Group-Based Expert Walkthroughs: How Immersive Technologies Can Facilitate the Collaborative Authoring of Character Animation

Ye Pan*
Disney Research

Kenny Mitchell†
Disney Research
Edinburgh Napier University

ABSTRACT

Immersive technologies have increasingly attracted the attention of the computer animation community in search of more intuitive and effective alternatives to the current sophisticated 2D interfaces. The higher affordances offered by 3D interaction, as well as the enhanced spatial understanding have the potential to improve the animators' task, which is tremendously skill intensive and time-consuming. We explore the capabilities provided by our PoseMMR, multiple users posing and animating characters in a mixed reality (MR) environment, animation via group-based expert walkthroughs. We demonstrated our system can facilitate immersive posing, animation editing, version control and collaboration. We provide a set of guidelines and discussed the benefits and potential of immersive technologies for our future animation toolsets.

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality; Human-centered computing—Human computer interaction (HCI)—Interactive systems and tools—User interface toolkits

1 INTRODUCTION

Character animation is widely used in filmmaking and game production; however, it is a complex and time-consuming process. This is especially true for key-frame based animation, with 2DoF mouse interfaces on 2D screens [6,16]. Alternatively, motion capture systems or performance-based animation were developed to overcome intrinsic limitations of 2D interfaces. However, the drawbacks of motion capture are that the physiology of performer limits the possible motions, and it requires expensive equipment, large performance spaces, skilled actors, and laborious post-processing steps [22]. Additionally, the rapid development of virtual reality (VR) technology allowed artists, filmmakers and other media producers start to explore virtual reality filmmaking and its place in the future of storytelling. But animators are, however, facing big challenges, when it comes to 360 degree and interactive VR. The old, established rules of filmmaking do not apply for VR films and important techniques of cinematography and editing must be completely rethought.

Professionals are increasingly interested into the development of immersive technologies, e.g., for articulating and animating characters: PoseVR [32], developed by the Walt Disney Animation Studios, is a recent example in this direction. As reviewed in the next section, a few VR based tools have been developed, but applications aimed at posing and animating CG characters are rare, and these systems are almost exclusively limited to a single user. However, as with creating animated content in VR, directorial and artistic reviews usually carried out with the director "in VR" using a headset, with other artists watching from "outside VR" on a 2D monitor. This resulted in a large perceptual disconnect between what the director and artists would see and subsequent difficulties in communicating notes in an environment where perspective matters a great deal.

We present the PoseMMR system which combines existing technologies of collaborative MR and character animation editing - making it possible for any number of artists and directors to enter an experience together and review the content in MR; or cooperating to adjust the pose of a shared 3D character. Building on the first-generation of VR tools, PoseMMR expands the functions with the direct input from in-house animators. In MR users can interact with the shared real world and the virtual world simultaneously, where spatial cues are provided, and that natural collaboration is facilitated. We also addressed policies to automatically merge and solve concurrent editing conflicts.

We evaluated PoseMMR as a novel approach for authoring character animation. We conducted four group-based expert walkthroughs with domain experts who have about 10 years of experience in the animation industry. We looked at several aspects (Immersive experience, user interface, collaboration etc.), while they collaboratively work with poseable rigs in a MR environment. We explored how to expand our current workflows while also showing the benefits and potential of MR for our future animation toolsets.

2 RELATED WORK

2.1 3D Character Posing & Animation

Today, the most common way to create 3D animated stories is to use high-end, key-frame-based animation software such as Maya, 3ds Max or Blender, with normal 2DoF mouse interfaces on 2D screens [6, 16]. The most time-consuming part of character animation is 3D character posing. By investigating posing further, researchers observed that the selection of body parts appears to constitute the largest part of the posing task [21]. Their interface combines a mouse with the Leap Motion device to provide 3D input, and found that users preferred the Leap Motion over the mouse as a 3D gestural input device. The Leap Motion drastically decreased the number of required operations and the task completion time, especially for novice users [21]. Alternatively, Held et al. [19] present a system for producing 3D animations using physical objects (i.e., puppets) as 3D input.

Recently, consumer VR head-mounted displays are now becoming widely available. This new medium enables 6DoF room-sized tracking for the HMD and both controllers, giving the user the freedom to animate 3D characters from different perspectives. The stereoscopic view of the HMD further supports the depth perception [36]. These features indicate that immersive technologies might have the potential to actually change the traditional animation process. A variety of tools letting animators create in VR, though the majority are currently developed for a single user and focused on VR experience, such as, AnimationVR [38], Facebook Quill [33], Tvori [37]. Some applications support multiple users, but often not aim for animating rigged characters, namely, Penrose Maestro [3]. Perhaps the most related previous display work to ours is PoseVR [32], which also targeted at posable rig, with the direct input of Disney animators. Inspired by these recently developed tools, we developed PoseMMR supporting multiple users animate characters with additional features in a MR environment. We further

*e-mail: ye.pan@disney.com
†e-mail: k.mitchell2@napier.ac.uk

discussed possibilities for evolving the workflow of CG character animation using immersive technologies.

2.2 Collaborative Mixed Reality

MR, as introduced by Milgram and Kishino [25], describes the blending of physical and virtual objects on a single display. Virtual objects are rendered on top of a video see-through display which creates the illusion as if they were situated in the same physical space [13]. A wide variety of collaborative mixed reality applications have been developed, ranges from online education, distributed work and training as well as entertainment [2, 7, 10]. However, few applications currently exist in the field of character animation.

MR technologies provide unique capabilities beyond the limits of the physical world. Being in a 3D environment enables a person to use their natural ability for spatial interaction. Also, VR and augmented reality (AR) environments seem to naturally support collaboration as they provide the means to create a shared environment where collaborators have a sense of each other's presence [27, 28]. Billinghurst and Kato pointed out that collaboration can especially benefit from AR environments, as they can decrease the cognitive and functional load on the user [4]. Another possibility is through a multi-scale MR collaboration, which utilizes the capability of VR to supports a multi-scale collaborative virtual environment (MCVE) and extends it to the real world using AR as shown by earlier research [5].

For example, Piumsomboon et al. [30] proposed a Mini-Me system and evaluated the system in two collaborative scenarios: an asymmetric remote expert in VR assisting a local worker in AR, and a symmetric collaboration in urban planning. They found that the presence of the MiniMe significantly improved Social Presence and the overall experience of MR collaboration. Additionally, they further proposed a multi-scale MR collaboration between the Giant, a local AR user, and the Miniature, a remote VR user [31]. They also provided design recommendations: a shoulder mounted camera view, while a view frustum with a complimentary avatar is a good visualization for the Miniature virtual representation.

Previous work (e.g. [29]) showed unique capabilities of collaborative MR, whereby in particular AR environments can provide the means to facilitate the natural communication and coordination between users [12, 18, 23]. We aim to grow the existing knowledge and demonstrate the potential of collaborative MR as a tool to pose and animate CG characters.

2.3 Synchronized Collaborative Animation Editing

The use of version control is a well-established practice in a variety of fields, especially for text-based documents, with commercial tools such as SVN or GitHub for code. For images, Chen et al. [9] have built a prototype system upon GIMP, an open source image editor, and demonstrate its effectiveness through formative user study and comparisons with alternative revision control systems. For 3D models, Dobos [11] et al. proposed 3D Diff, that supports differencing and merging of 3D models. For 3D animation, George et al. [24] proposed a novel 3-way difference, merging and conflict resolution techniques. Each of these is designed for a specific data type. Christian et al. [34] further presented a system for real-time collaborative game level editing.

Immersive technologies enables users to explore content whose physics are only limited by our creativity. Xia et al. [39] present Spacetime, a scene editing tool, built from the ground up to explore three novel interaction concepts: the Container, which objectifies space and time to situate interaction in context; Parallel Objects, which reduces the friction of and enables powerful parallel workflows for multi-user interaction; and Avatar Objects, which support natural social interaction while preserving an individual user's sense of agency. It showed how simple alterations of the fundamental conventions could lead to new perspectives of context, objects, and users in the environment, each of which results in a set of novel and powerful interaction techniques.

Build on these past research works, we introduced a synchronized collaborative animation editing approach in the style of cloud-based services such as Google Docs. Animation authors can work concurrently, while viewing others' edits as they are applied. We further discussed merging and conflict resolution techniques.

3 System Design

For the proof-of-concept implementation, we provided each user an AR system, using commercially available AR headsets. These AR systems were then networked, enabling multiple users to work with poseable characters in a shared environment, and interact with each other in a face-to-face arrangement (see Figure 3).

Our system also supports the remote collaboration scenario, where users are physically in separate locations while working together. We provided a gender-matched avatar in generic clothing taken from the Rocketbox Complete Characters HD set to represent the remote user. The avatar was dynamically controlled by using three point tracking (the headset and two hand controllers of the remote user) and inverse kinematics (the VR IK solver from the Final IK plug-in).

3.1 Immersive Posing

Two main approaches exist for controlling kinematics in character posing: inverse kinematics (IK) and forward kinematics (FK). With IK control, limb rotations are computed based on the position of the end effector. In FK control, the limbs are rotated directly. Similar to state-of-the-art animation software (such as Maya and 3ds Max), we include three types of control nodes: FK, IK and global control. While holding the trigger with the VIVE controller touching the node handle (see Figure 1(a) displayed in the wire frame.), animators can grab the object and move or rotate it (Note that pink for IK node which can only be rotated and translated; blue for FK node which can only be rotated; green for global control which can be rotated, translated, and scaled).

3.1.1 Forward Kinematics

Each joint of a character in the chain inherits the motion of its parent joint. Thus, if the character has four joints in a chain, when we rotate the root, the three child joints move based on the rotation of the root. This is useful in many situations; for instance, they are often used for basic arm animation for a character (e.g., see Figure 1(e)). However, it can be tedious and difficult to work with for other types of animation, particularly when animating the legs of a character walking or jumping.

3.1.2 Inverse Kinematics

The characters then set up with IK, using FullBodyBipedIK, LookAtIK, and FBBIKHeadEffector etc. from the Final IK plugin. Final IK is not a part of our tool and can be interchanged with any other IK solution. This enables the creation of more complex animations, as it reduces the number of objects that need to be animated (e.g., See Figure 1(c)) .

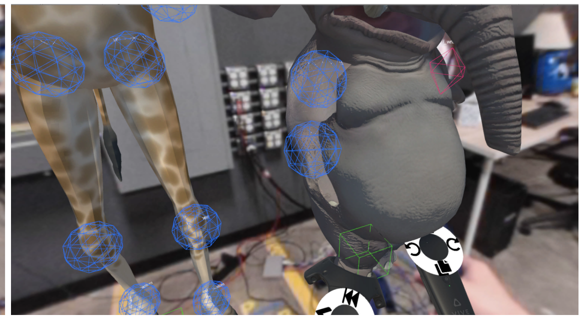
3.1.3 Master Control

We also created a selectable control to animate the position and the rotation of the character, and then group all of the parts of the character together so that it can be moved easily or scaled in the scene (e.g., Figure 1(b)).

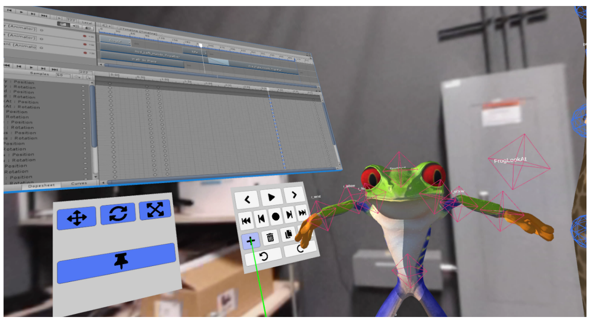
3.2 Animation Editing

Consulting frequently with our in-house animators, we created additional animation editing functions without leaving the 3D environment, including setting keyframes after posing the character, saving

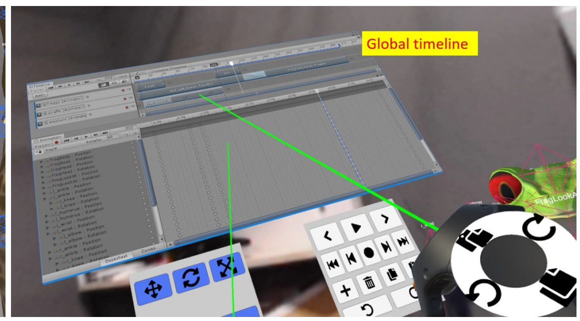
(a) Labels for three types of control nodes and the function layout of the controllers.



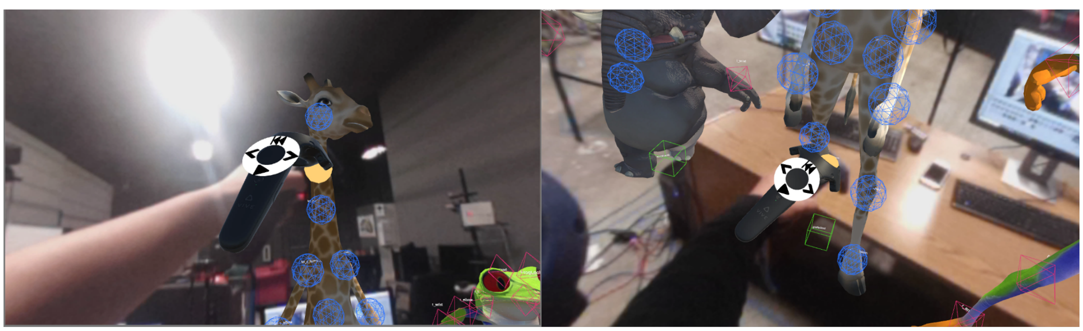
(b) Scaling the character to be full size human scale, or hand held doll size, or indeed gigantic using global control.



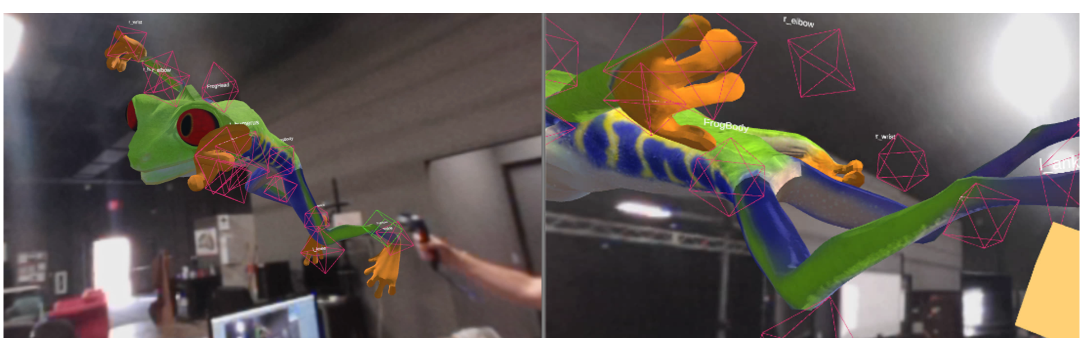
(c) Updating gaze direction of the frog using IK and key all items in the current frame.



(d) When pointing the controller to the timeline window, the pointer is displayed, and allows the user to move, smooth, scale, and delete animation clips.



(e) Two users collaboratively are adjusting the pose of the giraffe using forward kinematics. Left: one operator poses the upper body. Right: the other poses the lower body.



(f) Two users walking around the character and viewing it from different perspectives.

Figure 1: Various screenshots captured from the first-person views of users in PoseMMR

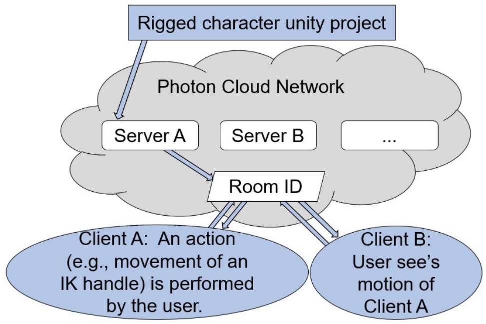


Figure 2: Networking diagram for character posing and animation using photon networking asset tool in Unity 3D.

the recording of the movements into an animation clip, reviewing the content in the shared environment.

3.2.1 Keyframe Animation

A keyframe records the pose of a character at a point in time on the timeline (see Figure 1(c)). When two keyframes are set for an attribute at different points in time, we interpolate the value between the two keyframes on the timeline, and the result is an animation.

We created the timeline window in MR, thus the user does not have to switch back to the desktop workflow for viewport navigation or timeline editing. The user interacts with the timeline by using a pointer cursor. When pointing the controller to the timeline window, a green color direction indicator will be displayed.

- Select the animation clip from the global timeline where they want to place a keyframe on, by pointing to the timeline window and pull the trigger.

- Move the current frame in the timeline to frame where they want to insert new keyframes or edit existing keyframes by dragging the timeline marker. The updated keys are represented on the timeline by a thin blue vertical line. Also, the touchpads of the controllers are used for easy-access commands (see Figure 1(a)), such as, play animation, return one frame, go forward one frame etc. It allows the user to be more focused on the posing and animation process when there is no need to interact with more sophisticated editing tools like the timeline window.

- Copy, paste, and delete keyframes functions are presented on the timeline window.

3.2.2 Motion-Path Animation

In order to further take advantage of the spatial awareness of immersive technologies, user can create a motion path in 3D space by grabbing the global control of a character and press the record button. The recording of the movements is saved into an animation clip.

3.2.3 Animation Layer

Animation layers separate the keyframe data applied to objects in the scene so that users can create variations of animations reviewed in 3D space, blend different animations (such as motion captured or pre-generated animations) together for a higher level of control, or organize the animated parts of an animation. Figure 1(d) shows that the global timeline allows the user to move, scale, delete and composition animation clips.

3.3 Networking Animation Poses

Networking in the prototype implementation of PoseMMR was enabled by Photon Unity Networking (PUN), and aural communication was enabled by Photon Voice. Figure 2 shows the networking diagram of the character posing environment developed in Unity 3D. The photon server links the environment to one of its internal servers. Once connected, clients can connect to different rooms through the room id. After a connection is established, the photon network monitors movement change in the environment so that everyone's motion is visible to all. To update a pose in the environment can be described in five stages:

- An action (e.g., movement of a control node) is performed by the user.

- The action is submitted to the photon cloud network servers.

- Server validates actions from clients and calculates new VR environment according to the updated action.

- The change propagates to all the clients.

- All the clients are able to see the motion.

3.4 Live Collaborative Animation Editing

With the ability to simultaneously edit animation poses on a shared live immersive view, the potential of conflicts among collaborators' changes arises and these must be addressed formally to maintain a coherent animation repository.

3.4.1 Synchronized Live Editing

In synchronized live edit mode, any changes by one artist are immediately visible to the other.

Any edit to any pose controller, e.g. an IK handle, gets immediately broadcast to the other participants, such that every participant sees the live effects of everyone's input.

If artists make simultaneous changes to the same IK handle, the following alternatives are possible:

- The system maintains a 'master' artist, whose changes overrides those made by others. Only conflicting edits result in any artists' changes being overridden by the master artist. The master artist selection state is maintained on the server, and can be switched at any point through mutual agreement.

- The system maintains a most recently changed rule, where the most recently change received at the server overrides those made previously among all participants. Everyone sees the results of most recent conflicting edits, and an agreement is reached interactively and responsively.

- The system calculates an average pose (position, orientation, scale) of the controller handle between the set of collaborator inputs and of course the corresponding effect on the character's mesh. Everyone sees the results of the average of most recent conflicting edits, and an agreement is reached mutually.

In both cases, the IK controller handle is visually flagged (e.g. red color) to denote a concurrent edit has taken place.

Shared edits to a given animation's keyframe are not committed until all conflicts are resolved.

Collaborative animation editing can process upon IK controllers, joints, mesh vertices including blend weights, and other forms of deformation controllers, and the above live simultaneous editing rules hold.

Figure 3: Experimental PoseMMR setup with two collaborators in the same space sharing edits of an animation rig.

3.4.2 Isolation of Simultaneous Edits

An IK controller may be formed non-globally to affect only sub parts of the character, e.g. a left hand IK controller only affects the pose of the left arm up to the left shoulder. In this case edits to the left hand isolated from the right hand and can be made entirely simultaneously without conflict. Generally, an effector mask for each poseable controller can locally partition the characters' deformable mesh subset to permit non-conflicting pose edits between distinct controllers.

3.4.3 Layered editing conflicts

Layered animations are key to a fully expressive character motion design, and each layer made edited independently without data conflict. However, a dependent layer in an animation edited by one artist, may affect the visible character pose for another artist editing a separate layer. In this case, each artist may flag other layers as fixed until they wish to update ('pull') the latest server version.

3.4.4 Shared space physical conflicts

In augmented reality or virtual reality with users in same space, but working in different timelines or layers a visual cue for potential physical collisions between participants can also be provided.

3.4.5 Concurrent Alternative Timeframes

In a live immersive setting, one editor can be working in a different timeframe from the other(s). For example, one person is examing the character's form in slow motion, while the other is viewing a single frame. The system flags whenever a common keyframe edit is in conflict, when that frame is current to the artist's view, even when they are viewing/editing in different remote/local timeframes.

4 Group-based Expert Walkthroughs

PoseMMR was evaluated with 3D character animation experts. The goals of the study were to determine the use cases, to identify problems, and to discuss new features for future versions. In designing a controlled experiment we had to make several choices - we only focused on multiuser mixed reality posing and animation aspect in this study and looked at the co-located scenario instead of the remote scenario; because the representation of the self-avatar for the remote user could affect the results [27, 28], which is an interesting avenue to explore, but beyond the scope of this paper.

4.1 Participants

Eight (four pairs) domain experts participated in the walkthroughs. The experts have had about 10 years of experience in the animation industry on average. They typically use Maya for 3D character animation. Their experience with immersive technologies were rated on a five-point Likert scale (1 to 5), where lower scores indicated non-experts ($Median = 1$).

4.2 Procedure & Task

Each session lasted approximately one hour and was structured in three parts, including an introduction (10 min), three use cases (30 min), and a group discussion (20 min).

The session started with participants filling out a brief demographic survey and a consent form, followed by an introduction to PoseMMR. We showed the participants the interface's basic controls (e.g., grab the 3D character, manipulate any part of its body by putting it different poses using FK or IK control, set keyframes, and playback the animation etc.). The participants were then asked to try on the HMD and adjusted the headset until well-fitted. After that, participants had a training session to get familiar with the interface.

In the subsequent session, three character animation tasks were performed using PoseMMR. In the first use case, experts were provided three characters in a T-pose (a frog, a giraffe and an elephant, standing upright with both arms outstretched horizontally). They were asked to collaboratively manipulate characters' poses in 3D using FK, and create animation clips. In the second use case, similar to the first, except that instead of using FK, IK was used. In the last use case, experts were provided with a pre-generated motion capture clips. They were asked to collaboratively edit the animation clips.

This actual walkthrough was concluded with a group discussion. The specific characteristics of PoseMMR were discussed, focusing on the efficiency of animation processes, effect of immersive technologies, and the usefulness of the setting for collaboration.

4.3 Results

We applied qualitative content analysis with an inductive category development to analyze the transcribed data (videos and notes from experimenters). The high level themes identified refer to the immersive posing, animation editing, version control and collaboration.

4.3.1 Immersive experience

Participants were all agreed that the PoseMMR offered them a familiar, simpler, and more efficient way to produce 3D content (e.g.,see Figure 1(f)). Several positive comments regarding the room-sized 3D tracking, 6DoF controllers, and stereoscopic HMD are as follows:

> *"Typical mouse-and-monitor setups require animators to perform several actions to complete even simple tasks, such as, countless wasted clicks and seconds pile up when switching between camera views, tools, and windows. It can speed things up."*
>
> *"I'm just moving around a little, looking at poses from different angles, intuitively, and thinking about the performance of what does this pose represents."*
>
> *"I'm just in it. I could get a 3D version."*

In terms of the used AR devices, the participants stated that they would prefer an AR environment compared to a VR environment in this collocated scenario - AR interfaces are very conducive to real world collaboration because the groupware support can be kept simple and left mostly to social protocols.

4.3.2 User Interface

From the observations of all groups it appears that participants get comfortable with the PoseMMR and start to concentrate on the tasks, almost immediately after the training session.

For 3D character posing, because many animators take different routes to create a pose, suggestions for ways of interacting the model were many and varied, and most animators will end up using a mix of these manipulation styles for different rigs. For example, one participant said:

> *"I like the precision of the FK, but I wish it could also stretch and squash."*

Another participant mentioned:

> *"For different characters, with rigid muscle and long leg, etc, like giraffes, I like working in the FK mode. But with the frog being such a squishy character, I like being able to stretch him."*

Pure FK "Screwdriver" mode gives animators direct control of a bone's rotation, only affecting the translation and rotation of that bone's children. It's especially useful when applying the axis isolation, and on high-detail jobs like the fingers. IK will preserve the location of the target as closely as possible unless a bone within the IK chain is directly selected for manipulation. One of constructive comments was the following:

> *"I wish I can also switch modes, like toggle switches. I can move things around and get the pose generally working, and then do refinement - just rotate the hand, and not have the rest of the arm moving at all. "*

Another participant suggested to improve the flexibility of the keyframe function:

> *"To set a keyframe, I'd like to be able to select multiple items, rather than all items, e.g., a character with the body stays still for the entire sequence but the head moves up and down. Since the body is not moving, it can be displayed in this scene using only one keyframe, while multiple keyframes are used to animate the head."*

For motion path creating, several participants reported the position and orientation of the moving object can easily be seen and understood in virtual 3D space:

> *"I can see the motion paths. My character has traveled."*

One participant suggested additional path editing tools, such as, position control points (e.g., [17, 26]) or smoothing function is needed.

> *"To me, live puppeting never worked so well, better to use keyframe. Because my hands are not so steady, but I know some people have really stable hands."*

4.3.3 Changing size & Perspective

Several participants highlighted the shrink/grow aspects of the PoseMMR:

> *"I like being able to change the size of the character. To get it big, manipulate certain aspects and take it small again. Like now, I am seeing the long shot of the same character, but I would like to get closer to it when I'm working on the different body parts."*

While creating the frog animation swimming along a spline curve, another interesting comment was the following:

> *"If you can scale that path, take whole swimming path and scale it up big, so it will swim around the whole ceiling above us; or shirk it down the little thing will swim around on the top of the desk."*

4.3.4 Collaboration

We observed that no groups used verbal communication during character posing process. Some participants didn't feel a need to constantly update the partner verbally on progress, as a quick glance was sufficient for sharing the partner's work; while others want to focus on their characters without distractions from the outside. One participant directly commented:

> *"For posing a character, people usually work individually. But going back and forth and reviewing it together would be very useful."*

In the words of another participant:

> *"I like it - be available for multiple people in different spaces to animate together. E.g., I do the frog, and the second person does the elephant."*

However, the conversations began naturally, when they move to animation review process. We frequently observed deictic references such as "this" or "that" along with pointing, instead of giving detailed instructions and specific descriptions to ensure the other partner could clearly understand their thoughts. For example, one participant said:

> *"I will try adding one (keyframe) in the middle here."*

PoseMMR visually shared participants' behaviors and task objects, thus they can refer quickly and easily to these objects combining gestures and deictic expressions.

4.3.5 Mixing Motion Capture & Keyframes

Motion capture data does not apply to characters of different sizes or proportions than the actor (e.g., the resulting motions have the feet skating and the hands failing to reach the object) [15]. Participants can use PoseMMR to adapt these motion capture data with additional spatial information.

More interestingly, one participant suggested combining motion capture technology with the keyframe method in PoseMMR:

> *"Is it possible to allow me to step inside of a character and do the mocap for it for a section, and step out of it and edit it."*

Throughout the years professional animators have used mirrors to capture facial expressions, even the use of full body mirrors to capture all of the characters movement to assist them in their animation (e.g., [20]). The mirror is a very important tool for animators.

> *"Mocap might be a different way of looking at mirror."*

PoseMMR can add this feature just using three extra VIVE trackers: Full body motion capturing can be achieved with one tracker on each foot, one around their waist, a headset and a pair of controllers [14].

5 DISCUSSION

5.1 Applications of PoseMMR

5.1.1 VR filmmaking

VR filmmaking methods are very different from the traditional film production methods [35], e.g., blocking is the positioning and movement of the characters to tell the story in visual terms. For VR films, instead of moving and positioning the camera, the characters have to move more dynamically toward the camera (stand up and down or move forward, backward, left, and right like theater blocking does) [8]. PoseMMR is designed for VR film producers and directors to produce more effective films in this medium. Different from previous VR tools (e.g., [32]), PoseMMR provides filmmakers with multiuser AR experience where they could be better integrated into daily working routines.

5.1.2 3D Character Posing & Animation

PoseMMR can accelerate the process of 3D character posing using AR to providing animators with a shared 3D experience. Firstly, it is more direct to create 3D contents in a 3D space than in a 2D interfaces. Secondly, by projecting three dimensions onto two, computer monitors distort our best indicators of depth. This forces us to rely on objects' scales and interposition to plot out our z axis. While the final shot will be flattened upon rendering, giving an animator a realistic sense of depth at all times prevents the mistakes that can easily occur from relying upon one camera.

5.1.3 Animation Reviewing

PoseMMR is cross platform sequence management and network playback tool, thus it allows multiple users to enter a MR experience together and review the animation. Reviews are a social process that requires the input of many people, including but not limited to the director. In a traditional process, participants can easily take control of playback with the keyboard, such as fast forward, rewind, and frame skip. We replicated this environment in PoseMMR. Playback is controlled synchronized across all clients, meaning all reviewers inhabit the same story at the same playback state. In addition, collaborative AR support face-to-face discussion during animation review process. For remote collaboration scenario, we used self-avatars to representing the remote people, thus the local users could see where the remote person might be, and where the remote person might be pointing at etc.

5.1.4 Physical simulation & Robotic Character Animation Mockup

As an example of a single user tool: *Actuator* [1] leverages real-time physics and tracked devices into the entire character performance pipeline. Starting with a 3D model, it can be rigged by spatially drawing physical joint primitives, and then effect a physically based puppet with direct manipulation controls or as an alternative one may create animation sequences using the real-time physics as a secondary motion for realistic follow-through effects.

In PoseMMR, physical simulation effects can also be cooperatively authored, for example the effects of gravity can be incorporated into the virtual character or objects' behaviours. In a more advanced embodiment a virtual fluid simulation could be cooperatively edited for later playback/performance. In the context of volumetric physical character simulations such as *Actuator*, cooperative puppetry with visible secondary motions or each artist recording motions into compositions with physical responses may be edited together simultaneously.

PoseMMR can also be used for prototyping robots roaming around the theme parks and physically interacting like an animated character. The virtual elements may combine in augmented reality with physical elements. For example, laying out ride buildings on a physical scaled map on a table with virtual characters can move while avoiding obstacles, or posing virtual character elements of the upper digital body, given a physical lower actual robot body. In some cases, the physical parts are replicated in each collaborator's local space.

5.2 Future research directions

Further work includes the provision of 3D visualisations of the animation controllers and their key-framed behavior over time sequences, e.g. with in-situ visual traces of animation curves plotted in 3D in the VR space. Such visual representation of the underlying abstract animation data, may provide a direct manipulation approach to fine scale motion curve edits.

6 Conclusion

We present PoseMMR, a system that leverages the strengths of AR environments. The stereoscopic 3D perception in room-scale space together with 6DoF input devices provide a natural interface for 3D character animation. PoseMMR also allows multiple users to simultaneously review the same scene in shared environment over the internet. The AR environments further allow for natural communication and coordination between collaborators.

The results of group-based expert walkthroughs demonstrated that PoseMMR can facilitate variety of integral elements of an animation pipeline catering to the unique needs of narrative VR production: 3D character posing, motion path generating, animation reviewing and collaboration. Based on these findings, we provided guidelines on cooperative simultaneous editing and designing tools for character animation using immersive technologies. In addition, we identified research directions to further facilitate the 3D character animation.

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