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Establishing Design Computing and Extended Reality Facilities for Remote Virtual Reality Training

Lap-Fai Yu*
George Mason University
Changyang Li†
George Mason University
Yongqi Zhang‡
George Mason University
Rawan Alghofaili§
George Mason University
Haikun Huang¶
George Mason University
Liuchuan Yu‖
George Mason University
Huimin Liu**
Purdue University
Minsoo Choi††
Purdue University
Brenda Bannan‡‡
George Mason University
Christos Mousas
Purdue University

Abstract

We discuss the existing facilities at the Design Computing and Extended Reality (DCXR) Lab at George Mason University, which comprise mostly commercial-off-the-shelf computing and extended reality devices, for conducting research on virtual reality-based training. We also share thoughts on extending the facilities for conducting more sophisticated virtual reality (VR) training research in the future, which features more advanced functionalities such as remote VR training, adaptive training, and co-training in VR. In particular, we discuss a remote VR training platform to be established between George Mason University and Purdue University.

Index Terms: Computing methodologies—Computer graphics—Graphics systems and interfaces—Virtual reality; Human-centered computing—Human-computer interaction—Interaction paradigms—Virtual reality;

1 Introduction

The increasingly widespread use of VR devices demonstrates its great potential in various fields such as medical training [1, 11, 14], safety training [4, 10, 12, 17], and surgical training [15, 16]. A key advantage of VR training is exposing trainees to a variety of realistic work or disaster situations so that they learn how to assess and safely cope with such situations to build resilience. This process results in enhanced cognitive information processing, which leaves its mark in long-term memory [12], making the training effective. Examples include VR training for teaching road safety to pedestrians [10, 13]. Results showed that using VR for such training is highly effective. Other advantages of VR training include high appeal to the trainees, making them more engaged in the training process as compared to traditional training methods such as reading training manuals or watching training videos. A recent survey paper [19] provides a comprehensive review of recent VR skill training works.

Global challenges such as the COVID-19 pandemic necessitates the broader use and development of remotely-connected training and collaboration platforms. By incorporating virtual reality (VR) into such platforms for 3D visualization, interaction, and demonstration, workplace training coaches and trainees can mitigate some of the difficulties posed by social distancing for professional training. Collaborative training in VR provides an opportunity to not only assess individual reactions and learning but also to study attention, behavior and adaptive responses of participants to build resilience.

This paper describes some VR training research projects enabled by the design computing and extended reality facilities at the DCXR Lab of George Mason University (GMU), led by Dr. Yu, based on mostly commercial off-the-shelf devices. To pursue advanced remote VR training going forward, we describe the idea of setting up a more sophisticated remote VR training platform between George Mason University and Purdue University, and how it may enhance the convenience, flexibility, accessibility, and effectiveness of remote training and collaboration.

*e-mail: craigyu@gmu.edu (corresponding author)
†e-mail: cli25@gmu.edu
‡e-mail: yzhang59@gmu.edu
§e-mail: ralghofa@gmu.edu
¶e-mail: hhuang25@gmu.edu
‖e-mail: lyu20@gmu.edu
**e-mail: liu2833@purdue.edu
††e-mail: choi714@purdue.edu
‡‡e-mail: bbannan@gmu.edu
e-mail: cmousas@purdue.edu

2 Existing Facilities and Research Projects

Supported by the National Science Foundation, Dr. Yu has acquired VR systems, most of which are commercial-off-the-shelf devices, to conduct VR training research. The supported research spans from perceptual data-guided computational design, performance-guided synthesis of virtual environments for personalized training, to worker-AI teaming to enable ADHD Workforce participation in the construction industry of the future.

While the facilities are housed in the computer graphics lab of the university, Dr. Yu also set up a VR Station with similar commercial-off-the-shelf VR/AR devices at the university's makerspace, which is open to students, faculty, and staff to use and experiment with. The VR Station is particularly appealing to general users as it allows them to instantly experience VR (e.g., trying VR apps, playing VR game demos) without investing any time, cost, and effort in VR hardware setup and system configurations. In the past, student organizations (e.g., Game Developers' Club) have hosted events such as demo sessions via the VR Station. It has also been used for university's IT training workshops to teach instructors how to integrate VR into their courses, and for outreach activities such as showing a VR bee hive documentary movie to students and the public.

2.1 VR Training Research Projects

We discuss some VR training research projects at the DCXR Lab. Table 1 shows the devices used by the research projects.

Construction Safety Training [6]. Construction industry has the largest number of preventable fatal injuries, providing effective safety training practices can play a significant role in reducing the number of fatalities. In view of such challenges, we devised a novel approach to synthesize construction safety training scenarios to train users

Figure 1: VR construction safety training.

Research Project	Devices
Construction Safety Training [6]	Oculus Quest 2
Earthquake Safety Training [5]	HTC Vive
Exertion-Aware VR Exergaming [20]	HTC Vive, Polar T31 heart rate sensor
Virtual Wheelchair Training [7]	HTC Vive, wheelchair with Vive trackers
Exertion-Aware VR Biking [18]	Oculus Rift, gym bike with resistance control by a step motor

Table 1: Devices used by the VR training research projects. The projects utilized commercial-off-the-shelf VR devices for visualization. Some projects utilized extra devices such as a modified gym bike or a wheelchair attached with trackers to provide realistic control and haptic experiences.

on how to proficiently inspect the potential hazards on construction sites in virtual reality. Given the training specifications such as individual training preferences and target training time, we synthesized personalized VR training scenarios via an optimization approach. Results suggest that personalized guidance VR training approach can more effectively improve users' construction hazard inspection skills.

Earthquake Safety Training [5]. We leveraged consumer-grade VR devices to provide an immersive and novel VR training approach, designed to teach individuals how to survive earthquakes, in common indoor environments. Our approach made use of virtual environments realistically populated with furniture objects for training. During a training, a virtual earthquake was simulated. The user navigated in the virtual environments to avoid getting hurt, while learning the observation and self-protection skills to survive an earthquake. We demonstrated our approach for common scene types such as offices, living rooms and dining rooms.

Figure 2: VR earthquake safety training.

Exertion-Aware VR Exergaming [20]. We devised a new VR plugin that can optimize the exercise intensity level (in terms of calories burned and heart rate) of VR exergaming experiences. Our novel approach optimized level designs by considering the physical challenge imposed upon the player in completing a level of motion-based games. A user evaluation validated the effectiveness of our approach in generating levels with the desired amount of exertion.

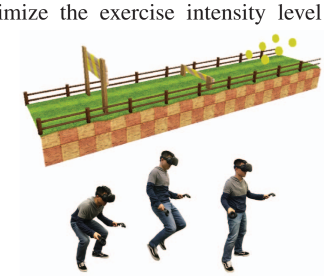

Figure 3: VR exergaming.

Virtual Wheelchair Training [7]. We devised a new 3D scene synthesis and path finding approach for generating scenarios for personalized wheelchair training in virtual reality. The generated virtual scenes and paths can be employed for rehabilitation training by a user wearing a VR headset and practicing on a real wheelchair. Users showed improvement in wheelchair control skills in terms of proficiency and precision after receiving the proposed virtual reality training.

Figure 4: VR wheelchair training.

Exertion-Aware VR Biking [18]. We devised a new path finding technique for generating paths on a given virtual 3D terrain that can be applied to drive an exercise bike to induce the right amount of exertion (in terms of calories burned) and matching haptic feedback on the user. Given an input terrain, our optimization-based approach generated feasible paths on the terrain which users could bike to perform body training in virtual reality. The approach considered exertion properties such as the total work and the perceived level of path difficulty in generating the paths. To conduct our user studies, we built an exercise bike whose force feedback was controlled by the elevation angle of the generated path over the terrain. Our user study results showed that users found exercising with our generated paths in VR more enjoyable compared to traditional exercising approaches.

Figure 5: VR biking.

3 Future Facilities and Research Projects

The previous research projects focused on single-user VR training on site. Going forward, we plan to establish a remotely-connected VR collaboration platform based on easily-deployable VR devices (e.g., VR headsets). Such a platform will allow a coach and a trainee who are geographically distant to participate in safety training and address complex emergency conditions in a shared virtual environment simultaneously and progressively. The platform will track the users' motion (e.g., head poses, body poses, gazes), analyze and understand the users' actions and intentions, and synchronize the users' behavior seamlessly to enable remote training. We will investigate practical issues such as latency, field of view, level of detail trade-off, visualization, and interaction techniques to reflect on action during and after remote collaborative VR training, providing novel support for progressive situation awareness and learning to build resilience.

3.1 Example Use Case

We use an example use case, *training teaching staff remotely on earthquake safety*, to guide the design of our envisioned remote VR training platform, as shown in Figure 6.

In modeling natural or man-made disaster scenarios in an immersive multi-agent VR learning environment, useful data is generated to capture and inform trainees' decision-making facilitated by command personnel and safety personnel coaches at GMU to train staff at Purdue on earthquake safety in the classroom using immersive collaborative VR. In addition to the collaborative behavior of responders and public safety personnel, we will also study the configuration, direction and highlighting of instructional cues by the coaches in this shared immersive environment.

Remote VR Training Process. We envision three major steps in a remote VR training session.

(1) Briefing: Given the blueprints of the site (in this case, a classroom at Purdue), first, our system will synthesize variations of training scenarios. The coach can control the synthesis, and each scenario will place objects and events differently according to the constraints and training goals authored by the coach. In our example, the variables may include the number of students in the classroom, locations of students, side effects of an earthquake event such as fire, the existence of obstacles in hallways, the position of the trainee in the virtual environment, etc. After the training scenario is set, the coach will model the task for the trainee (in the shared virtual environment)

Figure 6: Remote VR earthquake safety training on the envisioned platform.

to brief the participant about the potential dangers in the training scenario, and highlight useful strategies to protect oneself and evacuate during an earthquake.

(2) VR Training: After the briefing, the coach will initiate the VR training using a synthesized training scenario (which will vary in complexity from the training scenario used for briefing). During the VR training, the trainee will experience a simulated earthquake in the scene while applying learned skills to protect himself and evacuate his class of students. The coach will observe the trainee while his self-presence is not rendered by default (i.e., the coach can see the trainee, but not the other way round). However, under some situations, the coach may choose to make himself temporarily visible. For example, the coach may want to become visible to demonstrate the "drop, cover, and hold on" technique with his body. On the other hand, the coach may also give verbal reminders and specific instructional cues to hint the trainee about how to react to some events. The coach can highlight some regions or objects in explaining to the trainee (e.g., gesturing to highlight a potentially falling object). During the training, various forms of trainee's movement data and the coach instructions will be collected for review.

(3) Review: Based on the tracked data, the coach and the trainee will review the trainee's performance by replaying the recorded actions of the trainee from a third point of view. They can look at the replay from different visual viewpoints in the shared virtual environment. The coach may pause the replay anytime to explain any misperceptions or missteps that the trainee has made or what could have been done differently. The coach and the trainee will also quantitatively evaluate the performance by reviewing the path the trainee followed, the time taken by the trainee to evacuate, the reaction times to dangers, the gaze of the trainee, etc. This review and rehearsal in the VR environment will be analyzed to progressively inform future outcomes of this type of training in a shared immersive coaching environment.

After the review, based on the reflection on the actions of the trainee analyzed with the coach from the recorded performance in the previous training session, a new VR training scenario will be adaptively synthesized, which aims at improving the trainee's skills via presenting variations on the prior scene with opportunities for the learner to mitigate negative consequences and use enhanced decision-making. A progressive training process will then begin.

3.2 Envisioned Remote VR Training Platform

To conduct remote VR training research as illustrated in the example use case, we will design and establish one VR setup at each institution (GMU and Purdue). The setups will be connected to form a shared VR training platform for conducting collaborative training simultaneously. Figure 7 shows the major components of the VR setups. At Purdue, the setup will be hosted at the VR Lab directed by Dr. Mousas. At GMU, the setup will be hosted at the DCXR Lab directed by Dr. Yu.

System Components. At each site, the VR setup will consist of the following major components.

Remote Connection: The setups will constitute the VR training platform that remotely connects GMU with Purdue. The platform will provide multi-user interaction in a shared virtual environment satisfying the spatial constraints of both labs. The platform will use high-speed internet provided by GMU and Purdue to send and receive information to each end through a client-server architecture. Depending on the amount of 3D data and interaction data to be synchronized and the refresh rate needed, each remote VR training application will have its internet speed requirements. However, we expect that a download speed of at least 3 Mbps, an upload speed of at least 1 Mbps, and a ping rate under 150 ms, which are comparable to home internet connection speeds, should suffice the remote VR training platform.

The client-server architecture is considered a stable solution for multiplayer games that also ensures the needed synchronization between the two ends [2, 3, 9]. We will adopt a similar solution for sychronizing the VR training experiences between both sides. We will use the User Datagram Protocol (UDP) to enable the fast transfer of the pose and action data of each user so that the users (e.g., a coach and a trainee) can see each other and collaborate instantaneously.

VR Display and Interaction: The platform will use easily-deployable VR display and interaction devices (e.g., HTC Vive). Beside the HMD and the associated controllers for providing interaction in a virtual environment, tracking devices (e.g., VIVE trackers) will also be attached to physical objects (e.g., a door handle) pertinent to the virtual training scenario, whose spatial position and rotation can then be tracked. Such tracking allows the trainee to interact with not only virtual objects, but also with certain real objects, hence enhancing the realism of the interaction during the VR training. The research teams will calibrate a shared virtual environment to fit with the physical constraints of both labs, which will allow the spatial registration of the virtual world with the real world to be synchronized between the labs. Thus, the trainee and the coach at the two sites will have access to the same physical props, an aligned shared virtual environment, and virtual representations of each other.

Motion Capture: We will use the HTC Vive's lighthouse positioning system for tracking the trainee's head and hand positions, based on which inverse kinematics [16] can be applied for deducing the approximate positions of the other body parts. If more precise full-body tracking is needed, an Xsens motion capture system can be attached to the participant's body and calibrated, which allows participants to control virtual avatars by their body movements and captures the full-body motion for later analysis.

Eye Tracking: The HTC VIVE Pro Eye head-mounted display, which has embedded eye-tracking capabilities, will be used for collecting gaze data during VR training. Gaze-related features (e.g., fixation, duration) will be used for analyzing how participants perceive and interact with the virtual environment.

Physiological Measurements: If needed, electromyography, electrodermal, and heart rate sensors will be used to capture the muscle, skin, and heart activities of participants. The obtained data from

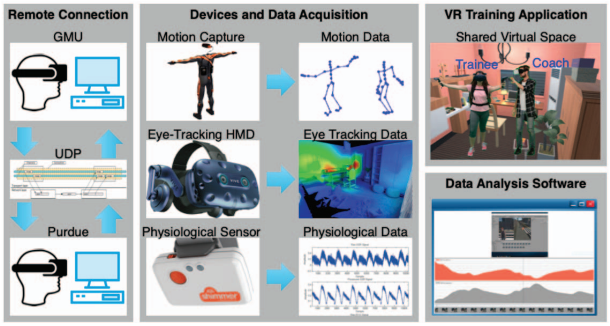

Figure 7: Major components of the VR setups at Purdue and GMU.

these sensors will help us understand whether the training tasks in VR are comparable with the prior session and projected to those performed in a real environment in terms of physiological effects.

Data Acquisition Software: The VR setup will be connected to a workstation computer that runs software developed by the team to record body data from motion capture and eye tracking during the training. Such data will be captured with the same frame rate at both sites to allow a frame-by-frame correspondence between the datasets. The data from the training sessions will be recorded so that they can be replayed and reviewed for further analysis.

Data Analysis Software: Software will be developed to analyze the collected body data using the application programming interfaces (APIs) provided by the respective device companies (e.g., HTC). The software will provide functionalities to analyze human motion using kinematics features (e.g., speed, duration, time, trajectory), eye gaze features (e.g., fixation, attention time, viewing angle), electrodermal activity (number and amplitude of peaks), electromyography activity (force generation and deformation of muscle, intramuscular and surface electromyography), and heart rate.

3.3 Expected Training Outcomes

We anticipate that remote VR training enabled by this collaborative platform will bring several key benefits. First, the trainee will be able to integrate knowledge to analyze, evaluate, and manage a possible emergency or disaster event by considering all the factors embedded in the VR scenario variations to which he or she has been exposed. Second, the trainee will be able to perceive, analyze, and communicate information on inherent risks and the consequences of their decision-making via experiential learning from the progressive VR training scenarios. Third, the trainee's situation awareness (perception and attention data), stress level (biometric data) and behaviors (activity data) will be captured along with progressive changes in performance, response time, and decision making to inform reactions to different emergency scenarios and scenes.

Advantages over Traditional Training. Compared to traditional training (e.g., instruction manuals, training videos), remote shared VR training may have many advantages: (1) in virtual reality it is possible to not only deeply reflect on the trainee's actions and decision-making in various training scenarios but also to provide stimulate different senses (e.g., visual, auditory, tactical, kinesthetic), which makes the training experience much more realistic through immersive presence; (2) VR training experiences, which provide unique rehearsal opportunities, permit a trainee to progressively learn from his own behaviors and decisions in unlimited variations of representative conditions; (3) as VR training is conducted in a virtual environment rather than a real environment, it avoids the risk and safety concerns of real-world training; (4) as the training is conducted remotely via shared virtual reality, VR training reduces the training budget while also providing scalability and accessibility and enhanced analysis; (5) the actions and performance of the trainee and the coach can be recorded and displayed for review and analysis. Concluding, remote VR training resolves barriers inherent to traditional training, while providing a more accessible, informed and customizable progressive learning experience.

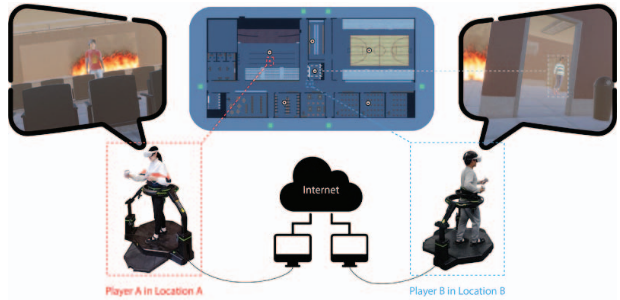

Figure 8: Two remote players wearing a VR headset on the VR treadmill in our preliminary work [8]. Their task was to guide virtual agents out of the building where a simulated fire emergency occurs. They could use voice commands to guide the agents to escape from the building, and a fire extinguisher to eliminate the fire in the building.

Advantages over Existing Systems. Compared to existing collaborative virtual environments for training such as those driven by cave automatic virtual environments (CAVEs), the proposed approach offers key advantages. (1) Handy Setup: The proposed system is based on two consumer-grade HMD-based VR setups (e.g., HTC Vive), which are inexpensive and easily deployable even at homes, while offering functionalities such as pose-tracking, head-tracking, eye-tracking, etc. that are critical for tracking and adapting training experiences. (2) Adaptive and Personalized Training: Unlike existing VR training experiences which are tailor-made and fixed, our optimization-based 3D training content authoring tools generate personalized VR training experiences adaptive to the perceptual data tracked on a trainee. (3) Performance Review and Visualization: Our collaborative VR training platform also provides toolkits for coaches and trainees to review trainees' performances and to capture their feedback in an iterative manner.

Novelty over our Previous Work. While our team has worked on various aspects of single-user VR/AR training approaches, the proposed remote VR training platform is novel in that the training experience is networked, collaborative, and multi-user based including potentially two trainees in collaborative work as well as a trainee working with a training coach. In addition to evaluating learning and performance via capturing progressive changes in behavior and decision-making based on varying contextual conditions, we will also evaluate the tools, algorithms, and user interfaces for authoring VR training experiences, facilitating instructions, enhancing 3D interaction and visualization.

3.4 Preliminary Results

We have started to explore setting up a collaborative remote VR training platform between Purdue and GMU. Figure 8 shows a collaborative VR fire training scenario [8] run on a setup in line with the proposed remote VR training platform. Note that we used Virtuix Omni treadmills to enable locomotion in a large virtual training environment, which was needed for our fire training scenario.

We synthesized virtual reality fire evacuation training drills in a shared virtual space to explore people's collaboration behavior. We formulated the authoring process of the fire evacuation training drill in a total cost function, solved with a Markov chain Monte Carlo optimization-based method. The trainees' assigned task in the synthesized training drill was to help virtual agents evacuate the building as quickly as possible using predefined interaction mechanisms. The trainees could join the training drill from different physical locations and collaborate and communicate in a shared virtual space to finish the task. We conducted a user study to collect both in-game measurements and subjective ratings to evaluate whether the synthesized training drills would affect how the participants collaborated.

4 Conclusion

We discussed VR training research projects conducted using mostly commercial off-the-shelf devices at the DCXR Lab at George Mason University. With the recent advancements of virtual reality devices for different purposes such as visualization, tracking, haptic feedback, etc., we envision to set up a remote VR training and collaboration platform between George Mason University and Purdue University, which would enable advanced VR training with capabilities such as co-training, remote coaching, and adaptive training.

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References

[1] P. B. Andreatta, E. Maslowski, S. Petty, W. Shim, M. Marsh, T. Hall, S. Stern, and J. Frankel. Virtual reality triage training provides a viable solution for disaster-preparedness. *Academic emergency medicine*, 17(8):870–876, 2010.

[2] M. Claypool and K. Claypool. Latency and player actions in online games. *Communications of the ACM*, 49(11):40–45, 2006.

[3] W.-c. Feng, F. Chang, W.-c. Feng, and J. Walpole. Provisioning on-line games: A traffic analysis of a busy counter-strike server. In *Proceedings of the 2nd ACM SIGCOMM Workshop on Internet Measurment*, pp. 151–156, 2002.

[4] Y. Lang, W. Liang, F. Xu, Y. Zhao, and L.-F. Yu. Synthesizing personalized training programs for improving driving habits via virtual reality. In *IEEE Virtual Reality*, 2018.

[5] C. Li, W. Liang, C. Quigley, Y. Zhao, and L.-F. Yu. Earthquake safety training through virtual drills. *IEEE Transactions on Visualization and Computer Graphics*, 2017.

[6] W. Li, H. Huang, T. Solomon, B. Esmaeili, and L.-F. Yu. Synthesizing personalized construction safety training scenarios for vr training. *IEEE Transactions on Visualization and Computer Graphics*, 2022.

[7] W. Li, J. Talavera, A. G. Samayoa, J.-M. Lien, and L.-F. Yu. Automatic synthesis of virtual wheelchair training scenarios. In *IEEE Virtual Reality*, 2020.

[8] H. Liu, M. Choi, L. Yu, A. Koilias, L.-F. Yu, and C. Mousas. Synthesizing shared space virtual reality fire evacuation training drills. In *2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, pp. 459–464, 2022. doi: 10.1109/ISMAR-Adjunct57072.2022.00097

[9] M. Mauve, S. Fischer, and J. Widmer. A generic proxy system for networked computer games. In *Proceedings of the 1st workshop on Network and system support for games*, pp. 25–28, 2002.

[10] J. McComas, M. MacKay, and J. Pivik. Effectiveness of virtual reality for teaching pedestrian safety. *CyberPsychology & Behavior*, 5(3):185–190, 2002.

[11] M. Reznek, P. Harter, and T. Krummel. Virtual reality and simulation: training the future emergency physician. *Academic Emergency Medicine*, 9(1):78–87, 2002.

[12] R. Sacks, A. Perlman, and R. Barak. Construction safety training using immersive virtual reality. *Construction Management and Economics*, 31(9):1005–1017, 2013.

[13] D. C. Schwebel, J. Gaines, and J. Severson. Validation of virtual reality as a tool to understand and prevent child pedestrian injury. *Accident Analysis & Prevention*, 40(4):1394–1400, 2008.

[14] S. Stansfield, D. Shawver, A. Sobel, M. Prasad, and L. Tapia. Design and implementation of a virtual reality system and its application to training medical first responders. *Presence: Teleoperators & Virtual Environments*, 9(6):524–556, 2000.

[15] L. M. Sutherland, P. F. Middleton, A. Anthony, J. Hamdorf, P. Cregan, D. Scott, and G. J. Maddern. Surgical simulation: a systematic review. *Annals of surgery*, 243(3):291, 2006.

[16] J. A. Thomson, A. K. Tolmie, H. C. Foot, K. M. Whelan, P. Sarvary, and S. Morrison. Influence of virtual reality training on the roadside crossing judgments of child pedestrians. *Journal of experimental psychology: applied*, 11(3):175, 2005.

[17] E. Van Wyk and R. De Villiers. Virtual reality training applications for the mining industry. In *Proceedings of the 6th international conference on computer graphics, virtual reality, visualisation and interaction in Africa*, pp. 53–63, 2009.

[18] Y. Z. W. M. H. H. L.-F. Y. Wanwan Li, Biao Xie. Exertion-aware path generation. 39(4), 2020.

[19] B. Xie, H. Liu, R. Alghofaili, Y. Zhang, Y. Jiang, F. D. Lobo, C. Li, W. Li, H. Huang, M. Akdere, C. Mousas, and L.-F. Yu. A review on virtual reality skill training applications. *Frontiers in Virtual Reality*, 2:1–19, 2021.

[20] B. Xie, Y. Zhang, H. Huang, E. Ogawa, T. You, and L.-F. Yu. Exercise intensity-driven level design. *IEEE Transactions on Visualization and Computer Graphics*, 2018.