Real-time Physics-based Interaction in Augmented Reality

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ABSTRACT

We propose a unified Augmented Reality (AR) based framework that combines the real-time physical multi-material simulation model and the efficient free-hand gesture interaction method. First, we employ a simple Red-Green-Blue-Depth (RGBD) camera to quickly acquire 3D environmental data to build the static boundary conditions. The real-time gestures are then detached and used as dynamic objects that interact with physical simulations. Finally, the calculated lighting parameters are used for real-time rendering and virtual-reality fusion. Our framework enables users to interact with various physical simulations in AR scenes, which considerably expands the applications of the fusion of AR and physical simulations.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction devices—Haptic devices ; Computing methodologies—Computer graphics—Animation—Physical simulation

1 INTRODUCTION

In most AR scenes, 3D objects just have geometric characteristics, making it impossible to physically interact with users. Interacting with physical phenomena in real-time AR applications is a meaningful yet difficult task. Meanwhile, portable gesture recognition interaction methods have a strong attraction for researchers, as they have the potential to not only widen the application scenarios of AR devices, but also to enhance the popularity of AR applications. Thus, real-time gesture recognition through AR technology makes it possible for users to participate in physical simulations.

On the other hand, multi-material objects can not only enrich the content of virtual scenes but also enhance the user's sense of immersion and experience, such as flowing water, flying snow, etc. However, there are currently only a few studies focusing on different materials in AR for real-time interaction based on physical reality.

In light of the foregoing, we intend to investigate the possibilities of using AR in real-time physics-based interaction between gesture detection and multi-material objects. Thus, we develop a unified AR-based framework that efficiently combines the physics-based multi-material simulation model and the free-hand gesture interaction method to broaden AR applications. In which, we voxelize the hand model of Leap Motion to particles and simulate different materials based on Material Point Method (MPM) algorithm using particles uniformly for effective interactions. Meanwhile, we conduct variety lighting parameters for rendering and virtual-reality fusion in real-time.

2 RELATED WORKS

Kinect and Leap Motion can recognize hand posture and track gesture movement in real time. Researches related to the two devices focus on the interaction between gestures and objects, which can be divided into pre-training and physics-based approaches.

Figure 1: Screenshots of the real-time interaction between hands and the virtual water in AR scene.

In pre-training methods, a consensus method is to collect gestures in advance and extract them from the pre-trained data when a similar situation is detected [1]. However, not only does this method necessitate a large dataset and time-consuming training, but the application scenario is limited in the dataset, reducing the ease of VR interaction.

In contrast, physics-based methods do not need pre-training but are limited in the speed of numerical computation. Researchers usually consider the gesture as a soft object, taking into account the muscle action on the fingers, and incorporate the contact area and friction into the calculation [2] [5]. While we map gestures and different materials uniformly into particles to achieve the interactions between gestures and virtual objects.

The MPM algorithm is a hybrid Lagrangian/ Eulerian discretization method, which is also regarded as an extended FLIP method. Hu et al. [3] presented the Moving Least Squares Material Point Method (MLS-MPM) enables the simulation of various new phenomena and significantly improves efficiency. We further apply the MPM algorithm to the Unity3D game engine to achieve real-time multi-material modeling.

Compared with these existing approaches, our scheme can achieve real-time physics-based interactions with a small space, low-performance overhead, and rich materials.

3 SYSTEM DESIGN

An overview of the proposed architecture is provided in Fig. 2. It consists of a main simulation program, an object representation structure (virtual objects), and an abstraction of input devices (sensors). we utilize the Intel RealSense Depth Camera and open3D technology to collect data and reconstruct the real scenes in the computer. And the Leap Motion is used for gesture recognition to control the movement of the hand model in the simulator. The gestures are recognized in real-time, and the gesture model is voxelized into particles to participate in the motion of interactions. Although Leap Motion can track the motion of the gesture well and reproduce it in the virtual scene, the hand model as a kinematic object will have problems such as penetration when interacting with virtual objects. The voxelized hand gesture model consists of particles, and with the

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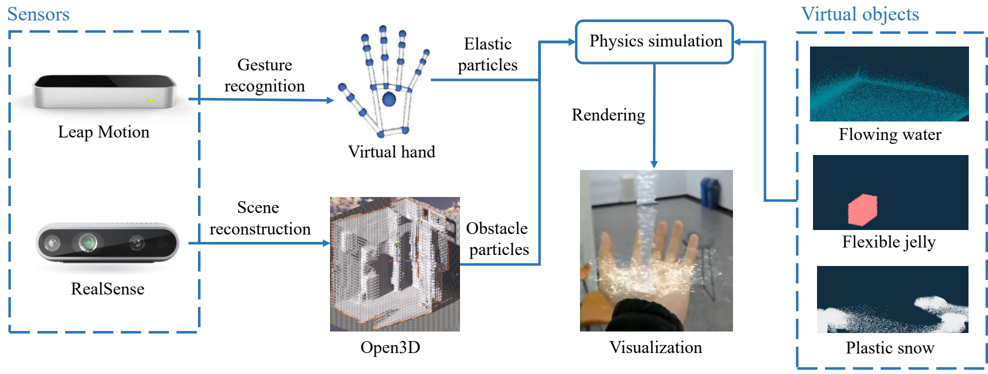

Figure 2: System architecture showing interaction flow.

help of the MPM solver, these particles can participate in the physical simulation uniformly, preventing the occurrence of phenomena such as penetration. It is worth mentioning that the particles that make up the gesture model are not completely rigid particles, but have a certain elasticity that matches the reality of human skin and muscles.

The physical simulation system will be realized by utilizing the multi-material particle method based on the MPM algorithm in the Unity3D game engine. Our approach does not require any pre-training and can be rapidly and readily applied in many settings for real-time interaction. After the acquisition of reality-based gesture data and scene information, the interaction with virtual objects is computed using the intrinsic model for particles of various materials, such as weakly compressible fluid particles, elastic particles, plastic particles, and rigid particles. Furthermore, we leverage the taichi [4] programming language's pre-compilation capability to accelerate the physics-based computation, which dramatically increases system performance.

Finally, the simulation results of the real scene and the virtual scene are combined to realize the real time rendering. The calculated lighting parameters are used for real-time rendering and virtual reality fusion. With the object comprehension process, the anisotropic depiction of particles based on screen space is realized in real-time. The rendering of particles, obstacles, and the unification of the observer's perspective are completed to establish a seamless integration of participants, virtual environments, and real-world situations to achieve a natural, realistic, and harmonious interaction in AR.

4 Results

We have completed some preliminary experiments based on the completed system. The test environment is a laptop, a Leap Motion, and a RealSense. The laptop's GPU is RTX 3070 LAPTOP, CPU is AMD R7 5800H, and memory is 16GB.

Table 1: The number of particles in Fig. 3

Object type	Particle numbers
fluid	60000
plastic snow	26198
elastic ball	15526
wrist bone	893
index finger bone	372
middle finger bone	364
ring finger bone	357
pinky finger bone	344
thumb finger bone	196

As shown in Fig. 3, we build a virtual scene, the number of particles is shown in Table 1. And the real-time interaction between hands and the virtual water in AR is shown in Fig. 1. During the actual operation, the frame rate is maintained above 150 Frames Per Second (FPS), the feedback effect of the multi-material objects is good, and the control of the gesture model is accurate and rapid.

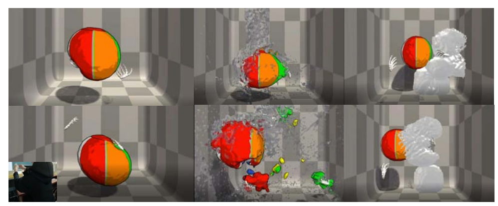

Figure 3: Screenshots of the interaction with the elastic, the fluid and the plastic. The bottom left image shows a user interacting with the simulator through the Leap Motion.

The recruited volunteers said that the physical simulation is real and interesting, and the interaction is simple, giving the system a very good evaluation.

5 Future Works

In our method, all the objects in the virtual scene in this scheme are composed of particles, which help to realize the effects of free topographic change, breakage, and fusion of virtual objects, and can largely enrich the physical interaction effects in AR. This project has achieved relatively good running results on PC, but it cannot run on a mobile device because it relies on the RGBD camera and Leap Motion for gesture recognition and scene acquisition. In the future, we will try to detach the gesture recognition and scene acquisition functions from specific devices and use laser detection and cameras on mobile devices to achieve these functions.

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