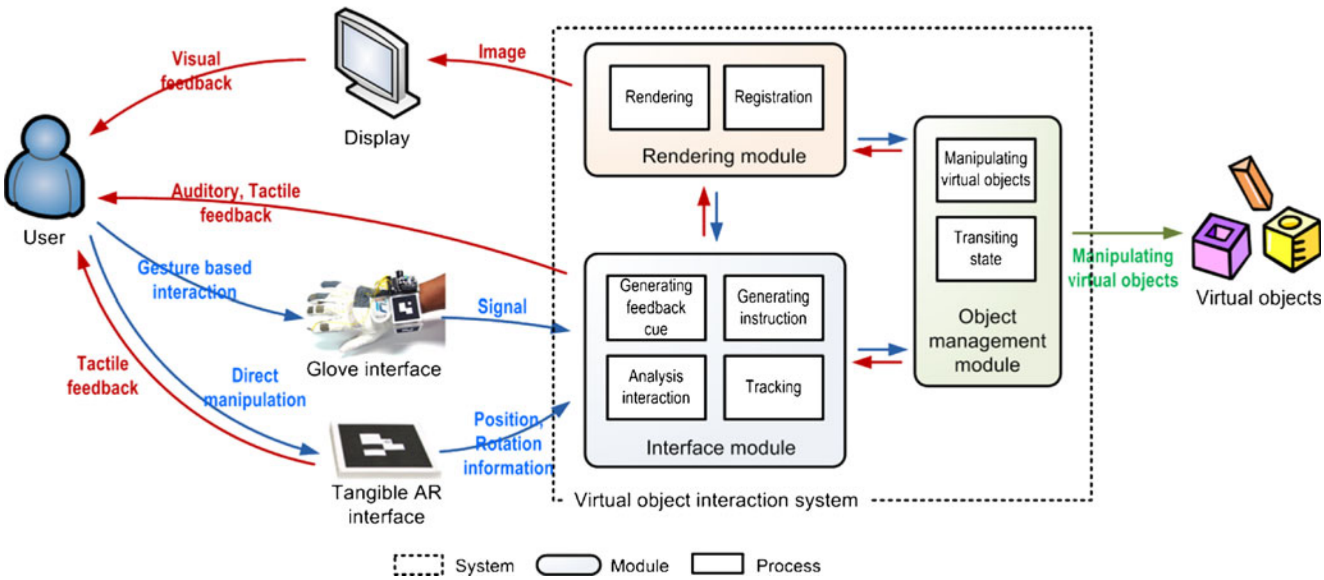


Fig. 1 Proposed tangible interaction

tangible MR-based visualization as shown in Fig. 1. The proposed system consists of three main modules: (1) interface module, (2) object management module, and (3) rendering module. The user wearing a pinch glove with MR visual markers can manipulate virtual objects by grasping, pointing, and gesturing. The signal captured from the pinch glove is sent to the system which interprets it and finds the intent of the user. At the same time, the rendering module calculates the position and orientation of the hand by analyzing the visual markers attached on the pinch glove. Based on the gesture analysis and location information, the system not only embeds virtual object on the specified visual marker, but also supports to intuitively interact with virtual objects similar to the manipulation task in the real world. During the manipulation, the user wears a pair of gloves on both hands. The right hand or dominant hand is used for object manipulation, and the left hand or non-dominant hand is used for menu instruction. Without loss of generality, roles of the dominant hand and the non-dominant hand can be exchanged for the left-handed user since both hands are symmetric in nature.

In particular, this paper suggests how to improve the intuitive interaction with virtual objects in MR environments. Because these objects have no physical reality, the user's awareness of the object is limited to only visual feedback. To overcome this limitation, we propose a more practical approach, utilizing various modalities. Thus, we developed a pair of pinch gloves as the main input device, which is similar to existing technologies as shown in Fig. 2 [18, 20]. However, we extended the functionalities and multimodal interactions and corresponding feedback by combining the pinch glove with MR. During the manipulation, the proposed approach provides alternative instructions based on the analysis of previous interactions while manipulating virtual objects, which makes it possible for the user to minimize manipulation errors during the actual manipulation phase or the learning phase. This guides the user to the right direction such that even a beginner can utilize the proposed system. In other words, the alternative instruction suggests a set of possible next gestures to manipulate the virtual object based on the current gesture. It is based on the analysis of the state transition diagram which contains a network of gesture instructions. A detailed description on the alternative instruction is explained in Section 3.2.

The pinch glove made in this research consists of a microprocessor (AT89C2051), RS232 interface with PC,

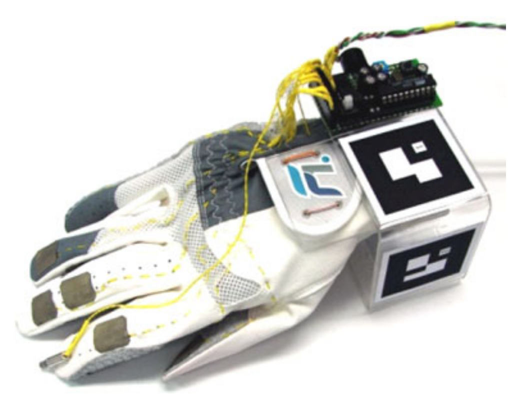


Fig. 2 Developed pinch glove for the hand gesture

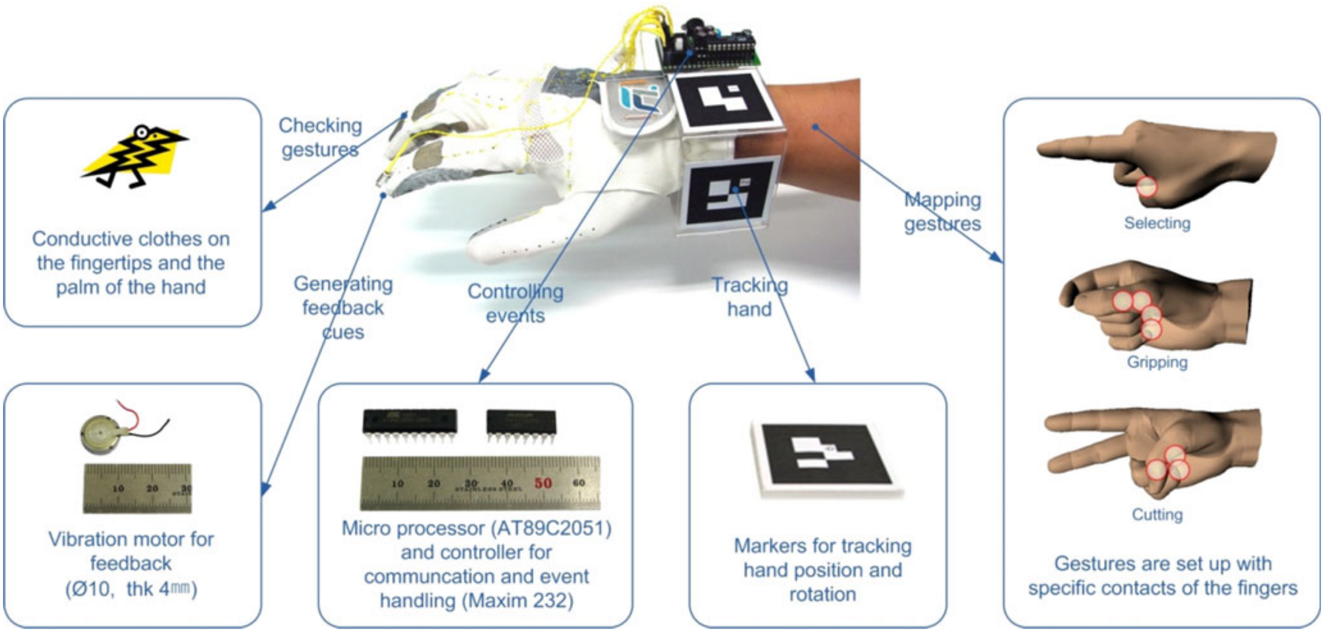


Fig. 3 Interface device controller

vibration motor widely used in a cell phone, a small speaker, and LED lights as shown in Fig. 3. Note that the RS232 interface can be replaced with a wireless communication without any difficulty such as Bluetooth^{TM} or ZigBee^{TM}. In particular, conductive patches are attached to at the tip of fingers and palm. By touching the patches in the pinch glove, the user can give an instruction for the manipulation. Whenever such an event occurs, the microprocessor sends it to the computer that finds the intended gesture-based on the stored tasks. Finally, the computer sends feedback to the user. If necessary, it sends a signal to the vibro-tactile motor and/or the speaker. At the same time, the user can visualize updated virtual objects on specified visual markers. Furthermore, such an event can change the status of the object. In particular, with the three AR markers attached on the wrist of the glove, the system calculates the 3D location of the hand in the MR environment. The 3D location is used to support interactions with virtual objects and generating multimodal feedback.

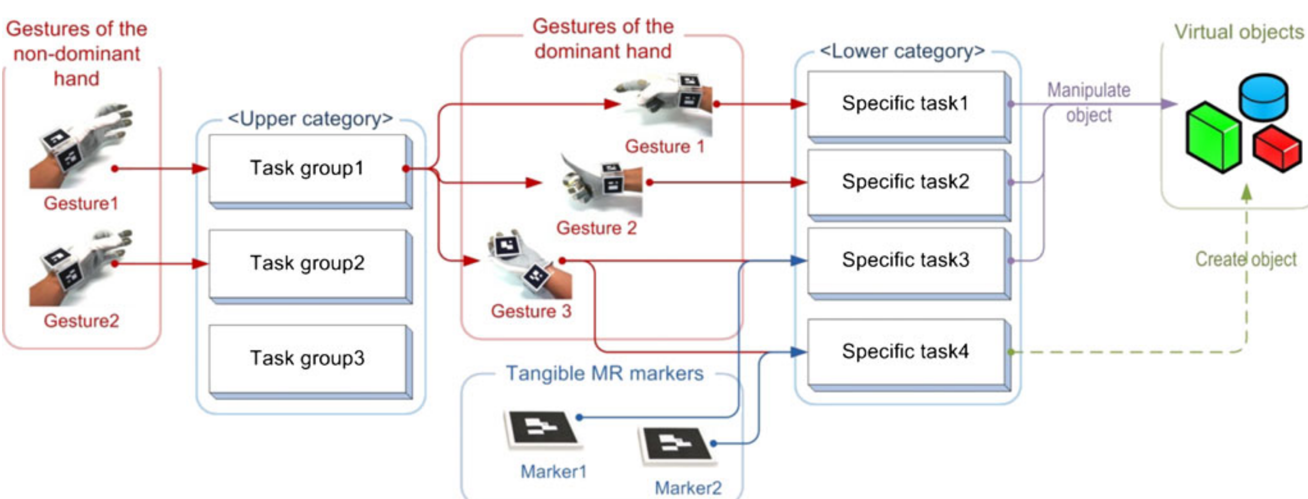


Fig. 4 Input manipulation

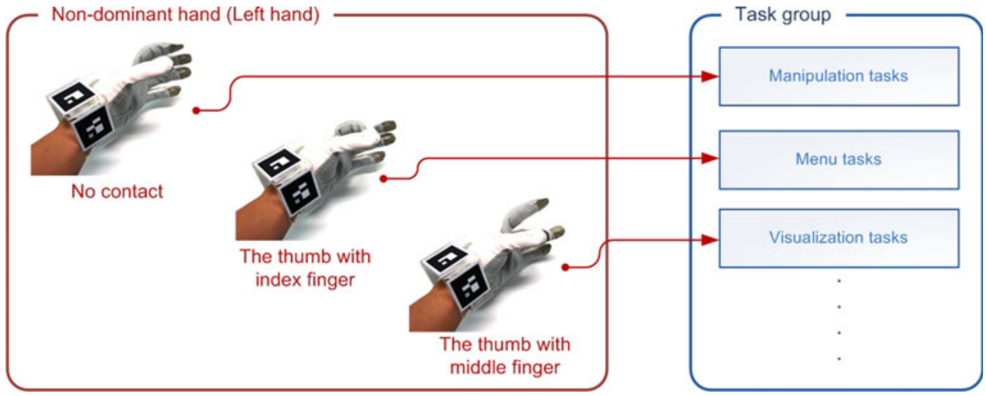


Fig. 5 Gesture-based instruction: upper category selection

In addition to multimodal devices, ARToolkit has been utilized as an MR visualization interface [22], which is a software library for building MR applications. In addition, an ordinary web cam is used for augmenting virtual objects into the physical world.

2.1 Gesture-based interaction using a pinch glove and MR

There are two main tangible interfaces: (1) gesture-based interface using a pinch glove and (2) MR marker-based interface. The gesture-based interface using a pinch glove is used to provide natural and human-like manipulation interactions since gesture plays a main role in human communication like speaking and listening. Usually, understanding a gesture is not so simple that data glove or vision-based recognition is widely used. However, in this paper, we simplified the recognition by utilizing a pinch glove in which conductive patches are attached at the fingers and palm. By analyzing the connectivity among those patches, we can recognize the instruction like sign language. However, the pinch glove can only provide instructions based on the connectivity such that it cannot provide visual feedback and visual interaction information [19]. To complement the pinch glove-based interaction, we attach MR-based markers on the wrist of the pinch glove as shown in Fig. 2. The main role of the marker lies in providing visual instructions and calculating the relative location of the hand for supporting interactions with virtual objects in the MR environment.

The input manipulation of the pinch glove-based interface is divided into two categories: upper category and lower category. As shown in Fig. 4, the non-dominant hand is used to provide upper tasks like menu selection and manipulation mode change. On the other hand, the dominant hand is used to provide specific or lower tasks based on the upper task such as selecting, grasping, and pointing. Each upper task covers a set of specific tasks. In addition, MR markers can also be used to provide tasks by attaching them on the glove. The role of the visual marker is to effectively calculate the location of the glove, which can provide natural interaction with virtual objects. Thus, we can provide numerous combinations of tasks. However, instruction errors or complexities may increase when the number of combination increases. To overcome this problem, we provide an alternative instruction suggestion mode using a finite state machine. This will be explained in detail in Section 3.

Basically, the user selects an upper category of the instruction using a non-dominant hand gesture as shown in Fig. 5. The non-contact configuration supports manipulation tasks, the thumb with the index finger configuration represents a menu task, and the thumb with the middle finger configuration shows a set of available next instructions.

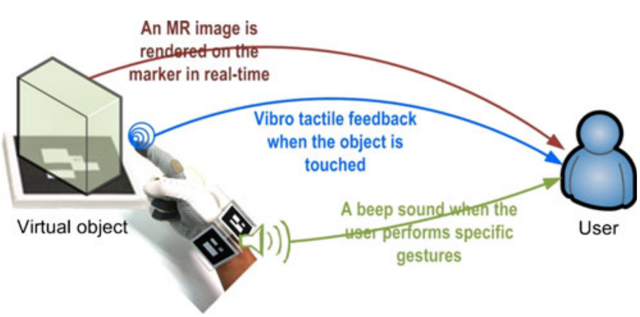


Fig. 6 Providing different types of feedback

2.2 Multimodal interface and feedback

To provide natural feeling and immersion, we have to provide various tangible feedbacks in addition to tangible manipulation instructions [18, 23]. We provide visual, tactile, and auditory feedbacks to the pinch glove. The visual feedback is based on the MR marker. By detecting

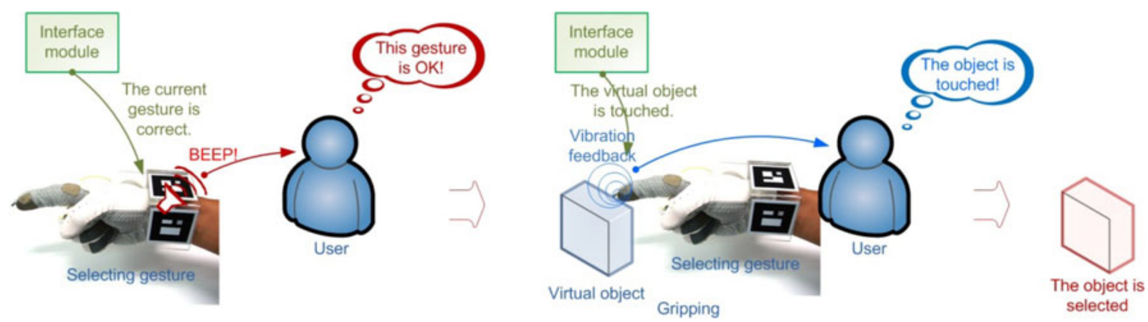


Fig. 7 Gesture-based instruction: object selection

and finding the location of the marker, we can provide visual feedback of the object manipulation. Since MR embeds virtual objects into the real world, the user can feel more immersion. Note that it is not easy to provide such immersive feeling in the VR environment since all the objects should be modeled realistically, and its computational cost is much more expensive than that of MR since only an interesting group of virtual objects are needed and embedded in the real world. However, one of the problems in MR-based visual interactions is that it cannot provide tactile feedback when the hand contacts with the object. For that reason, we attach a vibro-tactile sensor on the pinch glove such that the user can feel vibration when the hand touches with the virtual object. In addition to visual and tactile feedback, we also attach the auditory feedback to the glove. The beep is used to give the signal according to the actions of the instructions as shown in Fig. 6.

2.3 Scenarios for manipulating virtual objects

We will show scenarios for two hand gesture-based object manipulations such as touching, grasping, and moving. Basically, the user interacts with a virtual object using the dominant hand gesture. As shown in Fig. 7, the user gives a directing gesture for selecting the object. If the current gesture is correct, the system gives a beep signal. In addition, the system checks if the hand touches with the object by calculating the locations of the hand and the object and the distance between them. When the object is determined to be touched with the hand, the vibro-tactile sensor gives a vibrating feedback which ensures a touch. Finally, the selected object turns into red.

After selecting the object, the user can do another manipulation with a hand gesture. However, the user has a difficulty in selecting available possible gestures, which causes manipulation errors and undesired results. To solve this problem, the user can change the current mode into the instruction mode using the non-dominant hand gesture as shown in Fig. 4. The instruction mode suggests a set of possible alternative gestures to be performed. By analyzing the state transition diagram of current and possible instructions, the mode augments possible instructions on the visual marker. As shown in Fig. 8, possible gestures are pre-gripping, directing, and pre-cutting. Thus, even a beginner can interact with virtual objects with ease. With the guidance of the instruction mode, the user now can grip a virtual object and move it into a specific location. The user approaches to the object with a pre-gripping gesture and then gets a vibro-tactile feedback when the hand touches with the object. Then, the user can grip the object

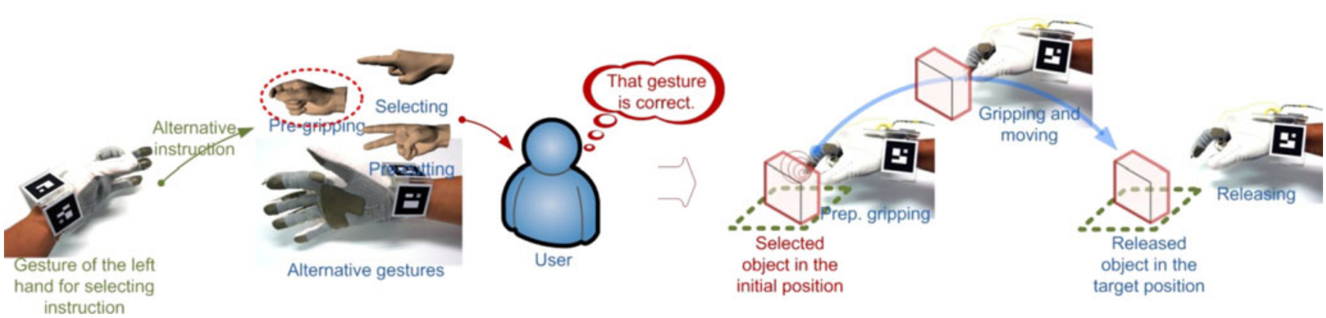


Fig. 8 Object manipulation: object gripping

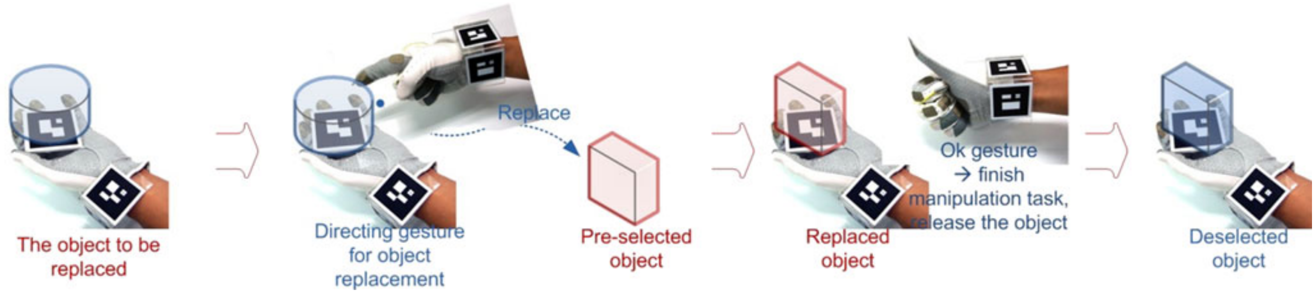


Fig. 9 Object manipulation: object replacement

with the gripping gesture, move it to a desired location, and finally release it.

Furthermore, the user can replace a specific virtual object with another as shown in Fig. 9. The user selects a replacing instruction. Then, the user gives a directing gesture to select an object to be replaced. Then, the pre-selected object is replaced with the original one. Finally, the OK gesture finishes the operation. This scenario shows that the proposed approach can provide intuitive interaction and natural feeling like in the real world.

3 MR and hand gesture-based tangible interfaces

3.1 Hand gesture configuration

Each hand gesture is defined by the different connections of conductive patches. Figure 10a, b show the relations between each connection and its corresponding hand gesture for the non-dominant hand and the dominant hand, respectively. As shown in Fig. 10a, Ⓐ, Ⓑ, Ⓒ, Ⓓ, and Ⓔ represent connection points of conductive patches attached to the non-dominant hand. As shown in Fig. 10b, Ⓐ, Ⓑ,..., and Ⓛ represent connection points of conductive patches attached to the dominant hand. Usually, conductive patches can be attached to finger tips, palm, and so on in the dominant hand. Furthermore, by the different connections, we can define lots of hand gesture configurations for various object manipulation tasks as shown in Fig. 10c.

The connection among them can represent a generic hand gesture configuration for a specific manipulation task. Table 1 shows the detailed configuration of the hand gesture according to the configuration of the connection. There are five hand gestures for the non-dominant hand, each of which represents a specific task for selecting a menu that determines the configurations of the dominant hand. For example, selecting 1 gesture, a menu for the object manipulation of the dominant hand, is detected when Ⓑ is connected to Ⓐ and, Ⓒ, Ⓓ, and Ⓔ are not connected to Ⓐ. Similarly, a pre-gripping gesture is detected when Ⓙ is connected to Ⓐ and Ⓑ and Ⓕ are not connected to Ⓐ. A gripping gesture is detected when Ⓑ and Ⓙ are connected to Ⓐ and Ⓕ is not connected to Ⓐ. Note that we do not check all the connections to configure a gesture. Instead, we do check a set of connections since the set can generically define a hand gesture. In other words, the system checks only a set of key connections for a specific hand gesture configuration that distinguishes that of the other hand gesture configuration. Whenever such a configuration is analyzed by the processor, an event occurs, and it is sent to the computer for further processing. The goal of the menu system is to allow the user to easily access the functionality of the application, in a logical manner, while not obscuring the user's vision or preventing other tasks [23].

3.2 Gesture analysis using state transition diagram

A beginner is not good at using this kind of device for authoring with virtual objects when he/she has not much experience in it. To solve this problem, our approach provides a possible set of next instruction guidance mode, which shows a set of visual and possible instructions with virtual object, gesture, explanation by analyzing previous instructions and actions. We use a state transition diagram [24] to check available gestures according to the current state of the gesture as shown in Fig. 11.

A state transition diagram is utilized to suggest possible alternatives considering the current status of the gesture. As shown in Fig. 12, each node represents a state of the hand gesture, and each edge represents an event that changes the state of the hand gesture. For example, when the current state of the hand gesture is *selecting*, the next possible gesture should be chosen among *pre-gripping*, *pre-cutting*, *copy*, and *none*. Other hand gestures are not allowed, which makes the user easily manipulate objects by minimizing operation errors. Table 2 shows the events to change the state of the gesture. Based on the state transition diagram of the possible gesture alternatives, the user can easily

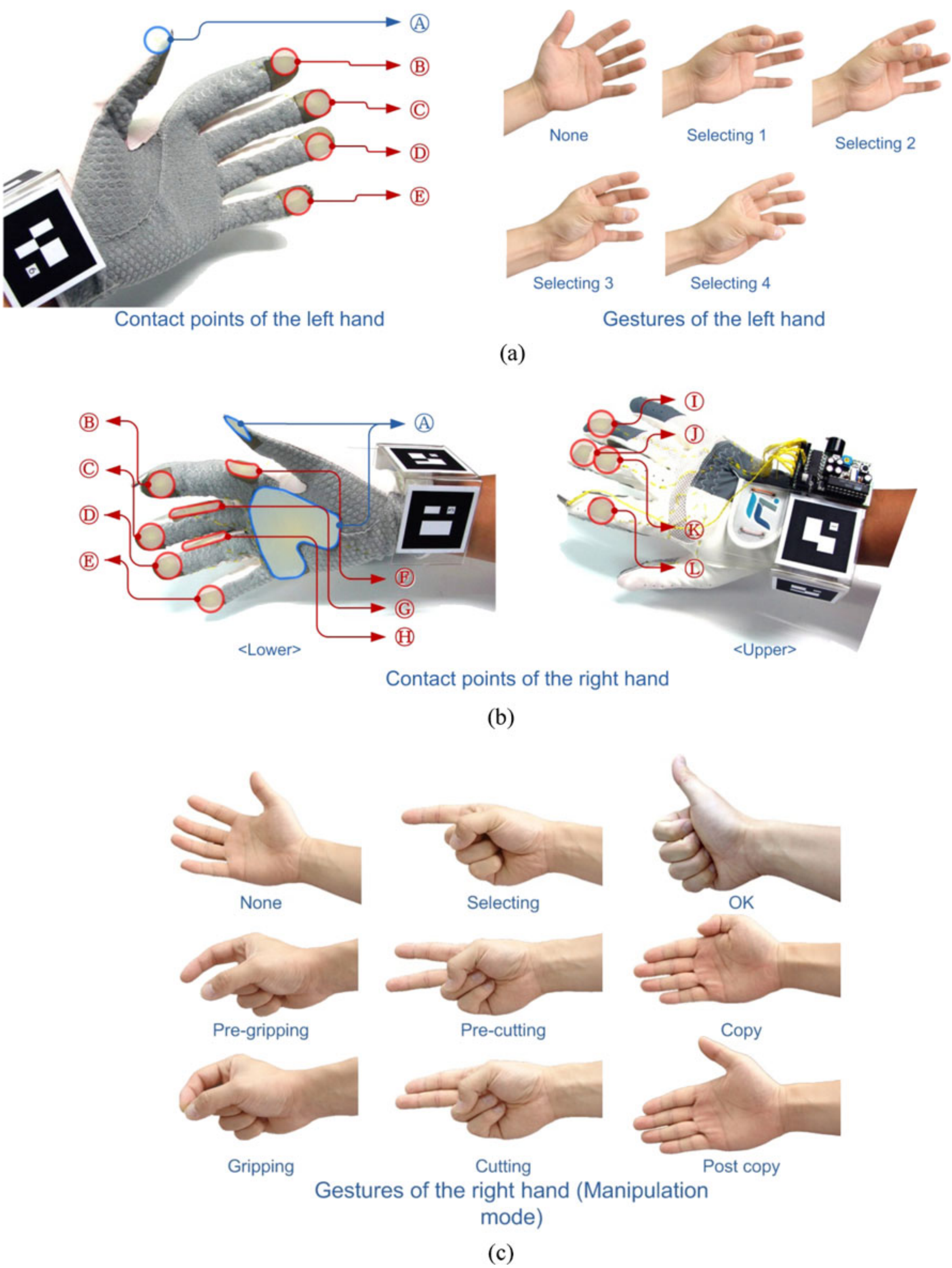


Fig. 10 Hand gesture configuration: **a** gesture configuration of the non-dominant hand, **b** gesture configuration of the dominant hand, **c** gesture configuration for object manipulation

manipulate objects by minimizing operation errors and decide the next gesture among possible alternatives, which can remove vagueness and complexity of using the pinch glove and hand gesture.

3.3 Visual tracking and object transformation

The visual interface is developed based on ARToolkit [22], a software library that can be used to calculate the real

Table 1 Hand gesture configuration according to the connection

Left hand gesture	Ⓑ	Ⓒ	Ⓓ	Ⓔ	Ⓕ	Ⓖ	Ⓗ	Ⓘ	Ⓙ	Ⓚ	Ⓛ	Task
None	○	○	○	○								None
Selecting 1	●	○	○	○								Select menu1
Selecting 2	○	●	○	○								Select menu2
Selecting 3	○	○	●	○								Select menu3
Selecting 4	○	○	○	●								Select menu4
Right hand gesture	Ⓑ	Ⓒ	Ⓓ	Ⓔ	Ⓕ	Ⓖ	Ⓗ	Ⓘ	Ⓙ	Ⓚ	Ⓛ	Task
None	○	○	○	○								None
Selecting	○									●		Select an object
OK	●	●									●	Release an object
Pre. gripping	○				○				●		○	Pre-grip an object
Gripping	●				○				●		○	Grip an object
Pre-cutting					○	○		●				Pre-cut an object
Cutting					○	●		●				Cut an object
Copy					●	●	○					Copy an object
Post-copy					○	●	○					Paste an object

●, Connected; ○, disconnected

camera position and orientation relative to physical markers in real time, allowing the overlay of virtual objects onto the physical markers. To support visual interface and manipulation with virtual objects, the relative transformation between the objects and the hand must be calculated. To make the calculation easy and simple, three visual markers are attached on the wrist of the glove as shown in Fig. 13. Thus, the transformation between the reference marker and object marker is calculated first (Object.pBlendTrans at Fig. 13), and then that between the reference marker and one of the visual markers at the wrist is also calculated (interface.pBlendTrans). Furthermore, a little tuning or aligning operation is made to find the exaction transformation between them. Thus, the system can match the events given by the pinch glove with the visual operation of virtual objects. When the distance between them is within a specific range and the hand gesture is gripping, then the system assumes that the user gripped the object and would manipulate the object.

4 System implementation

This section shows several implementation results based on the proposed approach. With the hand gesture-based and MR-based interface, the user can not only easily interact with virtual objects like that in the real world, but feel immersion and multimodal feedback. In particular, we have

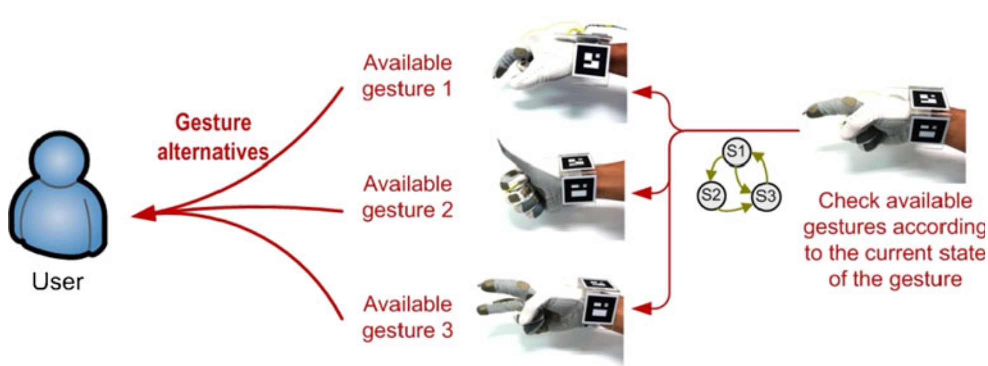


Fig. 11 Alternative instruction guide

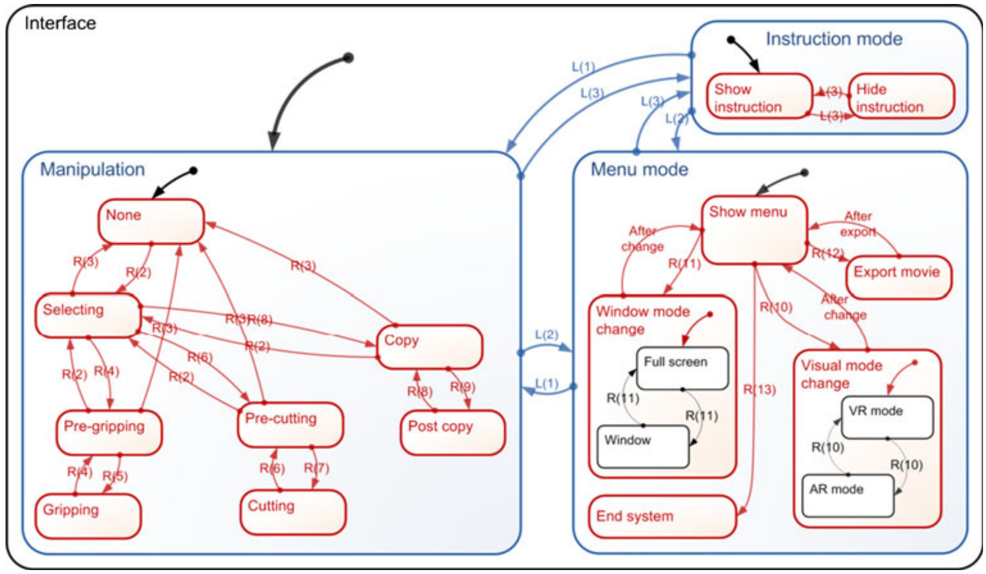


Fig. 12 State transition-guided gesture mode

provided a new way of combining feedback to multiple sensors for tangible and interactive studies. Furthermore, the user can test different combinations of feedback and measure the impact of these combinations to feel the nature of feedback with virtual objects.

Figure 14 shows detailed system modules of the hand gesture-based tangible in MR environment, which consists of MR interface, tangible tracking, rendering, and interface control modules. In particular, the interface control module plays the main role in linking the tracking module and rendering module to support hand gesture-based manipulation and visual interaction of virtual objects. In particular, the gesture analysis module analyzes the event from the tangible glove and performs necessary actions and sends feedback if the event is valid. Otherwise, the beep gives a warning signal for ensuring appropriate gesture recognition and guidance. A set of possible hand gestures are provided to the user to follow the next step and thus minimize operation errors.

Table 2 Events for the transition of hand gestures

➜ Right hand gesture event				➜ Left hand event	
No	Gesture	No	Gesture	No	Gesture
R(1)	None	R(8)	Copy	R(0)	None
R(2)	Selecting	R(9)	Post-copy	R(1)	Selecting 1
R(3)	OK	R(10)	Selecting 1	R(2)	Selecting 2
R(4)	Pre-gripping	R(11)	Selecting 2	R(3)	Selecting 3
R(5)	Gripping	R(12)	Selecting 3		
R(6)	Prep-cutting	R(13)	Selecting 4		
R(7)	Cutting				

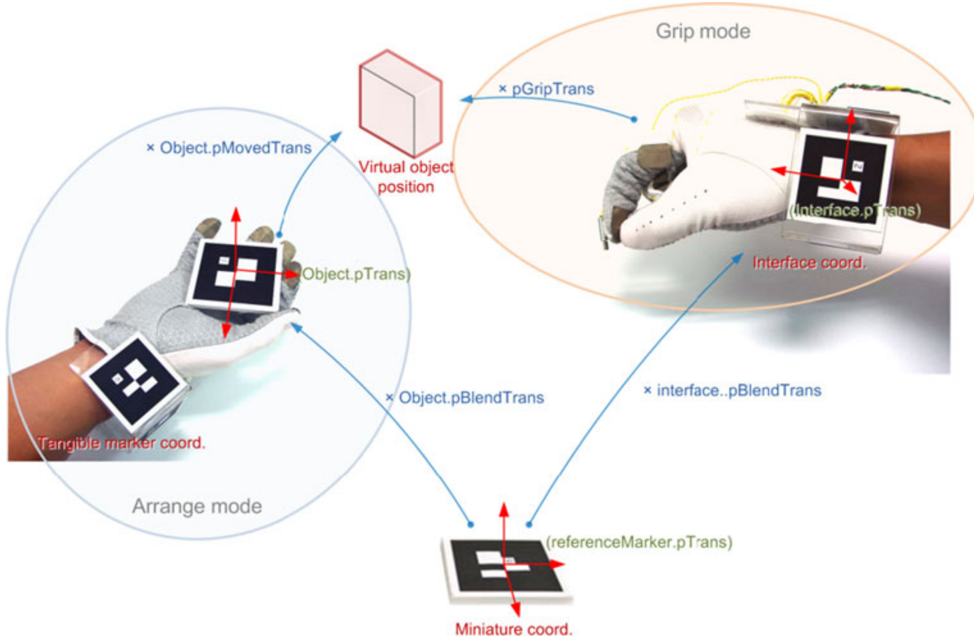
Figure 15 shows implementation results of the manipulation mode. At the initial stage, the user selects a manipulation mode with the non-dominant hand gesture. Then, the user selects a virtual object with a hand gesture with vibro-feedback, grips it, moves it, and releases it to a specific marker. When the user performs a selection operation and approaches the hand to the object, the bounding box of the virtual object is shown with the vibro-tactile feedback, which implies that the hand is touched with the object. Then, the user performs the gripping operation to grasp it. Similarly, the user feels the vibro-feedback and listens to the beep signal. Finally, the user can move it to another marker and releases it with the ok operation.

Figure 16 shows how to manipulate the menu system with the non-dominant hand gesture. According to the hand gesture of the non-dominant hand, the AR-based virtual studio displays a selectable submenu. During the menu mode with the non-dominant hand, the user can change the menu with the dominant hand. In this scenario, the user can change the MR-based studio into the VR-based studio.

Figure 17 shows the importance and convenience of the instruction mode which suggests alternative gestures to be expected for the next hand gesture. The system finds possible gestures available by analyzing the state transition diagram. Figure 17b shows that next gestures are none, pre-gripping, pre-cutting, and copying when the current gesture is the selecting operation. As the figure shows, the possible gestures are displayed on the MR environment with explanations.

We have also applied the proposed approach to design and manufacturing such as assemble of an excavator as shown in Fig. 18. The figure shows an assembly sequence

Fig. 13 Visual marker tracking



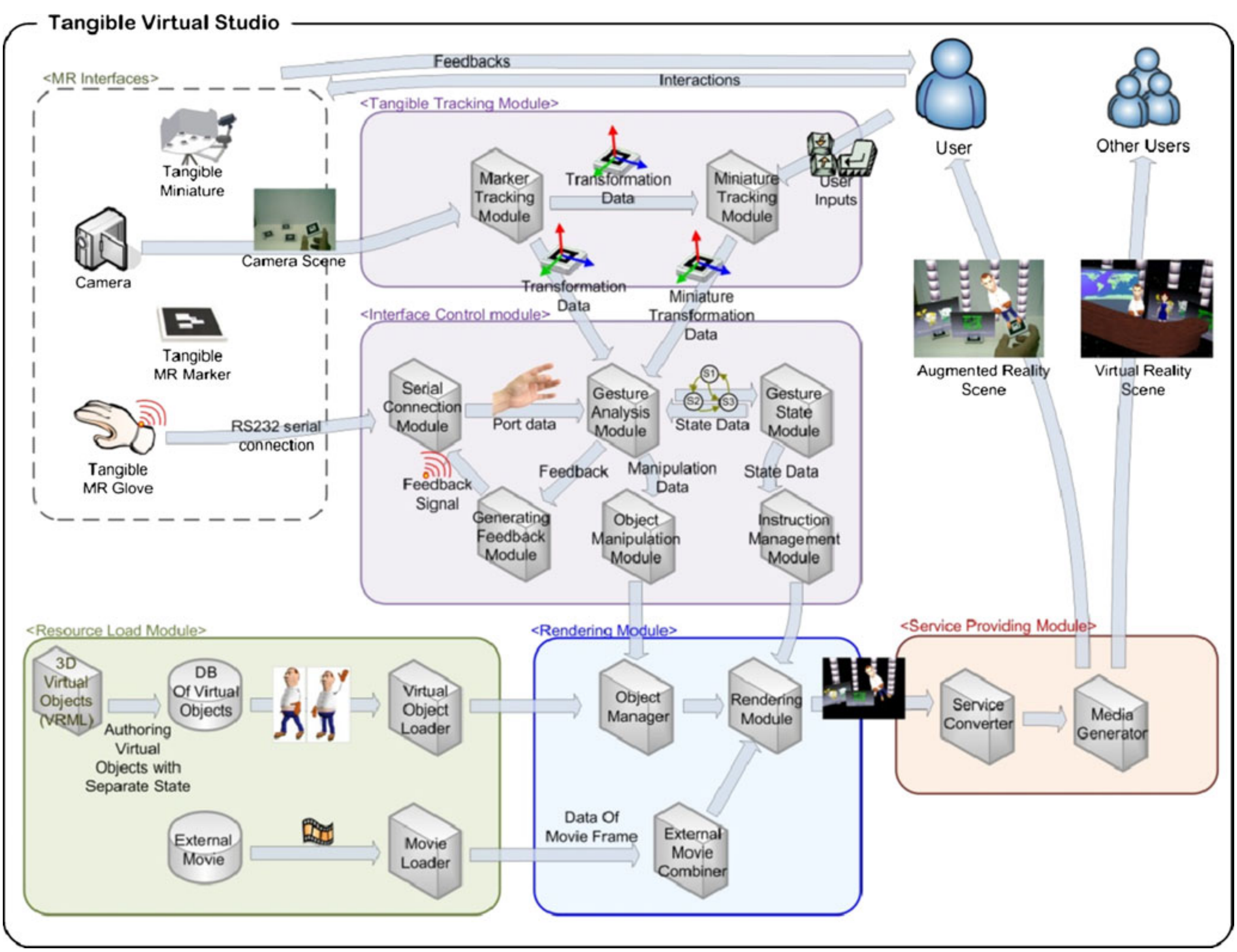


Fig. 14 Detailed system modules

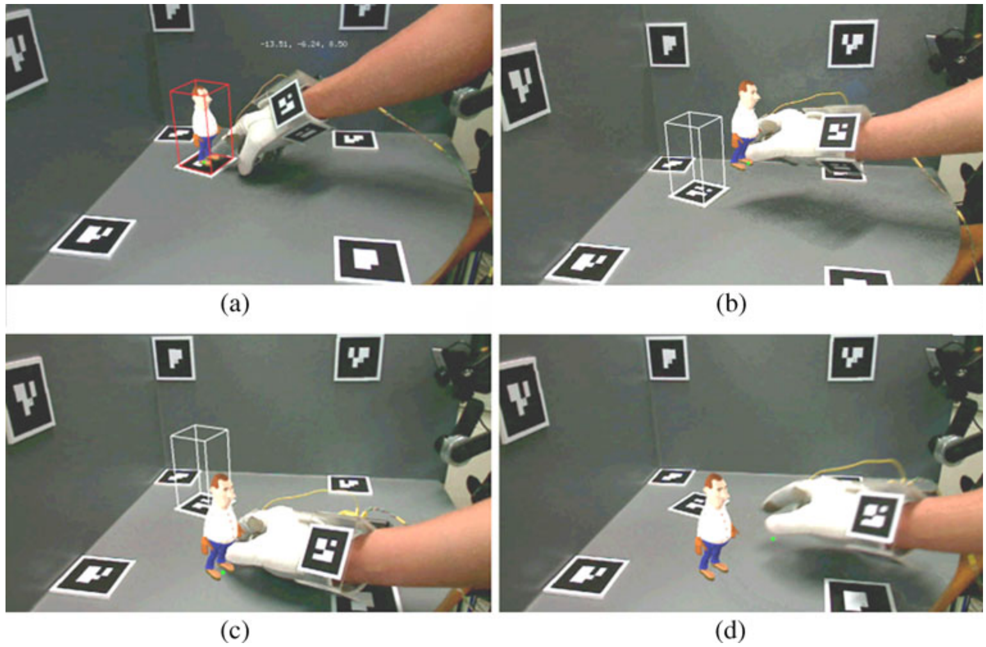


Fig. 15 Hand gesture-based manipulation and interaction: **a** object selection and corresponding vibro-tactile feedback, **b**, **c** gripping of the object and its movement, **d** pre-gripping and completion of the manipulation

based on the hand gesture-based interaction and MR-based visualization. In regarding several implementation results, we realized that the proposed approach could complement to existing methods that are based on a keyboard and a mouse, and it could provide a new way of an interaction interface to them.

5 Conclusion and future work

Most of the MR techniques just give priority to visual feedback such that the manipulation interface is different from that in the real world. Thus, it is considered that MR interfaces should allow for additional interactions with virtual objects, which should not only enable natural and intuitive interaction with them, but also help to provide seamless interactions between real and virtual objects at the same time. In this regard, several previous works have applied gesture-based interaction, haptic interaction, and other multimodal interaction to VR/MR environments. Although there have been much progress in providing tangible and interactive interfaces in MR-based applications, a more sophisticated research is still necessary since there are limitations and drawbacks in providing immersion, natural feeling, and convenience in providing augmentation and interaction interfaces.

This paper proposed a tangible interaction method by combining the advantages of soft interactions such as hand gesture and MR and hard interactions such as vibro-tactile feedback. One of the main goals is to provide more natural interaction interfaces similar to the manipulation task in the real world by utilizing hand gesture-based tangible inter-

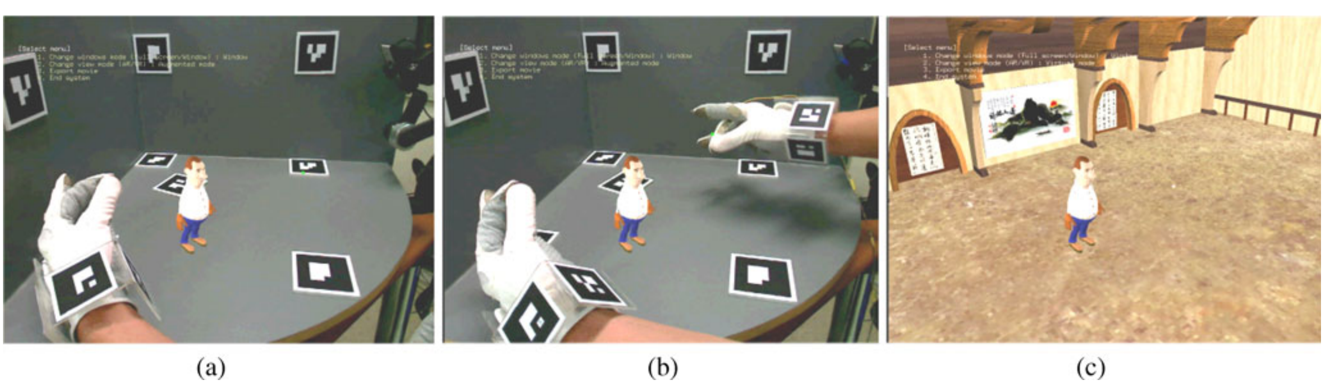


Fig. 16 Menu mode: **a** menu mode with the non-dominant hand, **b** MR mode, **c** changed VR mode

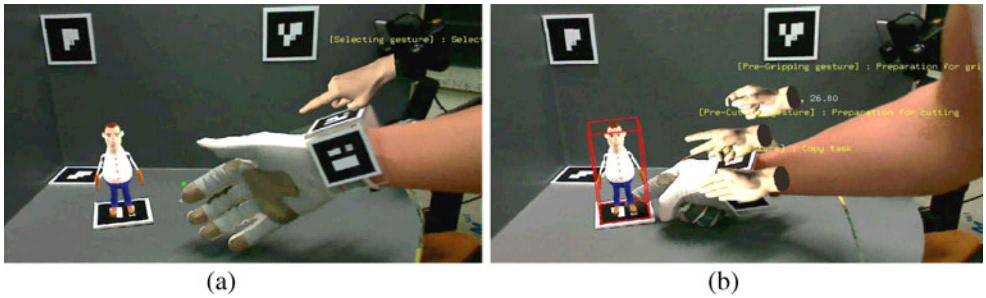


Fig. 17 Instruction mode: **a** the next instruction suggested is selecting, **b** the next possible instructions after the selecting task are none, pre-gripping, pre-cutting, and copying

actions. It also provides multimodal interfaces by adopting the vibro-tactile feedback and tangible interaction for the virtual object manipulation. Thus, it can make users get more immersive and natural feeling in the manipulation and interaction with virtual objects. Furthermore, it provides an alternative instruction guideline based on the analysis of the previous interaction while authoring virtual objects, which makes it possible for the user to minimize manipulation errors and guide the user to the right direction. As a consequence, the proposed approach have suggested a new way of natural, interactive, and instructive manipulation of the virtual object using hand gesture-based and MR-based tangible interfaces. The manipulation is very similar to that in the real world although the user interacts with virtual objects in MR environments. Furthermore, a finite state machine-based instruction mode which provides a set of possible next instructions based on the current one can provide a more user-oriented and natural interactions to the beginner. This makes the user minimize operation errors and decide the next operation easily, which improves control efficiency and minimizes interaction errors. In regarding several implementation results, the proposed approach can complement to existing MR methods and provide a new way of an interaction interface to them.

Several areas of research still remain. We have to investigate how other tangible devices and sensors can be added to provide more realistic interactions and tangibility. We also need to resolve occlusion in mixed reality and to support more natural and interactive interfaces. In addition, reducing tracking errors during detecting multi-markers in MR is another issue for providing accurate calculation of locations of the glove and virtual objects. To further evaluate the proposed system, we will apply it to various kinds of design and manufacturing applications.

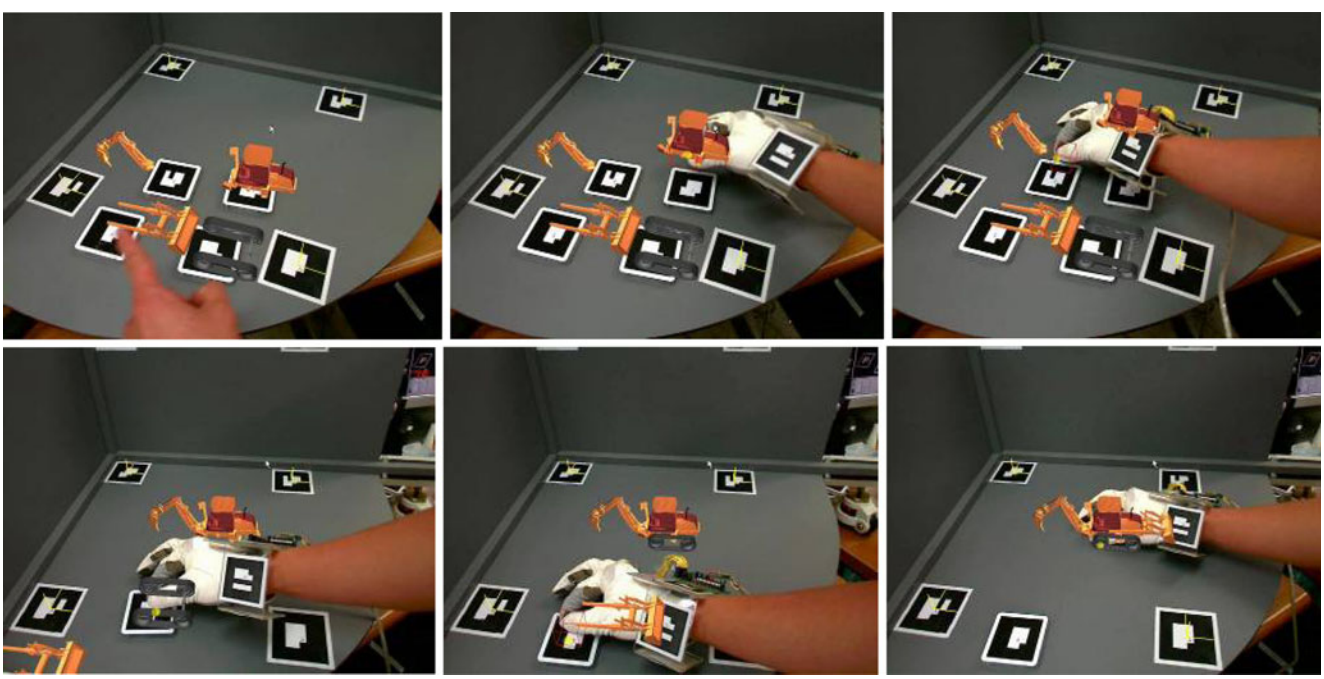


Fig. 18 An assembly scenario of an excavator based on the proposed approach

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