Immersive Prototyping for Rigid Body Animation

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Abstract. Prototyping is a vital process of artistic creation. Easy-to-use and animated prototyping helps designers to express their ideas and inspire the team to be more productive. Immersive environment brings more engaged experience and intuitive ways of interaction. In this paper, an immersive prototype animation production method is proposed, which adopts the design theory of natural interaction interface to allow users to quickly produce expected rigid body animation through intuitive interactions in VR environments. In our work, we designed a 3D user interface that allows users to interact quickly and easily in an immersive environment. We allow users to directly control the position, rotation, scaling and other attributes of objects in an virtual scene with their own hands. We have integrated and simplified the animation production process, and users can directly control the animation running speed with body movements. A quantifiable interactive efficiency evaluation method is proposed and compared to traditional methods. The results show that our method can improve the efficiency of prototype animation production.

1. Introduction

We define a prototype animation as a creative display animation that can be created quickly and modified easily. In the early design stage of films, animations and other artistic works, prototype animations can help a main creative team to determine the shooting plans, save production costs and improve production efficiencies. Current prototype animations are still made by traditional methods: animators pose characters in different keyframes, then computers automatically interpolate between keyframes to form animations. To implement body movements naturally, animators need to adjust the interpolation curve between different keyframes frequently or insert more keyframes, which consume a lot of time.

For the non-uniform curved motion of a single object, such as plane flying and car driving, which are common elements in movie shots, traditional methods have to add more keyframes and control nodes to constrain the motion speed at different time points to produce an expected motion effect. This approach does not correspond to our understanding of motion description in real life. People usually describe this intuitively by moving our hands through space, for example by controlling a doll to bounce to show how it moves, or by waving a paper airplane to show how it flies. These intuitive controls are effective at delivering the desired results.

To solve these problems, we propose an immersive prototype animation production method, which optimizes the traditional animation pipeline through the theory of natural interaction interface. The key
feature of our work is to allow users to control character animations directly through their bodies in immersive spaces. As a result, users can quickly produce low-precision prototype animations without mastering those complex animation editing tools, which help the creators express their ideas efficiently (see Figure 1).

Our goal is to improve the efficiency of prototype animation production through VR technologies. This paper designs a set of quantifiable evaluation criteria and conducts a series of interaction design based on this criterion. We chose the duration and the interaction-operation-sequence(IOS) to describe interaction efficiency, and use these two attributes to evaluate the interaction efficiency of our work.

In summary, we make the following contributions:
1) A VR 3d user interface that allows users to adjust basic settings and parameters. The traditional viewport no longer exists, and the user himself is in the same virtual space as the 3D character being edited. The menu system has also been designed considering this new environment. The location, style and interactive feedback of the menu are all suitable for VR environment.
2) A system that allows users to control the position and the direction of rotation directly by their hands. The system can significantly reduce the difficulty of using our tools and quickly build up a scene.
3) A series of intuitive animation control methods that avoid interpolation curve adjustments between keyframes. Users can directly use body movements to control the running speed of keyframe animations.

2. Related work
From the initial static story drawing to computer generation, prototype animation is gradually becoming more and more expressive and simple to use, and the innovation of interactive methods and technological progress are the continuous power of prototype animation.

2.1. Immersive User Interface
Riyadh et al mentioned the emergence of natural interactive interfaces in the last decade [1]. From command-line interfaces to graphical ones, human-computer interactions are constantly evolving toward a more natural and intuitive form. By nature, we mean that the user's actions in the course of interaction are based on the experience people naturally learn in real life, rather than the rules imposed by machines. Liu et al defined natural interaction interface as an emerging computer interaction method that focuses on higher-level cognitive functions such as touch, vision, movement and language expression of human beings [2]. Jacob et al build a descriptive framework for these emerging interaction styles consisting of four themes: naive physics, body awareness and skills, environment awareness and skills, and social awareness and skills [3].

Natural interaction interfaces save users from complex operations and directly interacts with computer applications in the most intuitive way. Gesture recognition based on multi-touch has been widely used in smartphones, where users can easily view or zoom in and out pictures through the
coordinated click movement of multiple fingers. The representative device of natural interaction interface in the video game field, Kinect uses gesture recognition interaction based on computer vision. A player can directly interact with Kinect by gesturing toward the sensor. However, this kind of technology is not accurate enough to capture user input, and it is easy to be influenced by light or position, which would interfere in recognition of player gestures. High precision tasks such as modelling, animation film and television editing require more accurate user motion capture.

With the continuous maturity of VR technology, interfaces for natural interaction are gradually developing into content production applications. Tilt brush is an immersive painting software, which takes advantage of the six degrees of freedom (6DoF) of the viewport and handles control brought by VR devices, allowing artists to draw 3D patterns freely in virtual space. MasterpieceVR is an immersive modelling software that enables users to operate controllers to build 3D models in the virtual space. The system integrates most functions of the modelling procedure, such as adding, hollowing, grinding, etc. Users can view the model from any angle in an immersive environment and edit it directly with controllers, just as they would with clay in the real world. Compared with traditional modelling tools, MasterpieceVR uses real-life sculpture and observation experience, enabling non-professional software users to get started with the pieces quickly and improve sculpting efficiency.

The interaction interface is simple and direct, but the technology behind it is becoming more and more complex [1]. Behind the concise speech interaction of speech recognition is a complex speech semantic recognition system, and multi-touch system performs a lot of analytic processing on every possible touch operation of users. Zielke et al proposed a medical training program based on voice interaction, in which test subjects conducted voice communication with emotional virtual patients in VR environment [4]. Galvane et al proposed a project of making pre-visualization for movies in VR environment [5]. Users can directly generate shooting scenes and characters in the virtual space to simulate the film shooting process. This authentic experience is behind the complex film and television shooting process simulation.

2.2. Prototype Animation

Prototype animation, formerly known as the story version, was widely used in the film and animation industry at the beginning of the last century. Special effects pioneer Georges Méliès is known to have been among the first filmmakers to use storyboards and pre-production art to visualize planned effects [6]. 3D computer animation is based on keyframe interpolation. Specifying each pose individually and controlling the timing through a timeline remains to this day the established pipeline [7].

Then, in order to further control more complex models, researchers successively proposed the Skeleton and Cage models to parameterize the mesh and manipulate the mesh with a lower degree of freedom. The role model used in this paper is based on the articulated skeleton structure. Furthermore, Inverse Kinematics (IK) [8]-[9] techniques were developed to further speed up the animation process and retain full control of articulated 3D characters. The current pipeline of computer animation is using modelling software such as MAYA or 3dsmax to pose keyframes of the articulated model with IK, continuously adjust the interpolation curve. This process takes a lot of time and requires professional software skills. It is not suitable for the application scenarios of prototype animation.

Hoshino et al implemented a prototype animation system based on the principle of computer animation and database, which can transform a simple static matchman story into an animated segment [10]. But the animation effect achieved by this method lacks details and relies on a large database of character actions. Hand drawing has always been one of the most intuitive methods of conveying information between people. Although the media on which the drawing if performed has kept abreast of various technological advances, the techniques of natural drawing have remained unchanged. With the development of natural interaction interface, researchers began to use hand-drawn sketches to make animation. Davis et al propose a natural user interface called K-Sketch which enables users to sketch animation effects [11]. Furthermore, users could draw circles to select objects and transform/rotate them. However, these features could only be applied to 2D shapes.
3D space adds a spatial dimension, resulting in a more complex process of character motion. Researchers tried to drive 3D animations through an affiliate control method. Guay et al defined Line of Action object, which transforms users’ sketching in 2D space to the motion of the character [12]. Mahmudi proposed another natural user interface to draw lines to posing the 3D characters [13]. Guay et al defined space-time-curve(STC) to combine the object moving trajectory and its posing into a single stroke, to make complex motion animation [7].

In recent years, the research further simplifies the animation production process so that beginners can quickly create animation. Ciccone et al create loop animations through a graphical animation editing interface and various motion capture methods [14]. Furthermore, tangent space optimization could use less keyframe control combined with IK for complex character animation [15]. These methods have improved the production efficiency of 3D animation and reduced the threshold of use, but they still rely on traditional 2D input devices, such as keyboards, mice or hand-drawn boards. Editing the 3D space within the 2D input scope inevitably requires multiple operations from different perspectives to make up for the limitation of input mode. At the same time, the parameterized animation editing mode does not accord with the human's understanding of motion. In recent years, the development of VR technology has provided new ideas for prototype animation. The latest VR devices allow users to move freely in the 3D space. AnimVR allows players to draw animations freely in the virtual space while supporting the hand-controlled virtual camera to shoot animated scenes. But AnimVR does not support skeleton models, and can only draw frame by frame animation.

3. Approach
Animation editing in an immersive interactive environment is very different from traditional GUI software. In an immersive environment, the user cannot directly see the controlling devices he is using, but instead operates two handles and some buttons on the handle, limiting the number of input terminals for the user. But the process of using content creation software such as animation is complicated, and traditional tools often have a lot of buttons and shortcuts to improve efficiency. Based on this situation, our work proposes a set of 3D virtual interaction interface, which makes use of the natural interaction characteristics of VR technology to implement the animation function with low operational complexity.

The 3D virtual interactive interface we propose is rendered in the virtual world. This 3D interactive interface is similar to the graphical user interface of traditional software. The user understands the current software information through the interactive interface and interacts with the system through buttons, scroll bars and so on. In the immersive environment, the 3D character animation production process is divided into two parts: keyframe posing and interpolation transition. This paper designed a series of auxiliary control objects as the interactive channel between the player's body movements and animation production. Edit character animations in the most intuitive way.

3.1. Interaction Framework
Human-computer interaction in immersive environments is very different from traditional computer applications, and our interaction framework is designed to provide users with a free and simple experience. On the one hand, the user's field of view is completely filled with computer-rendered graphics, and the 360-degree space around the user can present information and interactive elements. At the same time, VR equipment brings extra depth space to the user, which greatly expands the dimension of interaction design. On the other hand, users will be limited by physical constraints in the actual interaction process. During the interaction, the user always holds the controller with both hands, unable to use traditional input tools such as keyboard and mouse. This is a big challenge for animation production.

According to chu A’s test results [16], the user experience is most comfortable in an immersive environment with the user's perspective in the range of about 30 degrees to the lower 15 degrees to 50 degrees, so we set up a series of graphical interfaces in the virtual space around this range to show information about the status and data. The environment provides the user with 6 degrees of
freedom(6DOF) of manipulation, and we consider the design advantages of free movement as well as the user's physical exertion. Therefore, interactive graphic elements, such as buttons, scrollbars and so on, are mostly located between -30 degrees and -55 degrees, because it is within this range that the user can move the controller with the least effort (see Figure 2).

**Figure 2.** The interactive interface design (left), the horizontal range of the user interface (middle), and the vertical range of the user interface (right).

We added two additional display interfaces for the two controllers, which are mainly responsible for handling current user action information, such as function menus that are being executed, recall/redo buttons, etc., which are always in the most prominent position around the controller so that the user can easily notice important information.

### 3.2. Scene Object Control

In normal 3D content creation software, one or more Windows show the 3D scene being edited. Users need to change the viewport view frequently during the editing process to understand the special structure of 3D content. Window movement is usually accomplished by a combination of mouse and keyboard operations. Scene observation is frequently operated during the production of prototype animation. The user can enable scene observation by touching the scene observation.

After entering the scene observation mode, users press the trigger of the right controller to move in space to shift the world root position of the scene. Scene rotation is completed through the coordination of two control controllers. The left control handle presses down to determine the rotation axis, and the right control handle moves in space to make the scene rotate accordingly. Similarly, after the left handle determines the zoom center, the right handle pushes and pulls to scale the scene.

Users can also control all the objects in the scene through the similar interactive method. Compared with traditional 3D software, our work further simplifies the selection process. The user points to the target object and clicks the controller button to select it. Then, the target object can be translated, rotated and scaled by dragging the controller in space. For articulated skeleton objects, the virtual skeleton will be automatically displayed after the user selects the character, and the user can directly use the handle to drag the virtual skeleton like controlling a doll to pose the character. This intuitive control can greatly reduce the user’s scene editing time (see Figure 3).

**Figure 3.** Illustration of our approach transforming the scene. Left: drag the controller to translate the scene. Middle: two controllers combine the rotating scene. Right: scale the scene with the left hand as the center point.
3.3. Space-time Trajectory Animation
Traditionally, the trajectory animation of 3D objects is represented by spline curves. The user first determines several nodes in the space and then adjusts the node tangent to refine the trajectory. However, this method cannot draw 3D curves directly in 3D space, because traditional input devices only provide two-dimensional spatial data input, which leads to a curve constrained on a 2D plane in 3D space. As a result, the artist needs to change the angle of the viewport to adjust the spline curve frequently. Our work supports the controller handle to provide 6 degrees of freedom (6DOF) spatial coordinate input equivalent to reality. Drawing curves under this line can restore the drawing plan of the user to the greatest extent.

A space-time trajectory is a collection of points in 3D space. Each point represents the position of the trajectory at a particular point in time. Space-time trajectories not only describe the position information of the object movement but also describes the change of the speed of the object movement. Our work implements a space-time trajectory system based on natural user interface, allowing users to use the controller directly draw a curve in the virtual space, the space and drawing speed information such as records in the object of this curve, the motion curve was applied to any object can create a motion animation for the object (see Figure 4).

![Figure 4. Animation by hand dragging(left) and simplified timeline function (right)](image)

Users can draw space-time trajectories in 3D space for any object, and the drawing process will be recorded on the timeline. We design an intuitive rendering control system. The left controller is responsible for selecting the recording starting point, starting recording, canceling the previous drawing results and other process-control functions. By pressing the trigger, the user can draw a trajectory, which can be further refined after the drawing is completed. Our method avoids any parameterized curve generation method. The artist does not need to master the definition and modification knowledge of the spline curve, but only relies on the drawing experience in real life to deliver the object motion, which can improve efficiency as well.

3.4. Hand-control Loop Animation
The character animation of articulated mesh is also generated based on keyframe interpolation. Traditional methods cannot handle the transition between keyframes naturally. For example, in the process of limb movement, the upper and lower limbs rotate joints through instantaneous muscle contraction, which is affected by biological tension and inertia, and its motion track is full of explosive force and uncertainty. However, the current process of joint rotation methods can either be simple linear motion or formulaic acceleration/deceleration motion. If we want to deliver more accurate and natural motions, we need to add more keyframes and more complex transition control, which is not consistent with our basic understanding of "body movement". When we use body gestures to represent a character motion, the body movements conducted through our brain can express it precisely. We are inspired by this and apply it to our work (see Figure 5).
We introduce a key-frame interpolation control system which allows the user to control the transition between key-frames by hand motion. When the hand-control interpolation function is activated, a control scrollbar will appear on the main display interface. The user first edits different posture of the role, which can be inserted into any position of the scrollbar. When the animation recording starts, the user pulls the scrollbar with the right controller to interpolate the recording posture of the character between different key-frame. In this way, the transition velocity can be recorded accurately by the user's hand movement. The system is suitable for interpolation control of loop animation or ping-pong animation.

4. Implementation

We implemented the prototype animation production scheme proposed in this paper with the Unity engine. Unity is a cross-platform 2D/3D game engine developed by Unity Technology, and is widely used as a comprehensive creation tool for architectural visualization, games, real-time 3D animation and other types of interactive content. Unity contains a script control system that allows animation functions to be developed while providing realistic rendering effects. Our work implements a basic immersive natural interaction system where users interact with scene objects and UI elements via controllers by a ray or spatial contact. Simplifying the use of a timeline resulting in a clearer and controllable animation recording process. A series of auxiliary control modules are developed to accelerate the efficiency of animation production.

4.1. Architecture design

We have optimized the architecture of traditional animation production software, simplifying it into three modules: control, scene object and recording/playing. The scene object module exists in the virtual space, and any visible 3d entity can be edited and animated. The control system consists of controllers and various keyframe control modules, which together drive the motion of scene objects. Recording and playing are responsible for recording the position of the current object. Therefore, the animation production process of our work is simplified as follows: edit each animation control module, start recording, use controllers to animate scene objects, or operate auxiliary control module to drive scene objects to move, end recording.

4.2. User Interface

To reduce the learning cost for general users, our work integrated the basic interaction elements of the traditional GUI interface in terms of user interfaces, such as buttons, scrollbars and other interactive elements, while we made some optimization for the immersion environment. First of all, we unified the style of UI elements and adopted the combination of a strong border and low transparency, considering that it is difficult for users to carry out precise point selection operations in VR environment. An intelligent selection system was implemented to filter the point selection results to avoid the time cost caused by users’ misoperation. At the same time, the overall atmosphere of the environment is dark and soft, which can enhance the user’s visual experience and enable them to work in VR space for as long as possible (see Figure 6).
Figure 6. We chose the method of combination of remote ray selection and close contact selection to avoid frequent movement of users.

5. Evaluation
The goal of our work is to improve the efficiency of prototype animation through natural interaction interfaces. Therefore, in the actual design process, we need reasonable evaluation schemes to determine which method is intuitive and can improve efficiency. Our work uses two quantifiable variables to evaluate interaction efficiency: the average operating time required to complete an interaction and the length of the interaction-operation-sequence (IOS). The operating time is the duration taken by the user from performing the first interaction to the program feeding back the results of the interaction. An interaction-operation-sequence is the sequence of all the interactions required to complete an interaction. In general, the shorter the length of the interaction, the more efficient the interaction. The length of interaction-operation-sequence is affected by the input device, interaction design and other aspects. The length of IOS of complex tools such as animation modeling software is long, because their editing system contains a large number of functions, and the mouse and keyboard have a limited number of keys, so the interaction designer maps different functions through multiple sequence combinations.

5.1. Scene Object Control
Editing objects in a scene is a fundamental feature of all 3D content creation tools. Animators need to constantly change the Angle of view and modify the position, rotation and scale of objects during the animation process. We invited two professional animators and two non-professional testers to adjust.

Table 1. For each basic operation, we will compare the average operation time and corresponding interaction-operation-sequence (IOS) between the traditional method and our method. From the table, our method takes less time on average and has a cleaner IOS. For novices, our approach is even more significant in improving interaction efficiency.

| operation | user type | average duration | IOS                  |
|-----------|-----------|------------------|----------------------|
|           |           | ours  | traditional       | ours             | traditional           |
| observe   | expert    | 4.5s  | 4.7s | walk+aim           | mouse wheel click + alt + mouse move |
|           | novice    | 5.5s  | 7s  |                       |                         |
| translate | expert    | 2.5s  | 14.8s | click+drag          | Key w + mouse click + mouse move |
|           | novice    | 2.6s  | 1min50s |                       |                         |
| posing    | expert    | 30s   | 58.8s | click+drag          | Observe IOS + translate IOS |
|           | novice    | 43s   | 7min52s |                       |                         |

In general, the shorter the length of the interaction, the more efficient the interaction. The length of interaction-operation-sequence is affected by the input device, interaction design and other aspects. The length of IOS of complex tools such as animation modeling software is long, because their editing system contains a large number of functions, and the mouse and keyboard have a limited number of keys, so the interaction designer maps different functions through multiple sequence combinations.

For professional animators, they have been very skilled in the traditional way, so they can achieve the specified function quickly in both ways, and the time is basically the same. However, for non-expert testers, the combination of keyboard and mouse view adjustment method is not proficient and takes a lot of time. With our approach, they directly apply the experience of observing and controlling objects in real life (see Table 1).
5.2. Path Animation
The traditional approach of making curve trajectory animation must rely on the accurate control of the tangent value of the node by the bezier curve object, while the complex curve node control is difficult for beginners to master. We invited two groups of testers, skilled 3d animators and testers without experience in using computer software, to conduct a comparative test between the traditional scheme (Maya2014) and our approach. The object is the irregular curved motion of a small ball in space. The test results show that skilled 3d animators using our method can also significantly improve the speed of track animation production. On the other hand, non-professional testers can hardly master the traditional method of trajectory animation, but they can make the curve trajectory animation with our method in a relatively short time. The test results show that our scheme can greatly improve the efficiency of animation production, and greatly reduce the threshold of animation production, in line with the usage of prototype animation. Table 2 shows the average time of path animation production using our method and the traditional method respectively, and it can be seen that our method greatly reduces the production time. In addition, beginners were able to achieve the desired effect using our method, but were unable to master the traditional production process during the test (see Table 2).

Table 2. Average time spent in trajectory animation using our method and traditional method.

|           | Expert | Novice |
|-----------|--------|--------|
| Ours      | 34s    | 48.5s  |
| Traditional | 363s   | Unable |

5.3. Loop animation interpolation control
We designed a production scene of birds flapping their wings. In the course of wing flapping, the joints of birds are affected by instantaneous muscle force. Traditional methods need to add a lot of keyframe control manually. We invited two testers, skilled 3d animators and testers without animation production experience, to compare the traditional solution (Maya2014) with our method. The test result is similar to the test result of curve trajectory animation: professional animators use our method to improve the efficiency significantly, while non-professional testers cannot quickly grasp the traditional production method, and our method only needs to be learned quickly to deliver the test result. In table 3, the left shows that our method can effectively improve the editing speed of loop animation and enable beginners to grasp the production method of loop animation quickly (see Table 3).

Table 3. Average time spent in loop animation using our method and traditional method.

|           | Expert | Novice |
|-----------|--------|--------|
| Ours      | 144.5s | 172.3s |
| Traditional | 185s   | Unable |

6. Conclusion
We propose an immersive prototype animation production method. Through an in-depth analysis of VR environment and interaction patterns, we designed a set of interactive methods based on the immersive environment, allowing users to edit 3D animation through intuitive body movements. The results show that our method is friendly to both professional and amateur animators, who can quickly create prototype animations in a short time and meet the requirements of expressive force and production speed of prototype animations in the creative stage. We hope that our approach can explore new ways of the prototyping animation process.

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