Volumetric Video and Mixed Reality for Healthcare Training

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ABSTRACT

Healthcare training utilizes a variety of educational techniques to impart the necessary knowledge, skills, and abilities, including classroom instruction, medical mannequins, part-task trainers, and recently mixed reality simulations. Simulations employing augmented and virtual reality (AR/VR), often called mixed reality, provide users with an engaging and immersive visual experience. Typically, computer models and animation are used to create the virtual component in these environments. However, these techniques often require extensive time, resources, and expertise to create virtual objects with sufficient visual and behavioral fidelity. A novel technique to augment existing computer graphics is the use of volumetric video. Volumetric video begins with the capture of an object or person from multiple viewing positions using multiple cameras. The output is a 3D, or volumetric, video which can be inserted into a mixed reality scene. Within this manuscript, a research effort integrating volumetric video with virtual reality head-mounted displays will be discussed. The effort included the volumetric captures of tactical combat casualty care instruction, which were integrated into a series of training scenarios. Results from an initial user test focusing on user perceptions of the volumetric video will be presented, as well as future research avenues and potential applications in other simulation and training domains.

ABOUT THE AUTHORS

Matthew Hackett is a science and technology manager for the Combat Capabilities and Development Command Soldier Center. Dr. Hackett had led a variety of medical simulation and training research efforts, including holographic display research, serious gaming, training effectiveness, and simulator hardware. Dr. Hackett holds a PhD in Modeling and Simulation, an MS in Biomedical Engineering, and a BS in Computer Engineering.

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Elliott Mizroch has worked as a VR + AR producer focused on delivering hyper-realistic immersive experiences for both entertainment and enterprise clients. From ancient Egyptian tombs to operating rooms at the Cleveland Clinic his work is at the forefront of the immersive media revolution. Recently, Elliott led the production of photo-realistic tomb and artifact scans of Queen Nefertari, and King Tut, which won the 2020 Lumiere Award for Best VR Education/Museum Experience, 2020 Telly Award for Best Immersive & Mixed Reality Experience, and has been nominated for the Visionary Award at the 2020 Cannes Film Festival.

Simon Venshstain is the chief technology officer at 8i, a leader in the volumetric video space. Simon has lead software and R&D teams in the field of 3D reconstruction and volumetric capture for over 5 years. Simon holds an MS and BS from the University of Illinois and Urbana-Champaign.

Matthias McCoy-Thompson has worked in immersive tech for nearly a decade. He founded Agora VR in DC where he built immersive marketing solutions for organizations like GM and Singularity University. After moving to LA, he joined Kluge Interactive where he managed projects from ideation to delivery for companies like Foursquare, Miller, and Samsung and helped launch the VR rhythm game Synth Riders. He has been active in building immersive tech communities, founding both DCVR and XRLA and growing them to 1,500+ members.

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INTRODUCTION

Healthcare training is a challenging educational domain, requiring extensive knowledge of human anatomy and physiology along with an understanding of the skills and abilities needed to render patient care (Swanwick, 2013). To meet these demanding learning objectives, educators use a variety of educational pedagogies, including traditional classroom lecture, problem-based learning, and the apprenticeship model (Attree, 2006; Barrows & Tamblyn, 1980). These techniques have been shown to be effective in conveying the necessary information to future healthcare providers in both individual and team training settings (Colliver, 2000; Vernon & Blake, 1993).

In addition to varying teaching techniques, many researchers and educators have utilized novel technologies to augment healthcare education and training. In particular, simulation technology has been implemented into educational programs across the full spectrum of care for both civilian and military medicine (Kunkler, 2006). These technologies include medical mannequins and part-task trainers to impart psychomotor skills, as well as virtual trainers to impart procedural knowledge. Simulation-based education has been shown to be broadly beneficial and is widely accepted by the medical community (McGaghie, Issenberg, Cohen, Barsuk, & Wayne, 2011; McGaghie, Issenberg, Petrusa, & Scalese, 2010; Okuda et al., 2009). Further, serious games and virtual simulation for healthcare education have shown benefits in engagement and learning outcomes, though these modalities are used less often than physical simulation devices (Gorbanev et al., 2018; Graafland, Schraagen, & Schijven, 2012). Although the body of literature is still relatively limited, augmented and virtual reality (AR / VR) are also growing modalities for healthcare education showing substantial promise to improve engagement and learning outcomes (Barsom, Graafland, & Schijven, 2016; Kamphuis, Barsom, Schijven, & Christoph, 2014).

Military healthcare training combines the already challenging healthcare domain with the demands and stressors of a combat situation. Focusing on point of injury care, the provider must assist in neutralizing any opposing forces, continually assess the situation for threats, and communicate with the unit leader; all of this is required in addition to administering care. To this end, the military has established tactical combat casualty care (TCCC), which is the standard of practice for the treatment and stabilization of a battlefield casualty (Butler Jr, Hagmann, & Butler, 1996). TCCC focuses on the skills associated with reducing and eliminating the preventable causes of death on the battlefield, including hemorrhage control, airway management, and tension pneumothorax. The practice of TCCC also emphasizes that military tactics are followed, to reduce the potential for providers to themselves become casualties as they render care. TCCC has been proven effective with decades of evidence; notably, units that have fully implemented TCCC have the lowest incidences of preventable death (Kotwal et al., 2011). In 2017, the National Defense Authorization Act and Department of Defense Instruction 1322.24, “Medical Readiness Training”, mandated a standardized set of TCCC instruction requiring all Service-members, including over 1 Million Active Duty personnel, receive TCCC training commensurate with their role. To achieve this, a standardized curriculum incorporating modern learning science techniques such as spaced-repetition and action learning was developed (Hackett et al., 2020).

Similar to civilian healthcare training methods, military healthcare training employs a variety of pedagogical approaches and technology aids. TCCC training utilizes a combination of classroom instruction, hands-on psychomotor skills training, problem-based learning, and team exercises such as lane-training. Research is regularly conducted to improve TCCC training, including novel pedagogical approaches to better incorporate stressors and team dynamics (Milham et al., 2017; T. Sotomayor, Mazzeo, Hill, & Hackett, 2013). New technologies are also readily developed, including serious games designed to practice procedural TCCC skills (Brown, McIlwain, Willson, & Hackett, 2016; T. M. Sotomayor, 2010). AR and VR educational capabilities are an area of significant interest, including the development of AR-based training tools for combat medic or corpsman skills (Taylor et al., 2018). These trends are in line with the shifting technical landscape of military training, as increased utilization of AR and VR is expected (Haar, Kent, & Matthews, 2019).

As AR and VR capabilities continue to evolve, the graphical elements underpinning these systems remain critical to their training utility. The computer generated imagery (CGI) used in AR/VR is typically created by artists and animators using software tools and gaming engine capabilities. Unfortunately, this process is time intensive and requires extensive artistic and technical talent. Furthermore, this process still struggles to create sufficient realism for many use cases, in particular, the generation of virtual humans and virtual patients. When generating virtual humans and patients, subtle signs and symptoms and non-verbal communication are very challenging to create in a realistic manner, thereby limiting the fidelity of training. One potential solution to the challenges presented by current CGI techniques is the use of volumetric video. Similar to photogrammetry, volumetric video captures an object or person using multiple cameras arranged at differing viewing angles (Schreer et al., 2019). The resultant video streams are combined into a single volumetric video stream, thereby capturing not only the object or human in 3D, but also the movement of that item or person over time. The volumetric video can then be inserted into an AR or VR scene. Within a recent research effort, the US Army DEVCOM Soldier Center partnered with a commercial company 8i, to conduct research on the use of volumetric video to train TCCC procedures. This manuscript presents the development process including the technical approach to volumetric video capture and the design of the training system. Results of an early user test evaluating the usability of the system and the visual quality are also reported. Finally, volumetric video is discussed as a potential enabling technology for other training uses cases and further research avenues.

METHODOLOGY

Volumetric Capture

Volumetric video is built on established technologies that have recently seen rapid progress in popularity and performance. First and foremost is photogrammetry, or the use of multiple 2D images to reconstruct a 3D object (Mikhail, Bethel, & McGlone, 2001). In the last two decades there have been impressive advances in the computational techniques for extracting dense 3D information from 2D images. With the development of low-cost graphical processing units (GPUs), the cost of processing huge photogrammetry data sets has come down immensely, allowing visual effects researchers to start experimenting with capturing 4D scans, or volumetric videos, using multiple synchronized video cameras.

The volumetric video approach used in this research effort combines a unique software stack with third party camera hardware for use in a recording stage, allowing high image quality and realism and rapid processing times, thereby enabling content creation at scale. Scale is particularly important for the training of military personnel, where throughput is a significant challenge. In particular, this approach addresses two long-standing problems with volumetric video – data volume and data compression.

The most direct approach to creating volumetric videos is to use a very dense array of hundreds of synchronized high-resolution video cameras, so that a camera is ‘looking’ at the subject from nearly every angle. The dense array of cameras increases the frequency with which cameras are deployed to capture the same area, thereby ensuring complete 3D scans. But the sheer volume of data created by recording with so many cameras is impractical and prohibitively expensive to manage. Moreover, the capture system itself is very costly and difficult to deploy in most circumstances.

Instead, this approach uses sparse light field capture, allowing for the creation of high quality imagery with far fewer cameras and far less data (Huang et al., 2018). The stage setup with spare camera array is shown in Figure 1. This sparse capture approach is combined with advanced vision processing to output a compressed data representation. The GPU on the user’s device is then used to synthesize highly realistic imagery at fast rates in a multi-platform playback application.

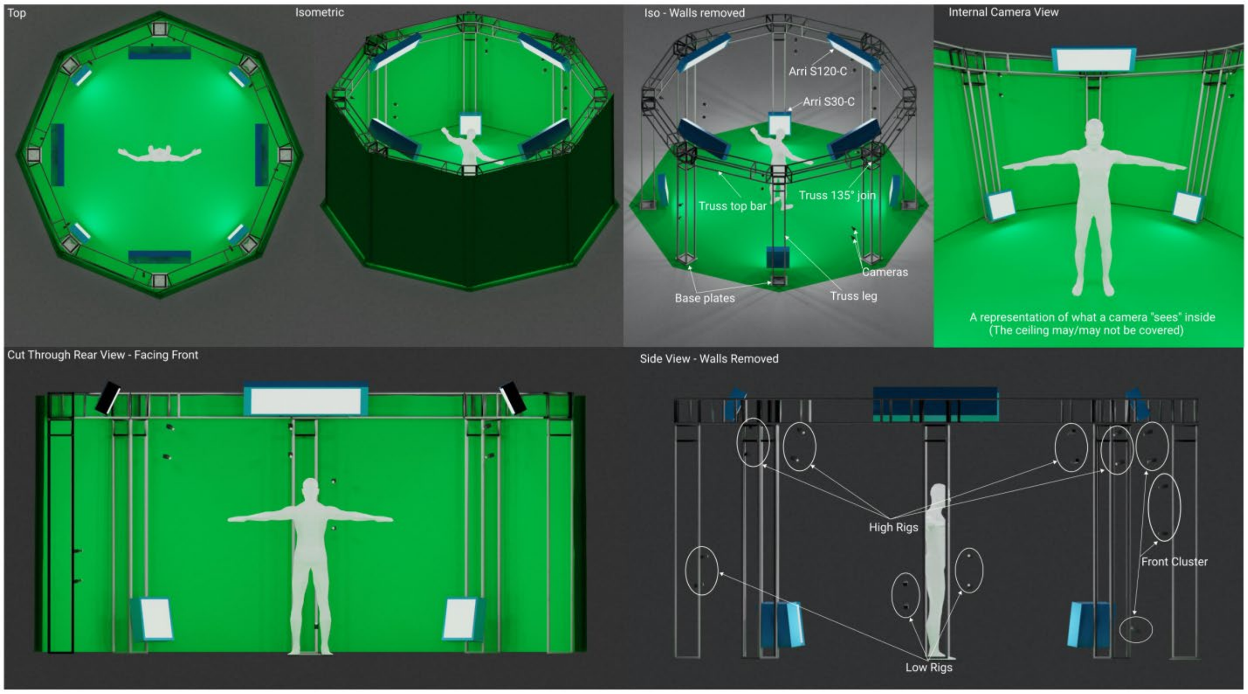

Figure 1: Volumetric Capture Stage

Even with a sparse light field capture approach, volumetric video requires managing large volumes of data. Fortunately, light field data captured from real world scenes is highly compressible. Even so, achieving the necessary compression ratios while maintaining high levels of quality requires exploiting the structure of the signal itself. The signal results from the transport of light from light sources, through material interactions in the scene, and finally into a camera. Using this signal, a codec compresses surface light field samples that include a location in space and multiple color elements, one per camera in the capture setup. By reconstructing these elements, users can see interpolated color reconstructions of captured content, viewable from any angle and location. The codec uses a series of algorithms to aggregate the surface light field samples into highly compressible regions based on localized topological constructs, estimation of surface material properties, and an analysis of the temporal motion field acquired by cameras in the stage (Su et al., 2020). Surface light field samples are then aggregated over time into treelike structures, using various heuristics that estimate the compressibility of data over time. These structures are then temporally compressed using a variety of techniques on a best match found basis.

The color signal and topological signal are dealt with in different ways. A combinations of techniques is used to compress color, derived from vector quantization, Laplacian image pyramids, wavelet transforms & discrete cosine transforms. These techniques enable the system to perform perceptual analysis of captured data, lossy compression of color, and removal of signals that the human visual system can't perceive.

Topological signals are handled in a way that enables surface light field samples to be tracked over time, by aggregating samples into regions that are found to be temporally and topologically similar. Analysis of local curvature, known as silhouette, is used to lossy compress surface and topology, allowing large compression ratios without visually impacting the faithful reconstruction of captured data (Peixoto, Medeiros, & Ramalho, 2020). The end result is a full software stack that captures video from a sparse camera array, synthesizes these video feeds into a single volumetric video, compresses the video using a variety of techniques, and ultimately delivers the volumetric video for use in a VR or AR environment.

Training System Development

For this study, volumetric videos were captured of TCCC instructors delivering training instructions on how to perform TCCC techniques. These recordings introduced users to the experience, gave an overview of the massive hemorrhage, airway, respiration, circulation, and hypothermia / head (MARCH) algorithm, and then walked users through each step of the MARCH algorithm. Two instructors were captured simultaneously, the first giving the instructions as well as performing the techniques on the second instructor. The training included step-by-step instructions for applying a tourniquet, compressing and wrapping a wound, inserting a Nasopharyngeal Airway (NPA) device, assessing the respiratory system, assessing circulation, assessing the head, and preventing hypothermia. The training was captured using a sparse array of thirty 4k cameras. The data was then processed to create volumetric videos that can be used in a VR experience.

To develop the TCCC VR training system, these volumetric videos were cut up into separate clips for each step in the training. These clips were ordered and set into a VR environment of a military field hospital. Slides for each step were created and put behind the volumetric videos. After each step, a menu appears that allowed users to repeat the step or advance to the next one. This system allows users to view the volumetric training videos within a VR headset as if they were in a classroom environment allowing for a complete immersive training solution.

Experimental Design

The experimental design focused on assessing the user perceptions from a single group of representative end-users. Participants were active duty Marine hospital corpsman taking a course in TCCC at Camp Pendleton, CA, with a total of 15 participants. To begin, volunteers entered a classroom, one at a time, and received a short brief on the purpose of the study and the technology being assessed. Participants were then fitted with the VR headset, an Oculus Rift, and given a short period to become accustomed to the display and controls. The participants completed the TCCC units on hemorrhage control and airway management developed using volumetric video. This included watching the volumetric recordings in VR, moving through the virtual environment to view from multiple angles, and controlling the various playback features associated with the volumetric viewing (Figure 2). Following the training experience, the participants completed a survey to assess their perception of the system. The study protocol was submitted to the DEVCOM Soldier Center Human Protection Office, who deemed the study exempt from full institution review.

Figure 2: Participant viewing TCCC instruction; Screen below shows participant view including volumetric instructor and patient

Two survey instruments were used to assess the user's perception of the overall system and the volumetric video in particular. The usability of the overall training system was assessed using the system usability scale (SUS), which is a 10 item, Likert scale survey (Bangor, Kortum, & Miller, 2008; Lewis, 2018). The SUS was analyzed in three ways to utilize the data as completely as possible. First, the SUS was scored using the intended method: (1) total odd-number questions and subtract 5 to get value (X); (2) subtract the total of even-numbered questions from 25 to get value (Y); (3) Add the values of (X+Y) and multiply by 2.5. These steps yield the final SUS scoring, out of a possible 100 (Smyk, 2020). In a subsequent analysis, averages and standard deviation were determined for all items to determine an overall level of positivity. The final analysis was conducted based on existing research which found that the SUS not only serves as a unidimensional assessment of usability, but also can be assessed for two factors: learnable (questions 4 and 10) and usable (all other questions). The learnable and usable responses were averaged to determine these subscales, with negative items reverse coded for analysis. The SUS has been heavily research, finding that the overall system usability scale was reliable (α=0.91), as were the factors learnable (α=0.78) and usable (α=0.98).

To assess the volumetric video quality, a composite survey was created to assess general visual quality as well as measure the uncanny valley effect. Quality was assessed using a single item rating the visual quality and the realism of movement. In robotics and computer graphics, the uncanny valley is the concept that as a robot or computer generated character approaches the visual realism of an actual human, the viewer gets an eerie and uncomfortable feeling. (Mori, MacDorman, & Kageki, 2012). The uncanny valley effect was assessed using an instrument derived from a set of scales by Ho and Macdorman (Ho & MacDorman, 2017). The scales ranged from 1-9 with the following end points: very artificial to very humanlike; very strange to very familiar; and not eerie to very eerie.

RESULTS

The results of the system usability scale were positive for all measures. To begin, the SUS was scored for each participant's responses, yielding an average score of 80.0 ± 12.1. Averages for individual survey items found that participants felt the system was easy to use and learn, and was not overly complex or cumbersome. Table 1 shows the average response for each item; it should be noted that items 2, 4, 8, and 10 are negative statements, so disagreement on those items indicates a positive sentiment from the participant. The learning subscale had an average positive response of 3.4 ± 1.3 and the usable subscale had an average positive response of 4.3 ± 0.8.

Table 1: Average Response per Item on the SUS (1 = Strongly Disagree; 5 = Strong Agree)

Item	Average	SD
1. I think I would like to use this system for learning TCCC	4.6	0.6
2. I found the use of this system unnecessarily complex	2.0	0.8
3. I thought the system was easy to use	4.1	1.2
4. I think I would need the support of a technical person to be able to use this system to learn TCCC skills	2.9	1.3
5. I found the various system functions well integrated	4.3	0.5
6. I thought the system was consistent in its performance	4.5	0.5
7. I would imagine that most people would learn to use this system very quickly for training	4.3	0.8
8. I found the system cumbersome to use	2.0	0.8
9. I felt confident using the training system	4.3	0.7
10. I needed to learn a lot of things before I could start using the system	2.3	1.3

The average responses for the visual quality item was positive (*m* = 7.5; *sd* = 1.2), as was the realism of the movement (*m* = 7.9; *sd* = 0.88). The items related to the uncanny valley found that the volumetric instructor and patient were viewed positively as well. The volumetric videos were found to be humanlike ((*m* = 7.6; *sd* = 1.4) and familiar to participants (*m* = 7.5; *sd* = 1.8). Participants did not find the volumetric representations to be eerie (*m* = 2.9; *sd* = 2.1). The averages and standard error for user perceptions are shown on their scales in Figure 3.

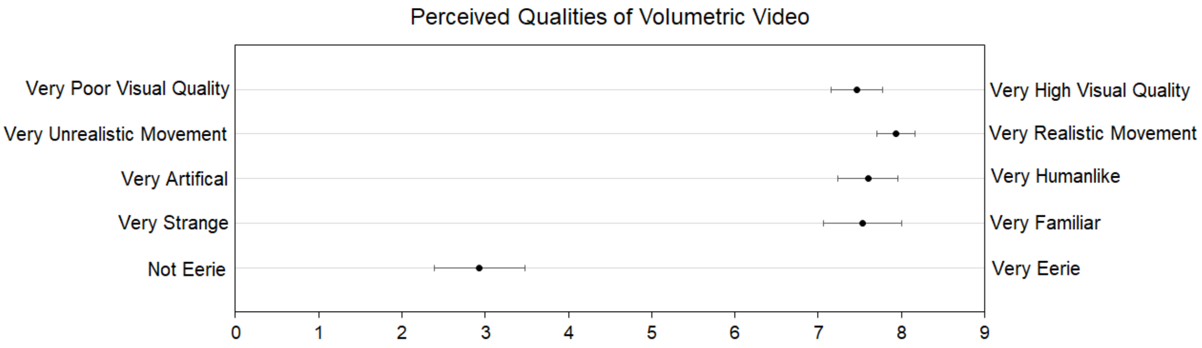

Figure 3: Assessment of Visual Quality and Uncanny Valley Effect related to Volumetric Video

CONCLUSIONS

This study assessed the usability and user perception of a volumetric video training system within the domain of TCCC. Based on the results of the SUS, the system scored an 80 in terms of usability. To provide the usability community a comparable benchmark for usability scores, a group of researchers reviewed a series of 241 industrial usability studies and created a curved grading scale, with a 68 as the midpoint grade of a C (Lewis & Sauro, 2018; Sauro & Lewis, 2016). Using their scale, the result of an 80 gives the volumetric video training system a usability grade of an A^{-}. To compare with commercial products, a usability score of 85+ was found on apps such as Pandora or Gmail, while an 80 was similar to the Weather Channel app or Instagram (Kortum & Sorber, 2015). These results were very promising, suggesting the system was highly usable even in the early prototype state that was tested. Looking at the individual items on the SUS, all of the averages were positive, indicating there was not a particular area of usability weakness. The worst rated item focused on whether participants would need a technical person to help them with the system, which was close to a neutral rating. Using the subscales, the system was rated very positively regarding the usable component, with an average positive rating of 4.3. The learnable component was less positive, with an average positivity of 3.4, indicating participants may need assistance learning to use the system. This is in line with the individual item results suggesting a technical person might be necessary in the current system configuration.

The volumetric video was highly rated in terms of overall visual quality and the realism of the movement. These results are encouraging and suggest the technique can be employed for the creation of both volumetric instructors and volumetric patients. The visuals were also assessed related to the uncanny valley concept. In this case, the volumetric video does not seem to fall in the uncanny valley. Based on the survey results, the volumetric instructor and patient seemed familiar and humanlike, without eliciting an eerie feeling.

The initial results of this research indicate that volumetric video shows promise as a training tool for TCCC. The usability of the system was high, combined with positive perceptions of the graphical quality. The potential use cases of such a capability are significant. To begin, instructors can be captured volumetrically to deliver lecture or demonstration for delivery in VR or AR. Faced with a shortage of qualified instructors, this capability could greatly expand the reach of instructors and improve the engagement of distance learning. In the same way a traditional video could be used to augment classroom instruction, a volumetric video can be used to augment VR or AR instruction.

Beyond volumetric instructors, non-player characters in a virtual environment can be easily created with volumetric capture. For example, to train bilateral negotiation or cultural awareness, an individual with the appropriate ethnic background could be volumetrically captured and placed inside of a training scenario. This would improve the current capabilities inherent with virtual humans, as the non-verbal communication and visual fidelity would be nearly identical to that of an actual human. Furthermore, conversation audio will sync with the movement of the volumetric human, since it is captured from an actual actor. For healthcare use cases, volumetric video could be used to train patient interview skills, psychological therapy, or simple bedside manner. In the current research effort, we also volumetrically captured the human actor who was playing the role of the patient, including simulated wounding and blood. Using volumetric video, interaction beyond conversational agents can be delivered, such as non-player characters simulating injured bystanders that require medical intervention.

There were multiple limitations to the current study. To begin, the study had a sample size of 15. While this is sufficient for usability testing, it should be noted that the study is not powered to provide generalizable findings. An additional limitation is the lack of a comparator intervention. The comparison of volumetric video with traditional CGI techniques would be highly beneficial to assessing whether volumetric video provides improvements in immersion, learning outcomes, or return on investment. As the results of this study were used to establish an initial baseline for usability and user acceptance, these comparisons were not conducted. Future research is planned to address these research questions.

Based on these initial results, the potential for volumetric video seems high. This sentiment is echoed in the commercial sector, with Verizon, Unity, Canon, NVIDIA, Intel, and others establishing a volumetric format association (Blanderson, 2021). The military use cases for a volumetric video training system are significant, including increasing the reach of instructors or improving virtual human capabilities. There are a multitude of additional research avenues currently being investigated. To begin, the volumetric can be delivered and used in AR as well as VR; future research will assess both modalities and provide comparisons between the two. Another notable research avenue is the capability to live-stream a volumetric capture, rather than pre-record the video. This would enable real-time 3D communication, facilitating use cases such as telemedicine, distance-based counseling or therapy, or distance-based standardized patients. Volumetric video technology holds the promise of enabling significant training capabilities, and warrants further research, development, and evaluation.

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