MAGES 4.0: Accelerating the world’s transition to medical VR training

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Abstract—In this work, we propose MAGES 4.0, a novel Software Development Kit (SDK) to accelerate the creation of collaborative medical training scenarios in VR/AR. Our solution offers a versatile authoring platform for developers to create medical simulations in a future-proof, low-code environment. MAGES breaks the boundaries between realities since students can collaborate using virtual and augmented reality devices at the same medical scene. With MAGES we provide a solution to the 150-year-old training model which is unable to meet the level of healthcare professionals needed. Our platform incorporates, among others, the following novel advancements: a) 5G edge-cloud remote rendering and physics dissection, b) realistic real-time simulation of organic tissues as soft-bodies, c) a highly realistic cutting and tearing algorithm, d) neural network assessment for user profiling and, e) a VR recorder to record and replay or resume the training simulation from any perspective.

THE METAVERSE is still being defined, both literally and figuratively. Along with it, many questions remain, including “who will build the metaverse and how?” Such questions often rise when we are referring to the metaverse\(^1\) as a massively scaled and interoperable network of real-time rendered 3D virtual worlds, effectively experienced synchronously and persistently by an unlimited number of users. Building such an ecosystem from scratch would require significant effort involving tasks of tremendous complexity, especially if a single tool would be used to create

\(^1\)https://bit.ly/3QEmUdJ
The extended pandemic crisis highlighted the need for effective medical training, along with the inadequacy of the 150-year-old training model. Computational medical science [1] aims to accelerate world’s transition to VR medical training in the metaverse and empower medical professionals to enhance their proficiency and ultimately improve patient outcomes.

To serve the causes above, we present MAGES 4.0, the medical VR industry’s first Software Development Kit that allows rapid prototyping of any shared, collaborative networked medical training in VR, in a fraction of time and cost. It draws its robustness from the 20 years of academic Research & Development, incorporating the latest advancements into a novel medical VR/AR software development kit.

The computational results achieved with MAGES SDK exceed those typically reached by large teams of domain expert developers of similar engines. Being layered on top of existing game engines, such as Unity3D and Unreal Engine (see Fig. 1-Left and 2), it brings a low-code virtual world authoring platform to developers with even a moderate knowledge of these engines. It is thus possible, even for a single developer, to create a full VR medical training simulation.

PREVIOUS WORK

In the past years, a variety of virtual world simulations [2] have been introduced, tailored to particular research problems, most of them presented as proof of concept. A great number of applications have been designed for entertainment-multimedia systems [3], education/training [4], [5], [6], collaboration, Cultural heritage, and medical training [4], [7]. Each simulation has various strengths, but because they were often designed with specific use cases in mind, each is also limited in different ways. Most VR systems provide high-fidelity photorealistic scenes [3], user immersion and presence that allow human-centric interaction in VR [8]. Existing simulation environments are differentiated from the other as they combine VR training functions in various domains, while others, only very few of them [4], provide realistic physics simulations on surfaces with rigid body, soft body, cloth, and fluids. Innovative multi-user virtual environments (VE) [3], [4] provide a great asset in all fields especially realized in the COVID era.

Some VE authoring tools [5], [4] allow reuse/import of content/assets that impacts the tool’s usability and effectiveness, as it enables designers to significantly reduce their effort, and generate custom user-experience that otherwise would be impossible. In that respect, some novel, innovative, and interoperable authoring platforms allow users with non or limited programming knowledge to design a VE fast and easy [4], setting early the basic and essential requirements for the building of the metaverse [2]. In that respect, VR software design patterns method [9] is a research concept with already concrete results that will be utilized in the building process of the next-generation VR training applications for the metaverse.

MAGES 4.0 INNOVATIONS

The MAGES SDK is named after its most unique features:

Multiplayer With GA Interpolation (M): A custom Geometric Algebra (GA) interpolation engine allows up to 300 simultaneous users in the same session of the VE. To the best of our knowledge, this is the highest number of active concurrent users in the same scene, whereas state-of-the-art applications offer only a few tens of concurrent users with only one active and rest being spectators. This remarkable achievement is accomplished by the transmission over the network layer of GA-based representation forms of the VR scene transformation data, which support higher data compression rates. The use of such alternative forms by MAGES reduce the required data that must be sent over the network by up to 33%, whereas the reduced amount of data sent in these forms yield visually better interpolated results, with the overall QoE being sufficient even when the network quality, in terms of bandwidth, seriously deteriorates [10].

Analytics (A): A powerful advanced analytic engine system allows tracking and visualization of the student’s progress. As this feature enables scoring per user action in a simple manner, it provides an easy way for the tutor or the students to quickly inspect and identify the parts of the training where they had great or poor performance.
Figure 1. (Left) The visual scripting editor. (Right) A surgeon with two students performing a collaborative Total Knee Arthroplasty as generated using MAGES, in Unity3D.

Geometric Algebra Deformable Animation, Cutting and Tearing (G): The under-the-hood GA engine used to solve the animation equation is responsible not only for model deformation but for a series of features that exploit it. Specifically, the ability to perform cuts, progressive tears and drills on skinned soft-body meshes is now feasible in real-time, with increased realism suitable for VR immersive applications.

Editor with Action Prototypes (E): An incorporated visual scripting editor along with the prototypes of basic building blocks, called Actions, are used to rapidly accelerate content creation for VR/AR simulations. Based on novel software design patterns [9], this tool enables creation of medical training operations, at a fraction of the time and cost previously needed.

Semantically Annotated Deformable, Soft and Rigid Bodies (S): Towards a highly realistic recreation of a virtual surgery operation, we have designed and developed a particle system, suitable for real-time elasticity simulations of human tissues and organs.

HOW MAGES WORKS IN 5 STEPS

In this section we present the five main steps, a developer should follow, to create a VR training simulation:

1) Design training storyboard: Utilizing our visual scripting editor, developers create the steps of each scenario.

2) Create virtual assets: Gather all the medical 3D content (tools, human anatomy etc.).

3) Author training Actions: Generate the Action scripts using our action prototype design patterns. Developers create programmable actions along with analytics and network behavior using the embedded authoring tools.

4) Build the medical VR training simulation: Build and deploy the executable application to a wide range of supported headsets/platforms, operating systems and computing devices.

5) License the simulation: Optionally connect a MAGES SDK provided cloud management license and analytics server to the training simulation.

ACTION PROTOTYPES

Code reusability and prototyping are two major principles in software architecture. The structure of software systems and the communication between its modules is described through software design patterns. Software design patterns are reusable solutions for common design problems that often occur during software development [11].

Especially in training simulations, developers need to implement highly interactive behaviors for the students to follow. For this reason, we introduce Action prototypes, as novel software design patterns for low-code behavioral tasks in training scenarios. We classified the majority of the physical tasks into programmable and easily extendable code patterns. We implemented basic behaviors like the insertion, removal, usage or
even cognitive behaviors like questions into separate programmable entities. Developers can inherit those entities and develop their own Actions with a few lines of code.

To minimize the need of coding, we developed an authoring tool to automatically generate Action scripts. Developers can create Action scripts by selecting the necessary physical objects for each task (e.g., tools, specific parts of the body) and subsequently the system will automatically generate an Action script. This script contains the basic-default behavior of the particular object, allowing also to easily include additional behavior by mounting extension-scripts.

THE TRAINING SCENEGRAPH

A training scenario contains a number of carefully defined steps, in a sequential or multi-path manner. MAGES lie upon training SceneGraph, a highly dynamic, acyclic graph representing the training scenarios. Each node defines an Action, a specific task to be completed by the trainee.

SceneGraph is not just a static tree, it’s a dynamic graph. An educational scenario can lead to multiple paths according to user’s actions and decisions. To accommodate this need, the training SceneGraph can generate new paths and deviate from its original form while the user explores the training scenario.

To rapidly accelerate the content creation we built a visual scripting authoring tool. This is a low-code system that enables easy authoring of Actions while revealing the scenario from a higher level perspective. The visual scripting editor, consisting of interactive nodes able to be modified by developers, is able to generate a training simulation in a future proof and easy to use graphical environment (see Fig. 1(Left)).

This novel system can create medical simulations eight times faster than without the visual scripting editor.

ANALYTICS EDITOR

User assessment is crucial in medical simulations as students can identify their skills, while teachers can note any difficulties or points of improvement. For this reason we integrated into MAGES an analytics system to assess and track the progress of each individual. In our training scenarios, we are asked from the medical advisors to track specific parameters through the operation. Those can vary from wrong angle during incisions or drilling, to time constrained decisions or even contamination issues.

MAGES features a novel analytics system to configure and present the assessment data. We build an easy to use interface on top of our visual scripting engine that, with minor modifications, enables analytic functionality to our Actions. For this reason, we introduced the scoring factor, a component that tracks data from objects or from the student’s actions. Some of the scoring factors we implemented are velocity scoring factors, to track if a user is moving a fragile object too fast, error collider scoring factors, to check for possible contamination, as well as angle scoring factors to check the proper placement of implants. Custom scoring factors are also supported allowing developers to extend the existing classes and create their own factors. Developers can assign multiple scoring factors in each Action. The final score for each Action is calculated as a weighted average of all assigned scoring factors.

After each simulation, users can visualize their analytics from within the VR/AR environment. Analytic reports are also uploaded automatically to our online portal allowing supervisors and teachers to view their students’ progress. To implement the upload to the portal, developers need to modify just a single API call in the MAGES configuration file.

Figure 2. Developing a Total Knee Arthroplasty with MAGES in Unreal engine.
Figure 3. A student has just dissected the left part of the liver, during a hemihepatectomy operation. MAGES provides a realistic simulation of hand postures when grasping various objects.

AUTOMATIC HAND POSTURES

Interactive virtual characters are nowadays common place in VR/AR applications. Designing a virtual human-like hand which is able to touch and grasp objects with realistic hand and finger adjustments, often trying to imitate the human brain way of reasoning, it’s a matter of necessity. Grasping hand animation itself includes several problematic aspects that make finding a unique solution extremely hard. Especially concerning human-like hands the main challenge is trying to imitate the human-brain way of thinking and replicate the unconscious movements a person makes to grab an object.

Reducing the number of possible grasp movements is fundamental. The applied methodology should also respect the physiology of the human hand [12]. This applies to anatomical joint limits, angle limits due to tendon links between fingers (dynamic constraints) as well as angle limits that force a natural posture.

In MAGES we designed an algorithm for intuitive object grasping with easy configuration an high accuracy mimicking the human way of reasoning. This algorithm is flexible enough to support hand structures having an arbitrary number of fingers and an arbitrary number of phalanges for each finger. Given the hand bones structure, the position of the character and an object, the algorithm finds the most suitable grasping position for the character’s hand on that object. Grasp poses are generated by a combination of a generic grasp movement and a target object the fingers collide with. Movements are stored using only an initial pose and a final pose, so that the algorithm can generate an arbitrary number of interpolations between them. The algorithm runs in real-time without performance issues even with complex objects (see Fig. 3).

To simulate grasp poses, we implemented a procedure that based on a start hand position and on a grasp movement, generates the grasping pose, taking into account the object, by computing the final positions and rotations for all the bones. When the user grabs an object, starting from the root joint of the hand, we interpolate the joints to reach the final pose. If a bone gets in contact with the object it is excluded from the following calculations. This algorithm runs recursively for each joint to reach a firm grip.

BLENDING REALITIES

Virtual worlds should not get limited from the used medium. They should blend with the real world in a discrete way. For this reason, MAGES can populate applications for both virtual and augmented reality headsets without complex configurations and additional work from the developer. We designed the SDK in such a way to enable the collaboration between VR and AR headsets in the same simulation (see Fig. 4). In this regard, if a developer needs to build an application for an AR headset (e.g HoloLens, Magic Leap etc), the only additional work required is to import the respective external SDK. Our universal XR camera works with any headset regardless the targeted reality.

We implemented this methodology with our custom device controller. MAGES encapsulates a central device controller to describe the needed methods for a device that runs one of our simulations. Those can vary from the camera movement to the controller button behaviors, forming a set of rules among the devices. In this way, the simulation remains clean of additional coding, regarding the Head-mounted displays (HMDs), while internally the device controller manages the HMD inputs. If MAGES detects an augmented reality headset, it automatically culls the unnecessary VE objects, like the walls of the operating room as they should not be rendered.

It is a breakthrough for virtual application
as we break the boundaries between different technologies that up until recently were used separately.

EDGE-CLOUD REMOTE RENDERING

Although the VR hardware landscape evolves rapidly, with SoC solutions that aim to reduce the performance gap to high-end desktop GPUs, still standalone/untethered VR solutions are less capable in supporting high quality strong interactive VR services due to their reduced GPU capabilities and battery life. This favors the exploitation of software solutions that offload computationally intensive tasks from end devices to cloud/edge resources to support processing and storage.

In our approach, a signaling server is integrated to complete the handshake and the ICE candidate negotiation between the HMD and the offloaded application, based on RFC 8445. The signaling server establishes a communication channel, either by using a STUN server to determine connectivity between the two components, or alternatively a TURN server, and decides which encoding format is the most appropriate to use for the video stream.

One major road-blocker for VR offloading using Unity3D Render Streaming, is that Unity3D does not support a capability for stereo render-to-texture. This further required a re-engineering of the render streaming by using two complete Unity3D cameras in the scene with customized settings for the left and right eye to render to separate textures for each eye, which are then blitted onto the final target. Furthermore, a custom data stream is used to send transformation and controller data from the HMD to the offloaded application. Due to the simulation of two Unity3D cameras the frame-rate between the offloaded component and the HMD decreases to approximately 200% the frame time or 44.5 fps on average. The offloaded application runs inside of a Windows virtual machine on a Linux host. By using KVM with GPU-passthrough, performance can come close to bare-metal speeds. Additionally, a custom TURN server is hosted inside of the VM, which allows WebRTC to consistently establish communication with the client, even if they happen to be behind a NAT.

DISSECTED PHYSICS ENGINE

A typical monolithic game engine pipeline involves the execution of physics related calculations, performed on CPU, alongside with scene rendering calculations, performed on CPU/GPU. Both these heavy computations are either performed on high-end untethered HMDs, or on VR-ready PCs with a tethered HMD.

The designed methods and techniques for the dissection of the Unity3D game engine pipeline, creates two autonomous, deployed separately, bidirectionally communicating components: the Host, and the Physics Server. The Host is responsible of maintaining the game logic and of processing the graphics rendering, while the Physics Server is responsible for performing physics computations (see Fig. 5). Main goal of the dissected Unity3D pipeline is to allow any game object on the Host’s scene to be fully simulated by the separated Physics Server (see Fig. 6).

The dissection approach is based on the splitting of the Host’s game objects into graphics objects, residing in the Host, and physics objects, residing in the Physics Server. This is accomplished by eliminating the physics attributes (e.g., mass, collider dimensions etc.) from all Host’s game objects, which are subsequently created in the Physics server as physics objects with the same parameters, in an easily transmittable and compressible format. The Physics Server acts on a completely passive nature since it retains no knowledge regarding the Host’s scene, the game loop or the behaviors. The imposed inter-calls are streams of transformations between the two services.

The dissected Physics Server runs inside of a
Figure 5. A high-level architecture diagram of the physics dissection. The physics are calculated only on the physics server while the render service receives the rendered image.

Figure 6. The physics are calculated only to the server while the client receives the rendered image.

Windows virtual machine on a linux host. Further containerization of this service is under consideration. The results of the dissected pipeline, show a minor uptake of 0.03ms on the latency from the new physics service, producing identical total frame-rate of 44.5 fps. The produced results have confirmed our plans of hosting extremely high intensity physics computations in a separate edge service orthogonally to the rendering service, and allow the Physics server to serve multiple Rendering services, collaborating in the same multi-user session, in a N-1 setup, instead of the current 1-1 setup.

SOFT-BODIES SIMULATION

In the real world, there exist certain deformable objects, e.g., soft or hard tissues, which are “naturally” deformed when external forces are applied on them. MAGES incorporates a framework that aims to achieve this, via the so-called soft-body mesh deformation. The idea behind this methodology is to create a layer of control points, called particles, on top of the mesh model that, when translated, would affect the vertices of a model in a weighted manner. Ultimately, the visual effect we aim is similar to what would happen in reality if we pinched and pulled the material at that point, towards the displacement direction of the particle.

The particles are spawned and bound via springs to some initial positions on the mesh’s surface, uniformly distributed via a Poisson Sampling mechanism. Particles lying sufficiently close are “connected”, forming the desired layer of control points. Furthermore, we assign vertices to particles that have a distance from them below a specific model-dependent threshold.

After this initial setup, every time a particle is displaced away from its initial position it will trigger several events. Firstly, the particle’s displacement will amount to a weighted displacement of all particles it is assigned too, with each vertex’s displacement being inversely proportional to its distance from the particle. Furthermore, the particle’s movement will affect connected particles by a fraction also inversely proportional to their in-between distance. As neighbouring particles are displaced, they will, in turn, affect vertices in a diminishing extent. Lastly, particles that are moved away from their initial position tend to return with a velocity that is proportional to the displacement, similarly to a spring. With these fundamental rules applied to the model, we are able to simulate elasticity on the model’s surface.

HIGHLY REALISTIC PROGRESSIVE TEARING AND CUTTING

By exploiting the GA-based interpolation engine, we are able to simulate realistic unconstrained consecutive tears or cuts, on a soft-body model, similar to the ones performed in real life by a surgeon in the operating room. Based on pure geometric operations on the surface mesh, we are able to perform such actions and obtain
Table 1. Running times required to tear and cat various softbody models: a liver and a heart. Results were obtained by running simulations in a PC with an i7-11375H CPU, 16 GB of RAM and an RTX 3060 GPU.

| Characteristics              | Liver | Heart |
|------------------------------|-------|-------|
| Number of vertices           | 515   | 2527  |
| Number of triangles          | 768   | 4968  |
| Number of particles          | 191   | 179   |

| Tear Operation               | Performance per tear segment |
|------------------------------|------------------------------|
| Perform Tear                 | 0.4 ms                       | 3 ms                         |
| Update particles             | 2.3 ms                       | 7.3 ms                       |
| Total Time                   | 3.25 ms                      | 11.19 ms                     |
| Output                       | 140 fps                      | 90 fps                       |

| Cut Operation                | Performance                   |
|------------------------------|-------------------------------|
| Intersection points          | 128                           | 356                           |
| Total Time                   | 10.9 ms                       | 17.2 ms                       |
| Output                       | 90 fps                        | 55 fps                        |

real-time results in XR, even in low-spec devices such as mobile VR HMDs. The specific calculations are performed in real-time within a 10-30 ms to preserve user immersion.

Although bibliography [13] describes diverse ways on how to cut a 3D model, most of these methods are not suitable for VR, since the specific calculations must be performed in a real-time manner within a few ms to preserve user immersion. Latest developments [14] allow for basic operations, such as cutting, tearing or drilling on a rigged mesh model, to be run in near real-time. The significance of this framework lies on the fact that it overcomes current state-of-the-art limitations, where similar tears on a rigged 3D model in VR are predefined via linear-blend skinning animations, in order to allow them to playback in real-time.

Paired with the soft-bodies framework, our tearing and cutting algorithms allows the simulation of realistic, surgical-grade continuous tears, especially valuable in the context of medical VR training. Furthermore, our algorithms are based on simple geometric predicates on the rigged mesh, and therefore do not require specific model pre-processing. Ultimately, our framework allows the user to freely cut or tear in a consecutive way any 3D mesh model, under collaborative networked virtual environment, reaching up to 140 fps depending on scene complexity (see Table 1). Tears can now be simulated to “open”, replicating the tissue behaviour in real-life tears, providing immersive visual results for soft-body materials. And of course, rigged models can be further re-animated and torn or cut again, enabling a number of complex surgical operations to be implemented in VR.

CONVOLUTIONAL NEURAL NETWORK ASSESSMENT

Despite the effort, only limited systems involve procedures for assessing user progress inside the immersive environment, that either evaluate only trivial tasks or require a huge amount of time by the reviewers [15]. On the other hand, the need for real-time automated evaluation of user’s actions is constantly increasing. State-of-the-art methods for similar tasks either require the development of complicated task specific computer vision algorithms or support very simple tasks [16].

MAGES proposes a deep learning based system, that is able to assess, in real-time, user actions within a VR training scenario. The method enables the rapid development of trained assessment functions, since it utilizes data augmentation to minimize the amount of labelled data (e.g., poor/mediocre/excellent performance) that need to be collected. Using this system, we are able to assess e.g. the incisions, i.e., tears and cuts, performed in VR medical operations by the trainees. The usefulness of this feature is especially highlighted in cases where we have a predefined operation, or exemplary task from a teacher, and students must be trained to replicate the teacher’s movements precisely. Furthermore, by using transfer learning, these assessment functions can be reconfigured to support similar tasks, thus reducing even more the amount of training
Various underlying techniques were used to make this achievable. Data collection involved capturing transformation data (translation & rotation) of the active virtual tool (e.g. a scalpel) on distinct frames. The data set was made uniform to amend for the fact that execution of an action is user dependent. Data augmentation techniques were applied to increase the training data towards enhancing the training process of the 15-layer CNN. Since low training and inference times are preferred, the lightweight model used is able to provide high-accuracy scoring results. Incorporating the trained CNN in the MAGES allows assessing the user’s actions with minimal performance overhead.

### VR RECORDER FOR ASSESSMENT

Recording a training session in VR can serve as an additional and powerful educational tool. Especially in virtual and augmented reality, a recorded session is not only a three dimensional video but the student can relive the experience from a different perspective. The bibliography shows great interest on this matter with the majority of projects focusing on video recording and motion capturing [16].

MAGES incorporates a different, highly accurate and lightweight solution to record and replay any collaborative training VR/AR session [17]. The underlying algorithm allows for the first time to record the VR/AR session by capturing the transformation of objects (position, rotation) and user-driven events (interaction, decisions). This results in a highly accurate recording of the scenario that requires minimal storage space (approximately 1MB per minute per user) and minimal overhead (see Table 2). Additionally, we efficiently handle and record the user audio and synchronize it using a timestamp algorithm.

After recording the session, users can select the recordings and replay them while observing as a spectators. They can join in the same environment as they performed the scenario and re-live their experience, paying attention to the details that were not possibly visible when they initially “played” the scenario.

### Table 2. Measuring the FPS burden of a VR application due to the Recorder feature. Results were obtained by running simulations in a PC with an i7-11375H CPU, 16 GB of RAM and an RTX 3060 GPU.

| Performance | Session without VR Recording | Session with VR Recording |
|-------------|-----------------------------|---------------------------|
| Average FPS | 89.56                       | 85.13                     |
| Minimum FPS | 76.56                       | 68.78                     |
| Maximum FPS | 93.29                       | 92.57                     |

### CASE STUDIES

In this section we present honorable medical simulations built with MAGES SDK.

**Total knee and hip arthroplasty:** In collaboration with University of Southern California and New York University, we created both orthopaedic operations as a part of their curricula. We also conducted a clinical trial that proves skill transfer from virtual to the real world [18].

**Emergency trauma scenarios:** This is a collection of emergency on-the-field simulations (extrication from car, first aid) and an intubation process as part of an online course for the University of Athens.

**STARS:** Patient education and empowerment through knowledge. We developed this informative and stress relief application for patients in collaboration with ICS-FORTH and the Human Computer Interaction Lab.
VRADA: In collaboration with the Aristotle University of Thessaloniki, the University of Thessaly and Biomechanic solutions we created a VR bike simulation with cognitive questions that allows older people with mild cognitive impairment symptoms to simultaneously practice physical and cognitive skills on a dual task. We published a clinical trial with our results [6].

Behavioral Health, Social Worker: Two cognitive training simulations for soft skills in collaboration with the Western Governors University and Fayetteville State University respectively.

Covid-19 PPE & swab testing: During the covid-19 pandemic, we developed this application to educate medical personnel the proper use of personal protective equipment and how to take covid samples for test (see Fig. 8). It was performed in collaboration with Inselspital University hospital of Bern and the New York University. We conducted two clinical trials [19], [20], to explore the effectiveness of VR simulations versus traditional learning methods.

Anatomical viewer: Non Nocere, developed an anatomical viewer for laminectomy and discectomy using MAGES SDK.

REBOA: In collaboration with the Inselspital University hospital of Bern we developed an endovascular balloon occlusion of the Aorta simulation.

CONCLUSIONS AND FUTURE WORK

In this work we presented MAGES 4.0, a novel development kit that allows rapid creation of any collaborative medical VR/AR simulation. The above novelties, rapidly accelerate content creation while maintaining a stable, multiplatform authoring tool for medical simulations.

In the future, we aim to improve the developer experience in MAGES. Our goal is to reach a point where a novice developer can learn and create with all existing actions, cloud and analytics in a single day. In addition, experienced developers should also extend the codebase (Actions, prototypes, mechanics) with ease. Furthermore, we consider to support the Universal Scene Description (USD), an open ecosystem that empowers the collaboration in 3D virtual worlds, invented by Pixar Animation Studios. There is a lot of research in this field which can be beneficial for medical training as we move towards metaverse.

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