

Physically Realistic Interface for a user inside VR

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ABSTRACT

Interaction between a user inside a virtual space and virtual objects is described. Incorporating a user's live image into a virtual space enables him/her to exist in the same place as objects and to interact with them. There are, however, the lack of guideline to design interaction style makes users confused about how to use it. This article proposes a common implementation framework that forces the interaction to be physically realistic. As a result, the look & feel of interaction becomes uniform. In a ball game application and virtual electronic controllers made by this framework, a user manipulated/played in the same way as those in the real world. This framework could provide novice-friendly or hands-free interface ubiquitous around public or daily places.

Keywords

Keywords are virtual reality, bodily interaction and interactive animation.

1. INTRODUCTION

Interaction between a user inside a virtual space and virtual objects is described.

Incorporating a user's live image into a virtual space enables him/her to exist in the same place as objects and to interact with them. Stepping-in presentation [Yos03a] is a presentation system in which a user can use his/her live image not only to give bodily performance but also to do operation such as page changing. [Kan04a] proposed a communication system in which participant's live image's can bodily express their emotion by touching each other. EYETOY [Son03a] is an interactive game that uses user's live image. Mirror interface [Hos03a] is an interface that enables a user's live image to manipulate a remote object.

There are, however, no guidelines to design interaction style inside a virtual space. For example, [Yos03a] and [Hos03a] use a specific color to manipulate as a switch switches red/blue (ON/OFF), [Kan04a] uses overlapping user's area, and [Son03a] uses whether the user is moving or not as a switch switches waving in a specific place. As a result, a user does not how to manipulate it.

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In order to provide in-VR interaction of uniform look & feel and its common implementation platform, this article proposes a framework that forces the interaction to be physically realistic.

In this framework, an allowed interaction consists of a user's action in a virtual space and a reaction of each virtual object that has to be interpreted naturally as operation in the real world. Note that user's actions are, by definition, limited to be those performed to some virtual object. This interaction is described by a rule that associates an action such as touching, detouching or moving with a reaction such as rotation or transformation. Using this framework, a developer can concentrate to working on an object's reaction without being bothered by choosing interaction style.

To demonstrate the effectiveness of this framework, a virtual object such as dial, a toggle switch, a spring, a pickable object, and a bouncing object were implemented. More over, using these objects, two application products were also implemented. V-VolleyBall is a ball game application made of a bouncing object. In this game, the players see themselves in the screen playing as if with a real ball. V-Rimokon is a virtual electronic controller that controls consumer electronic at a remote place made of a dial object. This controller used was able to in a same way as manipulating a physical dial. Experimental use showed that all the users could manipulate/play at sight.

Interactions build in this framework could be novice-friendly and hands-free interface ubiquitous around public or daily places.

2. Virtual Manipulation

In *Virtual Manipulation (VM)*, a user manipulates virtual objects watching him/herself in a virtual space. Figure 1 shows a scene in which a user is manipulating a dial in a virtual space. In this figure, the hand outside the screen is in the real world, whereas the user manipulates the dial watching the hand image inside the screen.

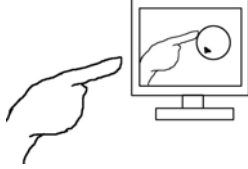


Figure 1. Using VM

VM consists of a *virtual interface* I_V , a *real interface* I_R and an *interpretation* J of I_V in I_R . This section, after giving the definition of VM, presents two components of I_V , *events* and *reactions*, the former of which describes basic actions of a user in the virtual space, and the latter describes responses of each virtual object.

2.1 Definition of VM

1. Basic Definition

The virtual interface I_V is defined by a triple $\langle E_V, A_V, \eta \rangle$, where E_V is a set of events in a virtual space, A_V is a set of reactions of objects in the virtual space and $\eta : E_V \rightarrow A_V$ is virtual response a function that returns a reaction given an event in the virtual space. Here, a reaction $a \in A_V$ is a function that changes the state of given objects. If the object under consideration is referred to as the *target* of $I_V = \langle E_V, A_V, \eta \rangle$.

The real interface I_R is defined by a triple $\langle E_R, A_R, \xi \rangle$, where E_R is a set of events in the real world, A_R is a set of reactions of objects in the real world and $\xi : E_R \rightarrow A_R$ is real response a function that returns a reaction given an event in the real world.

An event $e \in E_V$ is interpreted as an event $e' \in E_R$ by *event interpretation* $\phi : E_V \rightarrow E_R$ and a reaction $a \in A_V$ is interpreted in a reaction $a' \in A_R$ *reaction interpretation* $\psi : A_V \rightarrow A_R$.

By letting J be a pair $\langle \phi, \psi \rangle$ of interpretations above, a VM can be formulated as a triple $\langle I_R, I_V, J \rangle$.

Note that E_R, E_V and ϕ are common to objects and, on the other hand, A_R, A_V, η, ξ and ψ are determined by each object.

Example

In the example shown in Fig. 1, E_R is the set that consists of rubbing in the real world. E_V is the set that consists of movements of the point at which a user

contacts with the object. ϕ , given a movement of a contact point in a virtual space, returns rubbing in the real world.

In Fig. 1, the object is a dial, which determines the followings: A_R is a rotation of the dial in the real world. A_V is a rotation of the figure of the dial in the virtual space. η , given a movement of a contact point, returns a rotation of the dial figure in the virtual space. ξ , given rubbing the dial in the real world, returns a rotation of the dial in the real world. ψ , given a rotation of the dial figure in the virtual space, returns a corresponding rotation of the dial in the real world.

2. Reality Condition

VM must satisfy the following requirements (*Reality Condition, RC*) in order for the interaction to be physically realistic.

1. User's movement in the real world and movement in the virtual space are simultaneous and similar.
2. The reaction $a \in A_R$ that is caused, through ξ , by the event $e' \in E_R$ represented, through ϕ , by the event $e \in E_V$ must be equal to the reaction $a' \in A_R$ that is represented, through ψ , by the reaction $a \in A_V$ caused, through η , by event $e \in E_V$. That is $\xi \cdot \phi = \eta \cdot \psi$ holds. Figure 2 shows the commuting diagram for this equality.

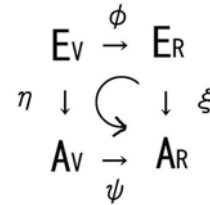


Figure 2. Diagram commutes.

In the following, VM request RC to hold.

Example (RC for a dial)

If user's live date taken by a video camera, a data glove, etc is used to incorporate the user, the user in the real world and the user in a virtual space moves simultaneous and similarly.

The rotation in the real world that is caused, through ξ , by the rubbing in the real world represented, through ϕ , by the movement of a contact point in the virtual space must be equal to the rotation in the real world that is represented, through ψ , by the rotation in the virtual space caused, through η , by the movement of a contact point in the virtual space.

2.2 VM for two-dimensional virtual space

Events

For the case that the user in the virtual space is a two-dimensional image, we propose following events as E_V .

Event interpretation ϕ is shown in Table 1 and the attributes for each event are shown in Table 2.

In the following and in the tables, the area of user's two-dimensional image is denoted by U , a two-dimensional figure of the object figure is denoted by F and a center of gravity for a two-dimensional figure is an average of the position of the point inside the figure. $G(U,F)$ given U and F , returns a center of gravity for the area where U and F overlap.

Reactions for a dial

F, A_V, η and ϕ for a dial are defined as follows.

F : A circle with a marker indicating a rotation angle (Fig 3).

ϕ : The mapping which maps a rotation of a dial figure in the virtual space to the same rotation of a dial in the real world.

ξ, η : Shown in Table 3.

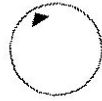


Figure 3. The dial figure in the virtual space

Note that the dial satisfies RC. We will see this in detail later at Physical Reality of the dial example in section 3.

3. Objects virtual interface in VM

An object with virtual interface can easily be described in VM. In this section, a dial, a toggle switch, a spring, a pickable object, and a bouncing object are described as examples of such object. In the explanation of each object, first, a specification of a real object is shown, next, actions are presented, and finally, RC is checked. The actual implementation of each object is shown in the next section.

3.1 A dial

Physical specification

A physical dial (Fig. 4) can be rotated by rubbing its circumference (after touching it).



Figure 4. A dial

Reactions

The target F is a circle with a sign indicating its rotation angle (Fig. 5). F becomes opaque on the event **Overlap**, becomes translucent on the event

$\phi(e) \in E_R$	$e \in E_V$
A user touches an object	Overlap : U overlaps F
A user releases an object	Release : U separates F
A user moves for touching an object	Move : U moves for overlapping F

Table 1. Event interpretation ϕ for two-dimensional virtual space

Event	Attributes
Overlap	x : an abscissa of $G(U,F)$
	y : an ordinate of $G(U,F)$
Release	
Move	before_x : an abscissa of $G(U,F)$ before movement
	before_y : an ordinate of $G(U,F)$ before movement
	after_x : an abscissa of $G(U,F)$ after movement
	after_y : an ordinate of $G(U,F)$ after movement

Table 2. Attributes of each event in two-dimensional virtual space

Release, and rotates on the event **Move**.



Figure 5. Dial figure

ξ, η : Shown in Table 3.

ϕ : Rotation of F means the same rotation of the dial in the real world.

Physical Reality

If overlapping area moves near the circumference of the target F , its moving speed is equal to that the sign, which is near the circumference.

3.2 A toggle switch

Physical specification

$e \in E_R$	$\xi(e)$	$\phi(e)$	$\eta \cdot (\phi(e))$
touches a dial	Give feeling of touch	Overlap	F becomes opaque
releases a dial	Give feeling of release	Release	F becomes translucent
 rubs while touching a dial	Rotates length rubbed	Move	$F \text{ rotates by}$ $\arctan\left(\frac{\text{Move.after}_y - F.y}{\text{Move.after}_x - F.x}\right)$ $- \arctan\left(\frac{\text{Move.before}_y - F.y}{\text{Move.before}_x - F.x}\right)$ degrees.

Table 3. ξ and η of a dial

$e \in E_R$	$\xi(e)$	$\phi(e)$	$\eta \cdot (\phi(e))$
moves downward ON to OFF	ON state switches to OFF	Move	If $\text{Move.before}_y > C_y$ and $\text{Move.after}_y < C_y$, F becomes state of OFF (Fig.7. Right side) .
moves upward OFF to ON	OFF state switches to ON		If $\text{Move.before}_y < C_y$ and $\text{Move.after}_y > C_y$, F becomes state of ON (Fig.7 Left side)

Table 4. ξ and η of a toggle switch(C_y is an ordinate of the center of F .)

$e \in E_R$	$\xi(e)$	$\phi(e)$	$\eta \cdot (\phi(e))$
touches a spring	A spring expands and contracts	Overlap	Position of F becomes Overlap.y
expand and contract a spring while touching	A spring expands and contracts	Move	Position of F becomes Move.after_y
releases a spring after pressing	A spring oscillates	Release	If Move.after_y is not equal 0, F oscillates.

Table 5. ξ and η of a spring

A Toggle switch (Fig. X) has the states up and down. To change the state up to down (ON→OFF), slant the bar downward, and vice versa.



Figure 6. A toggle switch

Reactions

The target F of the virtual toggle switch has two states ON and OFF as shown in Fig. X. The event **Move** which sweeps F upwards / downwards switches these states.

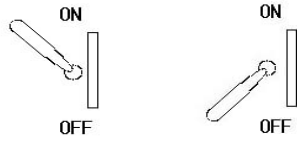


Figure 7.F/ON and F/OFF

ϕ : The switching ON to OFF or OFF to ON in the virtual space means the switching of the toggle switch in the real world.

ξ, η : Shown in Table 4.

Physical Reality

Two states (ON,OFF) can be switched by U , by the same action as the toggle switch in the real world. That is, if the user's image moves upward overlapping F/OFF, the figure turns to F/ON and vice versa.

3.3 A spring

Physical specification

As the finger moves down pressing the spring (Fig. 8), it expands and contracts. The spring oscillates if the finger is released after pressing it.



Figure 8.A spring

Reactions

The target F is a figure shown Fig. 8. F expands and

$e \in E_R$	$\xi(e)$	$\phi(e)$	$\eta \cdot (\phi(e))$
Two fingers pick an object up	Give feeling of touch	$\{\text{Overlap.x,Overlap.y}\} \notin U$	F becomes opaque
release an object	Give feeling of release	Release	F becomes translucent
Touch with one finger	Give feeling of release	$\{\text{Overlap.x,Overlap.y}\} \in U$	F becomes translucent

Table 6. ξ and η of a pickable object.

contracts by the event **Move**, and oscillates by the event **Release** for contraction.

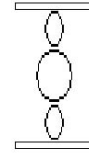


Figure 8. A spring figure

ξ, η : Shown in Table 5.

ϕ : The size of expanding, contracting and oscillation of F means those the spring in the real world.

Physical Reality

The size of expanding and contracting of the target F is determined by the position where it is overlapped by U and the oscillation is determined by the size contracted as a spring with some elasticity in the real world.

3.4 A pickable object

Physical specification

A pickable object can be picked if a user picks it up with two fingers and dropped if the user releases it. Picking and dropping can be judged from a sense of touch.

Reactions

The target F is a figure shown Fig. 9. F becomes opaque by the event **Overlap** which is caused by two separate overlapping areas, and becomes translucent by **Overlap** and the event **Release**.



Figure 9. A pickable object figure

ξ, η : Shown in Table 6.

ϕ : Becoming opaque and translucent in the virtual space means notifying touching and releasing some object in the real world.

Physical Reality

The situation that the gravity center of the overlapped area is outside U (Fig. 10) is usually the case that the object is touched at two points on mutually opposite side of the object.



Figure 10. Point(Overlap.x,Overlap.y) for picking

3.5 A bouncing object

Physical specification

If the moving object contacts with a user in the real world, the object bounces by elastic collision.

Reactions

The target F is a figure shown Fig. 11. The traveling direction of F is changed by the event **Overlap**.

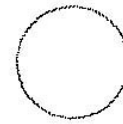


Figure 11. A bouncing object figure

ξ, η : Shown in Table 7.

ϕ : The bouncing angle of F means the bouncing angle of the object in the real world.

Physical Reality

Velocity change caused by the contact with U is similar to that of a real ball.

4. Real System

The method of the user's clipping is the back ground subtraction.

4.1 A dial

The tip of a finger is moved toward the circle until it overlaps (Fig. 12. up side) and is moved along the circumference of the circle (Fig. 12. down side).

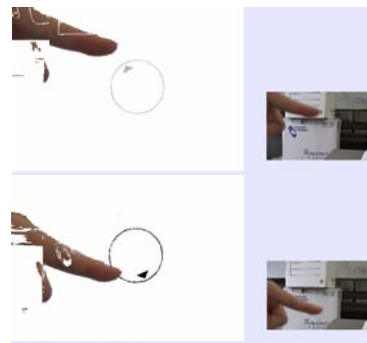


Figure 12. A dial

4.2 A switch

Touching the top of the switch by the tip of a finger (Fig. 13. up side) and the tip of a finger is moved below (Fig. 13. down side).

$e \in E_R$	$\xi(e)$	$\phi(e)$	$\eta \cdot (\phi(e))$
touches an object	An object bounces	Overlap	$\vec{n} = \frac{\begin{pmatrix} F.x - \text{Overlap}.x \\ F.y - \text{Overlap}.y \end{pmatrix}}{\sqrt{(F.x - \text{Overlap}.x)^2 + (F.y - \text{Overlap}.y)^2}}$ $\vec{v}' = \vec{v} - 2\vec{n}(\vec{v} \cdot \vec{n})$ <p>\vec{v} is the direction of travel of F \vec{v}' is the direction of travel of F after bouncing</p>

Table 7. ξ and η of a bouncing object

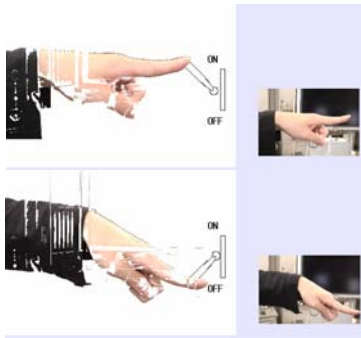


Figure 13. A switch

4.3 A spring

The tip of the finger is moved toward the spring figure until they overlap (Fig. 14. up side), the tip of the finger is moved below (Fig. 14. middle side) and the spring figure begins to oscillating when the tip of the finger is separated from the spring figure (Fig. 14. down side).

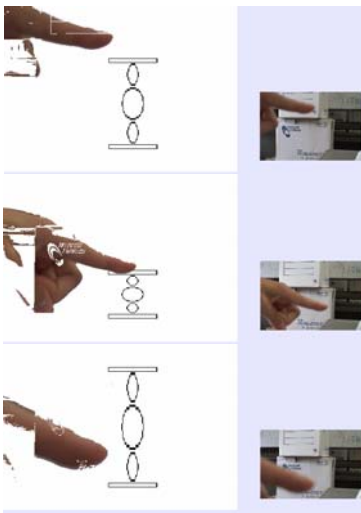


Figure 14. A spring

4.4 A pickable object

The two tip of the fingers are moved toward the circle until they overlap (Fig. 15. up side) and the circle is picked up by them (Fig. 15. down side).

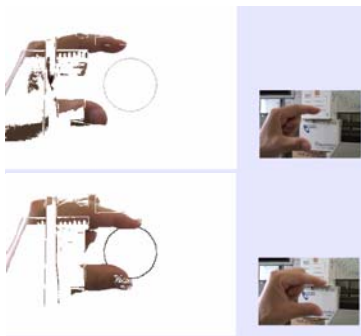


Figure 15. A pickable object

4.5 A bouncing object

The hand contacts with the moving circle (Fig. 16. up side) and the moving circle bounces (Fig. 16. down side).

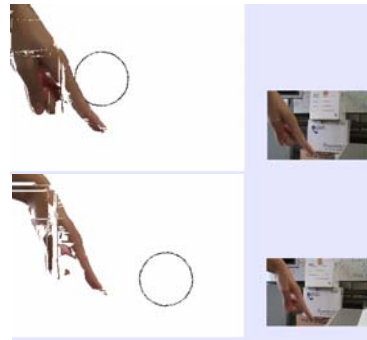


Figure 16. A bouncing object

5. Application

This section presents some screenshots of the scene in the game application (V-VolleyBall) and a remote controller (V-Rimokon) both of which use objects described in section 3.

5.1 V-VolleyBall

V-VolleyBall is a volleyball game application (Fig. 17. left side). Two players can play volleyball watching a virtual court in which the two players play with a virtual ball (Fig. 17. right side), a bouncing object described in section 3.



Figure 17. Using V-VolleyBall

5.2 V-Rimokon

V-Rimokon is intended to be used as a remote controller for the consumer electronic. The user can change the volume on the television in the same room but a little apart from him (Fig. 18. left side) by turning the virtual dial (Fig. 18. right side) described in section 3 on the screen



Figure 18. Using V-Rimokon

6. Result

6.1 Evaluation of Objects and V-VolleyBall

Usability experiment is done on low-school students (age 14), high-school (age 17) and graduate-students (age 23), each about ten subjects. In all groups, it is found that user can manipulate/play at sight without any instruction.

6.2 Developer's process

First, an object's figure is decided. Next, the action is chosen from among the fixed set E_V . Finally, the object's reaction is described.

7. Discussion

A framework for designing interaction between a user inside a virtual space and virtual objects is presented. In this framework, the granularity of description of events and reactions in virtual world is the same as that of description of those in the real world and each event-reaction rules in the both worlds are imposed to be semantically equivalent. As the result, interactions in this framework can easily be designed from given physical specification about real object and is necessarily physically realistic. The resulting interaction is physically realistic in the sense that not only its look and feel but also the needed actions to interact with objects are the same as those in the real world. V-VolleyBall may seem difficult to play because of the mismatch between the two places, the one where on the screen the user is watching the virtual ball running against to his virtual hand and the one where his actual hand volleying in the real world. Contrary to this expectation, however, experiment shows that the above mismatch does not matter in playing game.

This framework can also be applied to a three dimensional virtual space using pose-sensing device, for example, the data glove. Interactions build in this framework can be used as novice-friendly or deviceless interface ubiquitous around public or daily places.

Limitation

In VM, although the user's image is touching an object in the virtual space, his real body is touching nothing. Therefore, an actual user doesn't have the sense of touch. This situation makes the user's action in the virtual space unstable because the proper positioning is a little difficult without a physical surface. This problem can be solved by a haptic interface device that feeds back contact in a virtual

space to the sense of touch. However, the haptic device is applicable only when the point on the virtual body at which is to contact with objects is preliminarily fixed (as the tip of some finger, for example).

Related Work

Other methods for manipulating virtual objects use a hand glove. [Dor01a] present a system that allows a user to manipulate the virtual object by recognizing his/her hand's shape and gesture. Although, it can easily and accurately be obtained by hand glove, it can not be used in daily life.

Future Work

This interaction can be extended to 3D by the model-based reconstruction from 2D to 3D or encoding 3D-meaning in 2D-actions.

Deformation of virtual objects using a clayish object would be an interesting challenge along with this approach.

Conclusion

A framework that forces reality was proposed.

Interactions implemented in this framework were able to be used easily at sight.

8. ACKNOWLEDGMENTS

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