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Real-time Bi-directional Real-Virtual Interaction Framework Using Automatic Simulation Model Generation

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(a) Input Image
(b) Virtualized real (blue) and arbitrary (red) objects that has physical kinematic model
(c) User input (throwing a ball)
(d) Physical interaction with vitualized real object and arbitrary object

Figure 1: Real-time bi-directional real-virtual interaction framework. The system detects objects from input images (a) and assigns simulation models based on the objects' physical properties (b), such as rigid body for cans, articulated rigid body for lamps, and deformable body for punch balls. This enables bidirectional interaction between real and virtual objects, as demonstrated by the yellow arrow showing the lamp head hitting the punch ball and the virtual cans collapsing (c)(d).

Abstract

Most mixed reality researches require lots of event-specific interaction, such as assigning appropriate animations for each specific situation, without considering the physical properties of objects during the modeling process. We propose a new framework for bi-directional interaction between real and virtual objects that incorporates physical feedback on both real and virtual objects. Our framework automatically generates simulation-enabled *virtualized real objects* using only their 3D meshes and material types related to their physical properties and visualizes in real-time various bi-directional interactions among virtual and real objects having various types of physical properties such as rigid, articulated rigid, and deformable body.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality

1 Introduction

Realistic interaction in mixed reality (MR) requires virtual objects to interact not only with users but also with real-world objects and environments in real time [4]. Previous MR research has mainly focused on augmenting virtual objects on captured frames. [1]. However, this often requires extensive event-specific modeling and do not consider the physical properties for interaction. To address this, we propose a novel framework that covers the entire process of creating, simulating, and rendering virtualized real objects from 2D input frames. Our framework allows for physics-based interaction in real-time, considering the material properties of objects in both real and virtual events such as collisions, pushing, and so on. This approach can make virtualized real objects capable of interacting with virtual objects and vice versa, which we called this bi-directional interaction. Our approach presents an example of real-time, *bi-directional interaction* between the real and virtual worlds and can serve as a base step for the realization of the real-world metaverse.

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2 Bi-directional real-virtual object interaction framework

The framework consists of four main modules, as illustrated in Fig. 2: perception, automatic simulation model generation, scene rendering, and physics-based object interaction. The perception module recognizes and classifies objects to be virtualized in real-time, and prepares the information for generating the virtualized real object. The automatic simulation model generation module takes the information from the perception module, including the object's 3D mesh, physical properties, and material class, and adds joints for physics simulation into the object. This allows for different types of interactions among rigid, non-rigid, and deformable bodies based on their physical properties. It also assigns rigging parameters such as joint hierarchy and skinning weights for efficient soft-body simulation. The scene rendering module places the virtualized objects in the scene and inpaints missing parts of the real image. The physics-based object interaction module simulates and displays interactions between the virtualized real object and other virtual objects or the user.

2.1 Perception

The perception module prepares virtualized real objects from an input frame. It is divided into three main sub-components: object recognition, database, and mesh generation. The object recognition module detects and classifies objects and materials from a real image to assign physical properties to the objects [3]. The database contains 3D mesh models, physical properties, and rigging parameters for simulation.

2.2 Automatic Simulation Model Generation

This module begins by taking a 3D mesh model from a database as input, then generates a kinematic model by implanting joints for physical interaction. The kinematic model generation process involves inserting joints according to the shape of the object to allow for natural movement during the simulation. After that, simulation models and material parameters are assigned based on the density and elastic properties estimated from the detected material from the perception module. A proportional-derivative (PD) controller is used to express the physical properties of the object [6].

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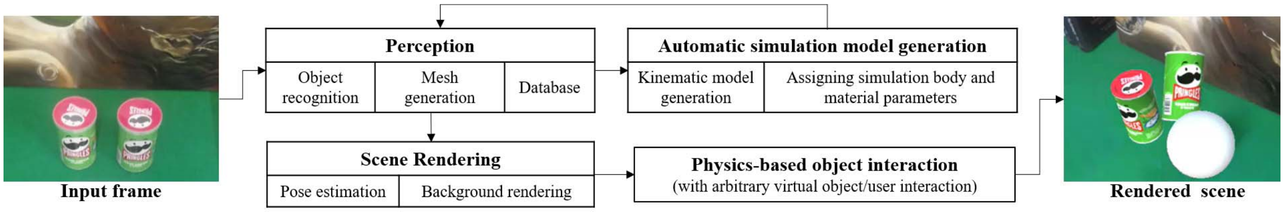

Figure 2: Overview of real-time bi-directional real-virtual interaction system.

Figure 3: Representative sample interaction scenes between virtualized real objects and a virtual rigid ball: (a) Rigid body(rigid box), (b) articulated rigid body(stand lamp), (c) deformable body(punchball).

2.3 Scene Rendering

The process starts with estimating the poses of the camera and objects for using the placement of virtualized real objects in the frames, in which camera tracking becomes available [5]. In order to achieve a more natural visual appearance, the background around the virtualized real objects is erased and inpainted [2]. Additionally, the method allows for real-time rendering of objects colliding with the real environment, including the ground.

2.4 Physics-based Object Interaction

The module is used to enable real-virtual object interaction. Virtualized real objects that have been simulation-enabled and properly augmented on the frame can interact with any other virtual objects, users, or other virtualized real objects in the environment. The objects in the mixed world move according to the laws of physics, colliding with each other. Users can also interact with the environment by changing the momentum of a specific object, applying forces, or generating a new virtual object in the scene.

3 Representative Sample Scenes

The paper demonstrates the use of the proposed framework for real-time virtualization of real-world objects by creating sample scenes that shows different types of virtualized real objects and interactions. Fig. 3 illustrates three types of interactions: rigid body, articulated rigid body, and deformable body. The first example shows collisions between rigid objects, a virtualized real box, and a virtual rigid ball. The second example shows an articulated rigid body, a virtualized real stand lamp, colliding with a virtual rigid ball. The third example shows a deformable body, a virtualized real punchball, bending and returning to its original shape after deformation. Through several sample scenes presented above, we have shown that we can effectively simulate collision situations of solid, connected solid, and non-solid objects. The majority of objects encountered in daily life can be categorized into the three groups. By combining them appropriately, it is expected that a variety of interactions can be effectively implemented in complex and diverse situations.

4 Discussion and Conclusion

In this paper, we propose a new framework for bi-directional interaction between real and virtual objects that allows for physics-based augmented reality simulations. We have demonstrated that the framework could successfully simulate in real-time various interaction scenarios among virtualized real objects, virtual objects, and the users. There are several important issues for further explorations. We need to make sure material labels are correct enough not to lead to unnatural motions. Also, as the automatic simulation generation module assumes that an object has a uniform physical property, recognizing physical properties for each part of the real object separately could be the next step we need to take for obtaining more sophisticated interactions. In addition, it would be interesting to incorporate sound feedback to improve the sense of immersion of the framework.

In conclusion, it is confirmed that the framework has great potential for physics-based interactions in mixed-reality environments.

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