Smart Motion Trails for Animating in VR

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***Abstract*—The artistic crafting of 3D animations by designers is a complex and iterative process. While classical animation tools have brought significant improvements in creating and manipulating shapes over time, most approaches rely on classical 2D input devices to create 3D contents. With the advent of virtual reality technologies and their ability to dive the users in their 3D worlds and to precisely track devices in 6 dimensions (position and orientation), a number of VR creative tools have emerged such as Quill, AnimVR, Tvori, Tiltbrush or MasterPieceVR. While these tools provide intuitive means to directly design in the 3D space by exploiting both the 6D tracking capacity of the hand devices and the stereoscopic perception by the user, the animation capacities or such tools remain strongly limited, and often reproduce classical 2D manipulators in VR. In this work, we propose the design of smart interactive manipulators which leverage on the specificity of VR to animate poly-articulated animations. We then perform a user study to evaluate the benefits of such manipulators over traditional 2D tools for three groups of users: beginner, intermediate, and professional artists. We build on this user to discuss how smart tools (*e.g.* using a variety of AI techniques) can be coupled with VR technologies to improve content creation.**

***Index Terms*—computer animation, VR, user evaluation**

I. Introduction

Given the importance that animations play in the spectators perception and reception of a visual storytelling experience, the design of complex animated contents has always been a challenging and time consuming task for artists. The authoring of animations in professional software essentially relies on keyframing+interpolation techniques: a number of poses are created (the keyframes) and various parameterized interpolation techniques link the keyframes together. Animators generally rely on a clean-and-lean principle which tends to minimize the number of keyframes, and exploit the parameters of the interpolation techniques to craft the desired motion. In the case of curve interpolations such as Bézier or Spline representations, animators indirectly control the curves in 2D panels, by manipulating the individual tangents on each degree of freedom to obtain the desired animation.

Improving such classical animation techniques then requires to assist the artists in the posing task and in the interpolation task. Many techniques have been proposed in the literature (from early inverse kinematics to ease posing of poly articulated figures [1], to more recent approaches using line of action constraints [2], or space-time sketching [3], [4]). Contributions such as tangent space optimization [5] follow this trend by favoring direct control of the interpolation, intuitively grabbing and manipulating the interpolation curves, and automatically optimizing the individual positional/rotational tangents to fit the desired manipulation.

Most of these improvements have been designed for traditional desktop animation tools. A recent trend, with the technical improvement in VR technologies, is to use virtual reality as an authoring environment to create and lay out contents. Multiple tools[1] (Quill, AnimVR, Tvori, Tiltbrush or MasterPieceVR,...) have been developed which build on VR specificities such as direct control of 6 degrees of freedom through devices in each hand, and stereo visualization which helps to resolve some depth ambiguities therefore avoiding multiple camera manipulations or multiple orthographic views that were necessary with desktop tools. VR tools were also used in filmmaking contexts with success as in *The lion King* movie [2], and *Ready Player One* movie that exploits VR to place the actors and cameras [3]. Such tools were essentially used for layout tasks, while more complex stages such as the animation of characters were still performed on traditional desktop tools.

The animation capacities of VR content creation tools have only been recently developed, driven by the higher affordances they offer and improved spatial understanding. For example, the MARUI plugin for Maya [4] offers all the traditional animation capacities by simply duplicating the 2D interface in VR and enabling direct 3D/6D manipulations. Other tools have also ported animation features to VR (Dreams, Quill, Tvori, AnimVR, MasterpieceVR) by directly transposing the features, or adapting them to the specificities of VR. While there is a demonstrated practice through the design and usage of these tools, the question we raise in this work is how can smarter tools, driven by AI/optimization techniques, rely on the VR capacities to improve 3D content creation.

Some prior work has demonstrated the benefits of animating in VR compared to animating with 2D interfaces [6], [7]. Researchers evaluated and demonstrated the capacity of VR techniques to handle tasks such as rigging (placing articulations and bones in meshes), skinning (designing the influence of bones on the mesh) and animating. Despite the displayed benefits of VR over traditional interfaces, the experiments proposed by the authors were limited in multiple ways: (i) first the tasks were performed on simplistic models and involved simplistic animations, which are not relevant of the real-life cases in production studios, (ii) second the implemented features only enabled the control of the poses through keyframes placements but did not offer optimized control on the interpolation technique in contrast with classical animation techniques where artists spend significant time in fine tuning trajectories and (iii) third, the paper transposed

[1]https://www.roadtovr.com/vr-painting-drawing-modeling-animation-art-tools-quest-pc/
[2]https://ai.umich.edu/blog-posts/how-disneys-the-lion-king-became-a-pioneer-in-the-use-of-virtual-reality/
[3]https://www.youtube.com/watch?v=W_6vTqIyPmM
[4]https://www.marui-plugin.com/

classical animation widgets (gizmos) in VR without necessarily thinking about their adaptation to VR specificities (natural affordances, 6D manipulation, improved spatial perception), finally (iv) the authors have separated the posing task into multiple subtasks, by separating a keyframing task where users were asked to pose a complex character on only one frame, interpolation task, and path manipulation task. Each was performed on simple and different objects, in an unlimited time which is not entirely representative of the work of an animator in a production environment.

The purpose of our paper is twofold: first to evaluate the benefits of VR techniques for complex animation tasks such as the authoring of character animations, by extending the scope of existing contributions such as [6], [7], and second to show how VR can benefit from smarter interaction tools using optimization techniques. To this end, we (i) propose a user evaluation of a complex and full animation posing task in a limited time, involving a 17 bones character animated over a sequence of 54 frames, comparing a traditional animation pipeline, with two different VR versions (traditional tools implemented in VR and a and a more sophisticated version with smart optimization-driven tools to manipulate interpolation and bones trajectories) for three categories of users: beginners, intermediate and expert animators, and (ii) propose a second user evaluation to precisely highlight the benefits of smart tools in VR animation tasks.

We formulated our experimental study in a way to verify following hypothesis: (i) VR interfaces improve the productivity of animators in complex animation tasks (keyframing plus interpolation), and (ii) smarter manipulation tools in VR are preferred to traditional tools adapted to VR. We build our evaluation by comparing a traditional animation tool (Unity) with VRTist, an open-source VR animation tool developed by Ubisoft. We selected the Unity animation tool (which is not the mainstream tool for animators) to avoid a strong bias in comparing a tool completely new (VRTist) with a mainstream tool on which users have hundreds of hours of training. We extended the VRTist with dedicated animation features, in particular by implementing dedicated trajectory manipulation tools such as tangent-controlled motion trails. A motion trail is a 3D curve representing an object's position and orientation over time. Over this motion trail, we implemented the tangent space optimization (**TO**) approach [5] so that the designers could directly manipulate the trajectories. Details on the system used for the experiments are presented in section 3, experiments are reported in section 4 and 5 before making recommendations and concluding in section 6.

II. Related work

Virtual Reality technologies have already shown a strong application potential, not only as a device to improve immersion in narratives but also as a mean to better learn and create. Well known examples include physical education learning where VR shows improvements in spatial orientation and distance estimation [8], or productivity increase in spherical videos editing tasks [9]. In the following, and in line with our contribution, we will present recent contributions focusing on the creative potential of VR techniques.

A. VR animation tools in the industry

A number of VR animation applications have been developed such as Tvori [10] or Quill [11]. Both propose keyframe-based animation systems. Quill is more sketch-oriented, while Tvori is more 3D object oriented. Tvori proposed animation tools using features such as curve manipulation. In Tvori, curves are available only for rigid and non-articulated objects and not for character posing. Furthermore, Tvori enables character animation using inverse kinematics. A constraint system is added that enables to lock some parts of the body (feet on ground/hand on table) while manipulating the animation.

B. Assessing benefits of VR animation tools

In [12] researchers proposed a Unity plugin using VR to animate objects and characters. They proposed some functionalities to keep an environment close to what traditional software proposed. Authors implemented a simplified timeline with blocks of animation instead of keyframes and proposed traditional 3D gizmos together with direct manipulation with VR controllers, as well as inverse kinematics. A current issue in VR selection is the number of actions necessary to move around the scene and to select and interact with entities. Here, the tool implements a local representation table which is a local copy of selected object or character, right next to the operator. It allows the animator to easily select/animate object's components independently from their root position and rotation. Animators can also incarnate the character and directly record the motion. The proposed work only followed a loose user evaluation through interviews with four expert animators. Main feedback was the ease of prototype, at the expense of preciseness.

Galvane *et al.* [13] proposed a VR tool to assist the movie previsualization task. The tool was designed to create storyboards and was reported to be satisfying to use and efficient for the task. The content produced with the tool was however evaluated as insufficient to be more than only previsualization material due to limitations in the features implemented and reported lack of intuitiveness. Regarding animation features, authors implemented a first proof of concept where designers could manipulate the character rig using inverse kinematics techniques, and could perform animation through the control of poses only (and not control on the interpolation techniques). No visual gizmos were added to manipulate the character. The user evaluation relied on a NASA-TLX evaluation (10 volunteers mixing novices and experts) as well as on a Technology Acceptance Model (TAM) evaluation (with 3 experts), yet objective performance measures were not performed.

More formal evaluations were conducted by Lamberti *et al.* [7] who designed four classes of experiments representative of simple animation tasks, and compared the traditional Blender interface and with a dedicated VR interface.

- **Posing task:** participants were asked to place a crocodile mesh composed of 17 bones in a pose as close as possible to a given target pose. The pose had to be done for only one frame.

- **Keyframing task:** participants were asked to place a car at the right position and orientation, but also to animate the car's color along time.
- **Performance task:** participants were given the ability to directly control joints with their 6D controllers (incarnation). Alike a motion capture setup, the selected joints will follow the translations and rotation of VR controllers. Participants were asked to animate a three joint eagle shaped mesh using **IK** and reproduce a given animation.
- **Path task:** participants were asked to place two keyframes and create a trajectory of two spheres to match a target trajectory.
- **Interpolation task:** participants were asked to manipulate a bouncing ball, placing 6 keyframes and manipulating the tangents in an editor graph in VR to fit with a target trajectory.

Results showed that the time to reproduce an animation in VR was lower than in native Blender interface. The experiment did not report a significant difference in animation accuracy between VR and Blender.

C. Discussion

The work in the literature closest to our own is [7]. Authors performed a separation of classical tasks for animators. Indeed, animators who perform the posing task usually start from a given animatic (represented by a target animation, pose, interpolation etc) and animate their character or object to fit as much as possible the animatic. The partition of this task in multiple smaller tasks with different objects may not be representative of a classical animation task as conducted by professionals. Indeed, the posing task with a complex character composed of 17 bones is very interesting but limited in the choice to do only one pose in one frame.Further, the path task is reduced to a simple primitive (sphere) animation. Despite this simplicity, the results in favor of VR should generalize to more complex objects such as characters with individual joint manipulations. Similarly, the interpolation task have been proven possible with their F-Curve tool in VR but using a simple object with no kinematic involved. To get a better understanding of the possible improvement of VR over traditional interfaces, it would be preferable to conduct and evaluate these tasks together with a posing task on more complex animations with a complicated character, and this is the objective of our work.

III. System overview

To perform our experiments, we proposed to compare the traditional Unity environment which provides manipulators for character animation, and a VR character animation environment that we developed above the VRTist tool[5]. We could have used a more artist-oriented traditional tool (Maya, Motion Builder, 3DSmax, Blender) rather than Unity, yet we wanted to avoid a too strong bias of intermediate and expert users towards these tools. Indeed, in the Unity interface, the interactions were not exactly the same than what expert and intermediate users are used to. Unity still proposed the same 3D gizmos than in artist-oriented tools and the shortcuts are almost the same. But the whole interface takes a little more adaptation time for intermediate and experts, who generally rely on strong habits.

VRTist is an open-source VR authoring environment developed by Ubisoft scene layout tasks in VR. A large range of features is proposed such as camera/light placement and recording, VR video editing, exporting, or rapid sketching of volumetric shapes.

[5]https://github.com/irisa-invictus/vrtist

A. Unity manipulation features

We introduce the features of the Unity animating tools.

1) Timeline and animation clips: . Unity implements animations using animation clips. An animation clip contains all the keyframes and interpolation curves related to a specific object. Keyframe manipulation can also be performed in the animation clip editor, where users can add, remove or setup auto keyframe. Classical auto keyframe mechanisms are also available in Unity (keyframes are placed automatically by the system as the user manipulates advances in time). It is also possible to display the animation curve and edit interpolations curves (*e.g.* using tangents with Bézier curves).

2) Custom experiment window: During the experiment users had a custom window to control the features: play/pause the animation or use a slider to skip through the animation, display the reference animation as a ghost (translucent character), overlay the ghost to original position to refine the animation, and finally a control to stop the process.

B. VR manipulation features

This section describes the VR features we implemented to animate characters by building on the VRtist tool. Given the possibility to directly manipulate in 6D with a device, manipulation features are essentially based on forward kinematics (**FK**), inverse kinematics (**IK**) and tangent space optimization (**TO**). Since navigating in menus in VR is also a complex task (compared to standard menus), we followed a general process that consisted in replacing feature selection by triggering visual gizmos directly on the entity (the character to manipulate). In our case, the designer was offered a specific gizmo for **IK**, **FK** and **TO**.

1) Experiment window: As in the Unity traditional interface, users had an interface in VR with the same buttons to start the experiment, generate the ghost, play the animation, move in time and terminate the application.

2) Exploiting **TO***:* Tangent space optimization (**TO**) relies on displaying the temporal trace of an object (or part of an object) trajectory (Fig. 1). By integrating in VRTist the tangent space optimization framework [5], we provided users with the possibility to directly manipulate in VR the trajectory (positions and rotations of a joint). As the user moves a hand device close to a motion trail, the trail is selected and the area of effect (area between two keyframes) is highlighted. As the user grabs the motion trail, the trajectory is deformed following the controller's translation and rotation, while respecting constraints such as **IK** angle limits (see [5] for more details).

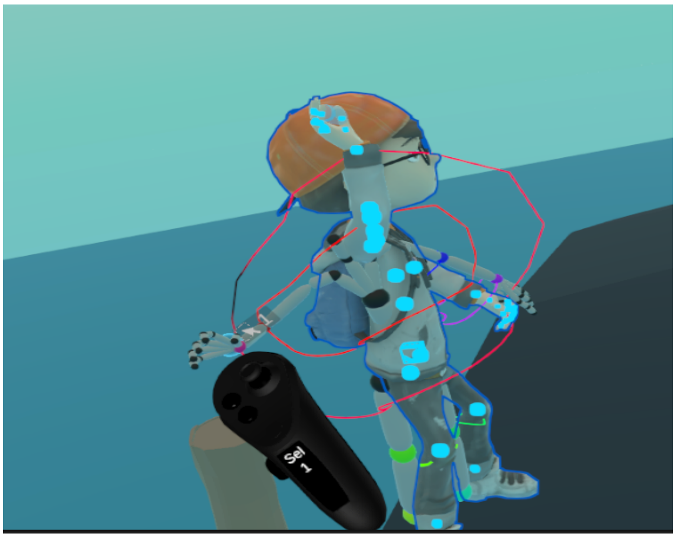


Fig. 1: Tangent optimization manipulation on a character where a user grabs a motion trail to edit the trajectory. The tangents are then optimized to fit the required edit.

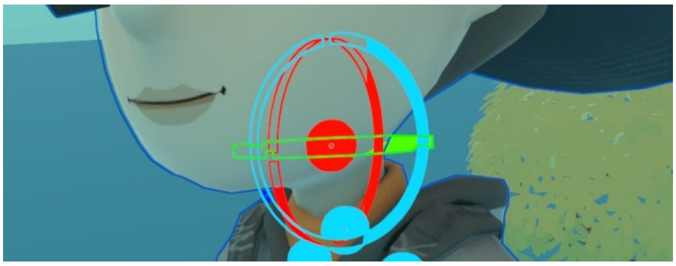


Fig. 2: Rotation gizmos in VR to manipulate joints precisely on one axis.

3) 3D gizmos: Traditional rotation gizmos were also made available in VR (Fig. 2) as the animators still strongly these tools for precise single axis operations.

4) Timeline: To manipulate time and keyframes, a timeline interface (Fig. 3) is available to users. Participants can add or delete keyframes, or activate the autokey frame mode. The interface also allows the interpolation to be modified to allow blocking (no interpolation) or linear interpolation or Bezier curve interpolation. This window also allows to play the animation in play mode and to move through time in the scene.

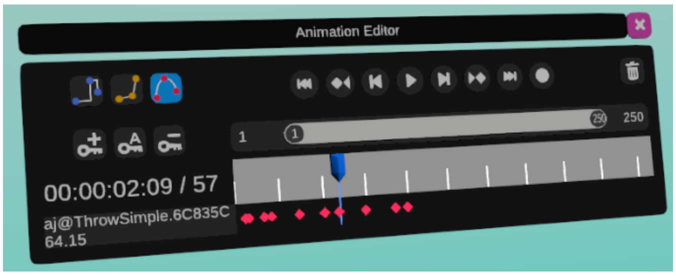


Fig. 3: Timeline in VRTist. Red dots are keyframes positions.

5) Tools menu: A dedicated VR tool menu allows to specifically modify the manipulation mode: forward kinematics (**FK**), inverse kinematics (**IK**) or tangent space optimization (**TO**). The user can also display or not the skeleton of the character at each keyframe. Similarly, the offset section allows to display the skeletons and curves placed in space in order to improve the visualization over time.

IV. Experiment #1

We recruited 14 participants aged between 19 and 51 ($M = 30.1; SD = 8.7$), separated in three groups according to their animations experience. Four participants (three males one female) were animation experts with more than five thousand hour of animating, five participants (five male) were intermediate level, and five were novice. In these three groups the experience in VR was heterogeneous. In the expert group, one was expert in VR which means more than 100 hours using a headset, and three were novice which means less than ten hours. All participants in intermediate group were novice in VR. In beginner group, one was master in VR experience, three were novice and one was medium (more than 10 less than 50 hours).

A. Protocol

For this experiment, participants had to recreate an animation of a complex humanoid character in 15 minutes. The target animation is a character throwing a bottle into a tire. The character has 54 joints all of which can be manipulated. For the sake of the experiment the 3 joints of each finger were not taken into account to avoid to lengthy experiments. The experiment was realized in three parts and the order was drawn randomly. One part was performed on Unity with the traditional animation interface (**TUI**) where the participants had to modify the clip animation by manipulating the joints of the character via the rotation gizmo in the same way as on Blender or Maya. Animation curves of each joint could be edited by changing the tangents in the unity dedicated interface. The traditional VR part (**VRTT** for VR Traditional Tools) offers the same manipulation possibilities than with Unity, which means forward kinematics (**FK**) manipulation through gizmos or direct**FK** manipulation through the 6 Degrees of freedom of the VR controller (like in [12], [7]) and finally the smart VR part (**TO** for tangent optimization) allowed users to manipulate the keyframes and motion curves in **FK** or **IK**.

B. Evaluation criteria

During the evaluation, the software collected an accuracy metric which is expressed as the sum from frame 1 to last edited keyframe K of angular distances between target animation joint j' and participant animation joint j, for all joints but fingers.

$$\forall j, j' \in J, J', Accuracy = \frac{\sum_{i=1}^{K}(\theta(j_i, j_i'))}{K} \qquad (1)$$

where $\theta()$ measures the absolute difference in degrees between two joints. In addition the software collected few crucial quantitative metrics:

- **Number of actions**: Number of primitive actions performed by the user (trigger pressed, grab pressed, right clicks, left clicks etc...)
- **Number of frames with a keyframe**: total number of frame where the participant placed at least one key frame.

To complete this data, a NASA-TLX form was submitted to subjects to collect qualitative data for each step of the evaluation. An additional form was used to collect impressions about the following points:

- **VR Experience**: amount of experience in VR;
- **Animation Experience**: amount of animation experience;
- **Tools rating**: which tool was found the most efficient, easiest to learn, easiest to perform the task, natural, comfortable, satisfying, less tiring and frustrating;
- **Motion sickness**: did the subject feel any VR sickness?
- **VR usage pleasure**: did the subject enjoy using VR?
- **VR efficiency to animate**: does the subject think that VR can be used efficiently as an animation tool?
- **First thought/last thought**: did the subject change his mind about usability of VR as an animation tool after the evaluation?

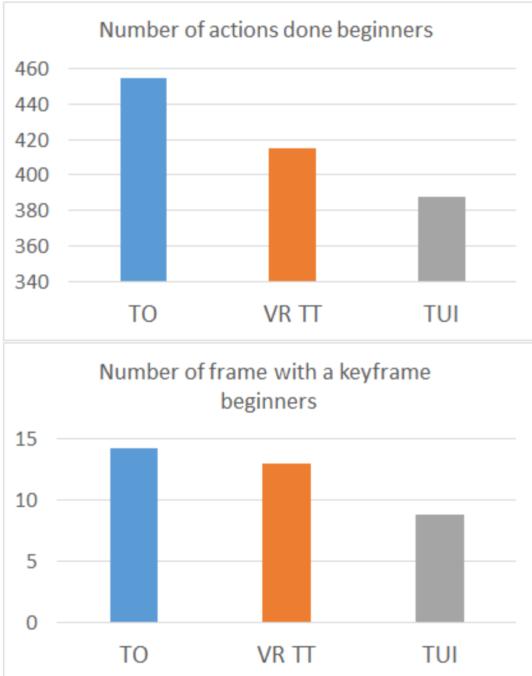


Fig. 4: Number of actions performed by beginners to complete the task, and number of frames with at least one keyframe placed for experiment #1

C. *Results*

For Experiment#1, the results of the users were grouped according to their experience in animation. We report results in terms of how the techniques influenced the accuracy of animated sequence, the number of keyframes placed (as a proxy for productivity), as well as qualitative results.

1) Influence on accuracy.: As found in literature [7], for all three groups, the results in terms of accuracy between traditional VR (**VRTT**) and traditional tools (Unity **TUI**) showed no striking difference. The group with the most difference in accuracy (see Fig. 7) is the professional group where the animation produced on **TUI** was a little more accurate than the animation produced with the traditional VR tools (paired t-test value=0.878 and p-value < 0.05). Over all the joints for all the frames of the animation, the one made on Unity has on average a difference of 21 degree compared to the reference animation. The traditional VR animation has an average difference of 26 degrees. For the rest of the users the difference is even smaller, with one degree difference between the **TUI** and **VRTT** version. However, the most striking difference is between **VRTT** and Tangent Optimization (**TO**). It appears from the data that the smart tools have allowed all groups to be more accurate: in the beginners group, a difference of almost 10 degrees was found in average on all joints when using **TO** (paired t-test=-3.59, p-value < 0.05).

2) Influence on number of keyframes.: For the rest of the quantitative data, several interesting points can be observed. In the figure 4, the group that placed the most keyframes on all three stages is the group of beginners. On average a little more than 14 keyframes were placed with the smart tools, 13 with the VR offering traditional tools, and 9 on the traditional Unity interface. This means that for this group the keyframes placed with **TO** were more accurate than the keyframes placed with **VRTT**. The ratio of angular difference per frame is 1.07. For **VRTT** this ratio is 1.84. For **TUI** this ratio is even greater (2.66).

For the intermediates group (Fig. 5), similarly, the most productive tool in terms of keyframes created is **TO**. However this group was also very productive on Unity (a little more than 12 keyframes for **TO** against a little less than 12 keyframes for **TUI**). In terms of angular difference per frame, values are 1.47 for **TO**, 2.05 for **VRTT** and 1.62 for **TUI**. Similar to the beginners group, the intermediates were more productive and accurate when using the intelligent tools in VR. However, they performed better on Unity than on the traditional VR tools.

For the group of professionals (Fig. 6), they have created very few keyframes compared to the two previous groups. Indeed, on average, the professionals created a little less than 8 keyframes in **TO** against a little more than 5 in **VRTT** and 6.5 in **TUI**. However, they managed to be overall more accurate (Fig. 7). This can be explained by a greater precision on the created poses as well as an more manipulations of the interpolation curves to fit the best with the reference animation.

This further supports our belief that performing a complete posing phase for complex animations (including interpolation) is necessary to properly evaluate the relevance of a VR animation tool. We obtain a ratio of 2.62 for **TO**, 4.80 for **VRTT** and 3.23 for **TUI**. However, one drawback we can note is that for all groups, the use of intelligent tools in VR requires more actions than the traditional interface. As illustrated in the figures 4, 5 and 6 **TO** on average required 481 actions against 430 for **TUI**.

3) Qualitative evaluation: . The qualitative data illustrates the difference in performance among beginners. As shown in Fig. 8(a), the mental load was much higher on **TUI** than in VR (both **VRTT** and **TO**). Surprisingly and identically, beginners found TUI more physically challenging than VR. The level of productivity to validate a pose is also reflected in their responses to the NASA TLX, as in terms of completion time, the **TO** task was not felt to be especially difficult to complete in 15 minutes while the **TUI** task was reported to be difficult to complete in the allotted time.

The accuracy score is also reflected in the responses of the beginner participants, who felt that they did very well on the task in **TO** but not so well on **VRTT** and even worst **TUI**. Indeed, the ratio of success to amount of work is much higher on average in **TO** (2.6) than in **TUI** (0.5). The feeling of stress and discouragement was also much more present in **TUI** (5.1) and **VRTT** (4.2) than in **TO** (2.1). However, regarding the qualitative data (Fig. 8(b)), the results collected during the experiment are not the same as the participants' feelings. Indeed, as shown in the figure, with **TUI**, the mental load was much higher than on the **TO** and a bit higher than **VRTT**. However, as expected, the physical load was perceived as superior in VR by the intermediates.

For the rest, overall VR setup was preferred to **TUI**, noted as less stressful, more efficient to perform the animation in the given time, with participants feeling more successful in recreating the animation for less hard work (except for **VRTT** where participants success feeling is higher in **TUI**). Regarding the responses of professionals to the NASA TLX, the mental load in **TO** was less than with **TUI** but the most demanding task was **VRTT**.

However, as with the intermediate group and as expected, VR was perceived as a little more physically demanding (Fig. 8(c)). The task seemed much more difficult to do in the time allotted on **TUI** than in VR (5.5 in **TO** versus 5.95 in **VRTT** and 7.3 with **TUI**). For the feeling of success, the results are in agreement with those of accuracy Fig. 7. Indeed, the professionals estimate that they have done better in **TO** with a value of 4.5. For the **VRTT** task they estimate their success at only 3.5 which is less than **TUI** which obtained a score of 4.2. The task that gave them the most stress and difficulty was the **VRTT** task with a very high score of 8.2. **TO** was once again the most appreciated (6.5 and **TUI** 7).

V. Experiment #2

The purpose of the second experiment is to better understand which tools proposed in experiment #1 were the major reason of the good performance in animating in VR. This remains a preliminary study due to the low number of participants, and results must be considered with care. Yet first elements seem to display interesting results. Four participants aged between 19 and 30 ($M = 25.25; SD = 3.9$) were recruited, composed of two groups based on their animation skills and experience. Two were complete beginners in animation and two were intermediate with more than two hundred hours of animating. All participants were male aged between 19 and 33 years old. About VR experience, one in each group had a medium experience in VR (*i.e.* between 10 and 50 hours of VR). The last in the intermediate group was a confirmed VR user (+100 hours). The last in the beginners group was also a VR novice.

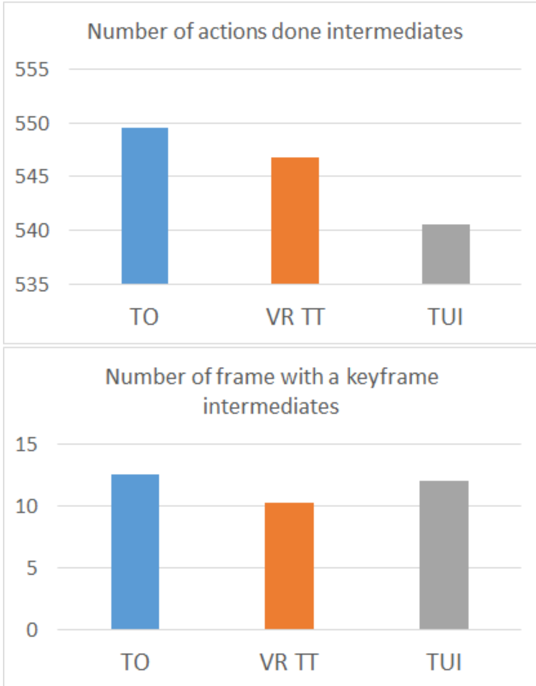


Fig. 5: Number of actions performed by intermediates and number of frames with at least one keyframe placed for experiment #1

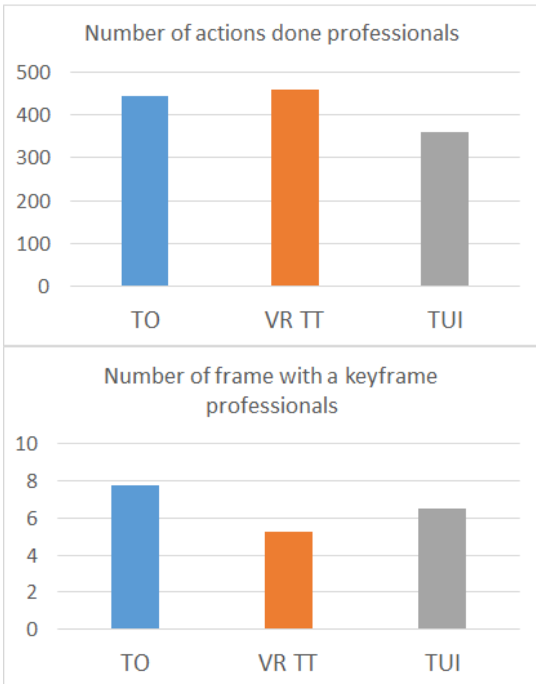


Fig. 6: Number of actions performed by professionals and number of frames with at least one keyframe placed for experiment #1

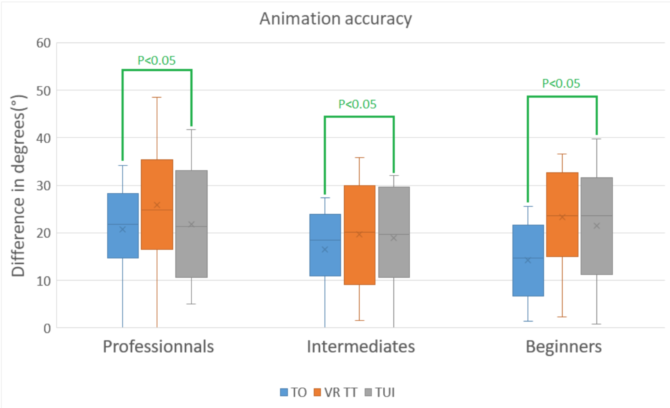


Fig. 7: Animation accuracy for each group of participant (Beginners/Intermediates/Professionals) **VRTT** vs **TUI**, in Experiment #1.

A. Protocol

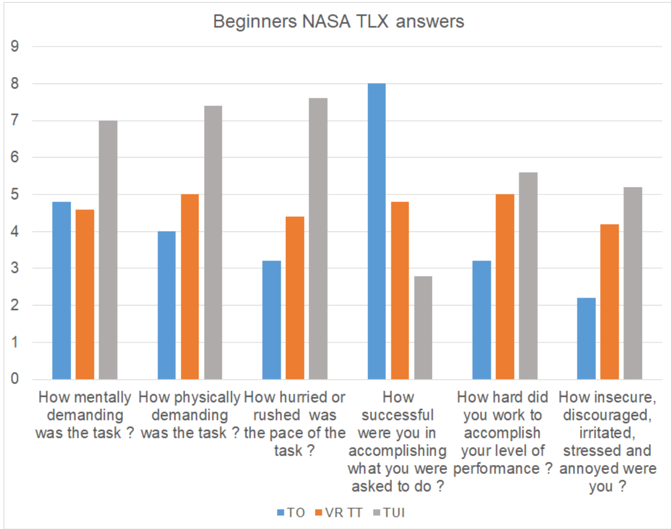
For the second experiment, there was no limitation of time. Participants had four different steps to validate. All tasks consisted in manipulating a character arm through a wall with a crack, avoiding as much as possible collisions. There were two different setups, an easy mode and a hard mode (Fig. 9) where the wall gap was more complicated with more obstacles. In the easiest mode, three keyframes were already placed and in the hard mode five keyframes were placed. To manipulate the arm joints, different tools were allowed, the same as in experiment #1 in VR. Subjects could manipulate joints with the 3D gizmo to rotate the joints in forward kinematics (**FK**) precisely, they could also grab the joints in **FK** (only rotation) or in inverse kinematics (**IK**) (which impacts both translation and rotation). If they used these tools, they necessarily had to add keyframes to edit the animation trajectory in a way to avoid collisions. With the tangent optimization (**TO**), participants could directly grab the trajectory and adjust it to avoid wall collisions.

The first two tasks were drawn randomly. Both were run with the easiest setup. One task had only enabled the use of **TO**, the other only allowed to use **IKFK**. The purpose of these two tasks was to give some training time to the user for each tool. The third and last task were not drawn randomly. Third task was also with the easy setup but with all tools enabled. Participants could choose which tool to manipulate the arm joints position rotation or interpolation. The last task was with the hardest setup. As in the third task, participants had the choice of the tool.

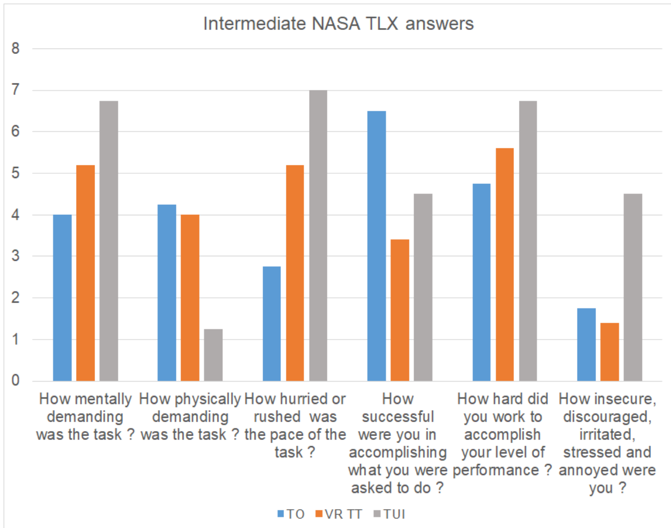
B. Evaluation criteria

As in the previous experiment, there were two types of data collected, quantitative and qualitative. The software collected:

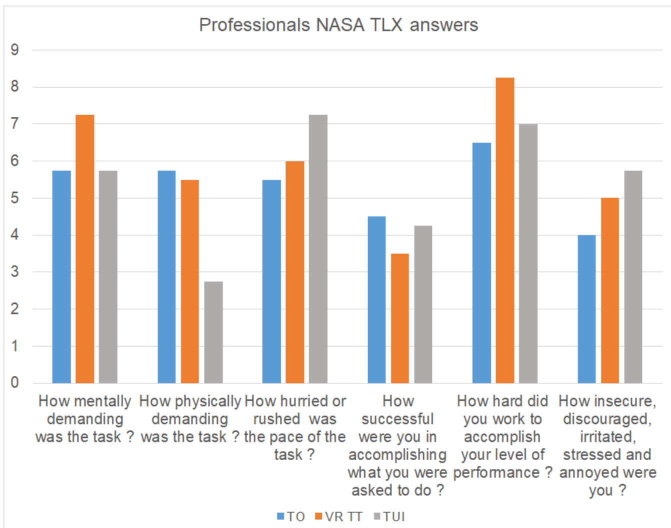
- **Completion time**: how long did it take to participants to perform the tasks?
- **Collisions**: how many collisions were encountered with the wall during the tasks?
- **IK interactions**: the number of interactions to animate the character with **IK**.



(a) Beginner answers



(b) Intermediate answers



(c) Professional answers

Fig. 8: Nasa TLX answers for each group of participants (Beginners/Intermediates/Professionals), experiment #1

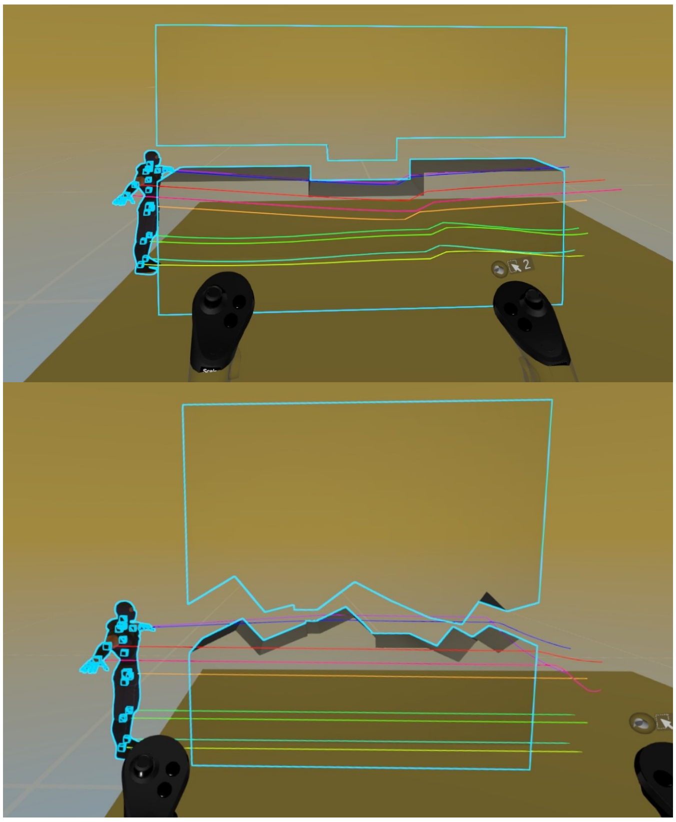


Fig. 9: Experiment #2 consisted in animating a character's arm through a gap in a wall while avoiding collisions. Two level of difficulties were designed (easy setup (top) *vs.* hard setup (bottom)).

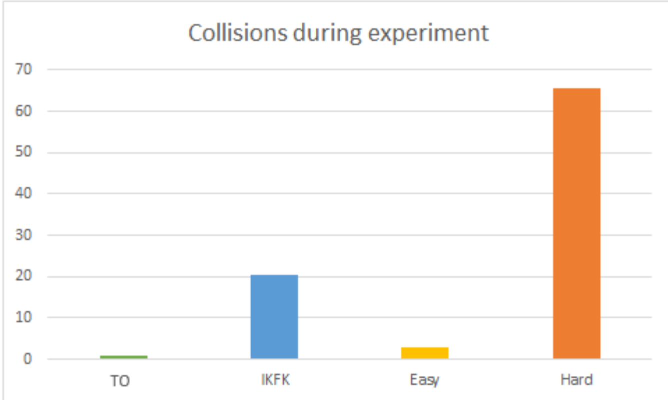


Fig. 10: Collision during the experiment #2 between arm joints and walls for each task (**TO**/ **IKFK** / Easy / Hard), experiment #2.

- **FK interactions**: the number of interactions to animate the character with **FK**.
- **TO interactions**: the number of interactions to modify the trajectory between pre-placed key frames.
- **Amount keyframes**: the total number of keyframes placed by the designed for the shoulder, forearm and hand.

And the form submitted to the participants collected:

- **Preferred tool**: which tool did the participants prefer for the easy and hard setups?
- **Motion trails usage in main software (traditional)**: if participants used motion trails in their main software such as Blender or Maya to display joints trajectory.
- **Motion trails accuracy and usability in their main software (traditional)**. If participants answered "no" to the previous question, would they now use it after they tried it in the experiment.
- **TO and motion trails accuracy and usability in VR**: do participants think that **TO**/motion trails are accurate and good tools in VR?

C. Results

The first interesting point is the completion time (Fig. 11). For the first two tasks (training) the completion time is almost equivalent. With the third task (the setup being the same), we see that completion times are different, which shows the benefit of the training for the participants. Participants took 40 seconds less than the first two tasks with similar tools. These data are interesting to cross with the figure 10. Indeed, we can see that during the **TO** task, the participants made much less collisions than with the **IKFK** for the same completion time. Another interesting point is that for the task where the participants had the choice in the easy setup, they all used the motion trail to validate the task (Fig. 12). However, they made a few more collisions than on the motion trail task. This could be explained by the fact that they went faster (Fig. 11).

The analysis of the data of the difficult task is interesting. Three people out of four preferred to use the **TO** to perform this task (Fig. 12). The last person was the only one who preferred to manipulate the character in **IK** rather than via **TO**. The person had to add numerous keyframes to edit the animation trajectory. However, this took him much longer to complete, taking 222 seconds longer than the average of the other three participants. On accuracy, he also made many more collisions. The tendency of the **IK** tool to be less accurate is confirmed here again.

For quantitative data, participants were given a questionnaire to complete. Of the two with intermediate experience in animation, neither used **TO** on their main software. One thought they could be useful for traditional interfaces and one thought not. However, both agreed that they are useful and effective in VR.

VI. Discussion

A form was given to all participants of both experiences concerning VR in general and as an animation tool. No one hated using VR, three people liked it a little and the rest enjoyed it. Concerning the idea of performing animation in VR, three people were skeptical about its practical use, and they all changed their mind. No one changed their mind in the other direction.

Overall VR was found to be more productive and accurate than TUI for all groups of participants. The biggest difference between the two interfaces was logically found in the beginners, proving the superior affordance of VR. The NASA

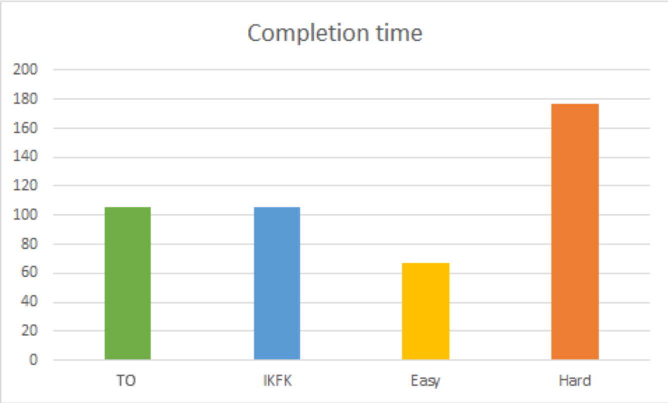


Fig. 11: Completion time for the experiment #2 for all tasks (**TO** / **IKFK** / Easy / Hard).

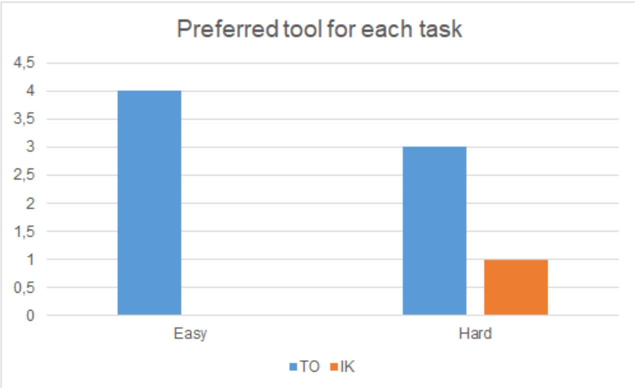


Fig. 12: Preferred tool for both tasks in experiment #2

TLX showed a greater interest and satisfaction in using VR to animate. This is combined with an increased sense of accomplishment for less work effort.

The results of experiment #2 provide a better understanding of the findings of experiment #1 and the difference with the results obtained by [7]. Indeed, the use of VR with traditional tools like rotation gizmos or even the manipulation of characters in inverse kinematics (**IK**) and forward kinematics (**FK**) shows an improvement of the completion time. Yet animation created only with these tools made the precision lower or equal to the traditional tools. With tools like tangent optimization (**TO**), it seems we can further improve the completion time, while improving the accuracy of animation. Our studies clearly show the importance of controlling the accuracy of the animation techniques proposed in VR. Smarter tools should therefore be designed in ways to build on the natural affordances of VR, yet need to compensate for the lack of accuracy, especially is professional designers are targeted. None of the participants complained in NASA-TLX form about exhaustion. One expert artist was already using VR as a content creation tool and has stated to be used to work and spend a long time in VR. She admitted that the back to reality is a bit tiring at first yet became used to it without any drawback.

VII. Limitations and Future Work

Our work illustrated the capabilities of VR in performing complex animations and demonstrated the benefits of smart interaction techniques. This enabled us to draw some general guidelines, typically showing how the lack of accuracy in VR can be compensated with smarter interactive tools. With a focus on animation character posing, there is still a lot of work that can improve animation creation in VR, by exploring how more evolved AI-driven approaches can assist the designers. This requires both to develop creative-driven AI tools, for which techniques such as deep-learning remain problematic due to the limited availability of dedicated professionally animated dataset, and to design ways to interweave such automated approaches with natural interactions, that would improve accuracy and naturalness of interfaces.

VIII. Acknowledgement

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References

[1] A. Aristidou, J. Lasenby, Y. Chrysanthou, and A. Shamir, "Inverse kinematics techniques in computer graphics: A survey," in *Computer graphics forum*, vol. 37, no. 6. Wiley Online Library, 2018, pp. 35–58.
[2] M. Guay, M.-P. Cani, and R. Ronfard, "The line of action: an intuitive interface for expressive character posing," *ACM Transactions on Graphics (TOG)*, vol. 32, no. 6, pp. 1–8, 2013.
[3] B. Choi, R. B. i Ribera, J. P. Lewis, Y. Seol, S. Hong, H. Eom, S. Jung, and J. Noh, "Sketchimo: sketch-based motion editing for articulated characters," *ACM Transactions on Graphics (TOG)*, vol. 35, no. 4, pp. 1–12, 2016.
[4] M. Guay, R. Ronfard, M. Gleicher, and M.-P. Cani, "Space-time sketching of character animation," *ACM Transactions on Graphics (TOG)*, vol. 34, no. 4, pp. 1–10, 2015.
[5] L. Ciccone, C. Öztireli, and R. W. Sumner, "Tangent-space optimization for interactive animation control," *ACM Transactions on Graphics*, vol. 38, no. 4, pp. 1–10, 2019.
[6] A. Cannavo, C. Demartini, L. Morra, and F. Lamberti, "Immersive virtual reality-based interfaces for character animation," *IEEE Access*, vol. 7, pp. 125 463–125 480, 2019.
[7] F. Lamberti, A. Cannavo, and P. Montuschi, "Is Immersive Virtual Reality the Ultimate Interface for 3D Animators?" *Computer*, vol. 53, no. 4, pp. 36–45, apr 2020.
[8] M. Gómez-García, J. M. Trujillo-Torres, I. Aznar-Díaz, and M. P. Cáceres-Reche, "Augment reality and virtual reality for the improvement of spatial competences in physical education," vol. 13, pp. 15–16, 2018.
[9] C. Nguyen, S. DiVerdi, A. Hertzmann, and F. Liu, "Vremiere: In-headset virtual reality video editing," *Conference on Human Factors in Computing Systems - Proceedings*, vol. 2017-May, pp. 5428–5438, 2017.
[10] Tvori VR (version 0.8.1.8122), "Tvori," 2018. [Online]. Available: https://tvori.co/
[11] Quill (version 2.9), "Quill," 2021. [Online]. Available: https://quill.art/
[12] D. Vogel, P. Lubos, and F. Steinicke, "AnimationVR-Interactive Controller-Based Animating in Virtual Reality," *25th IEEE Conference on Virtual Reality and 3D User Interfaces, VR 2018 - Proceedings*, pp. 781–782, 2018.
[13] Q. Galvane, I.-S. Lin, F. Argelaguet, T.-Y. Li, and M. Christie, "Vr as a content creation tool for movie previsualisation," in *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*. IEEE, 2019, pp. 303–311.