Applications of Virtual Reality Hand Tracking for Self-Defense Simulation

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Abstract

KickVR is a self-defense training simulation designed to help users learn how to better defend themselves as a last resort. In collaboration with the Mount Pleasant Police Department, KickVR empowers users in the community to learn self-defense even if they do not have the time to attend in-person classes or none are accessible in their region. Virtual reality provides convenient access to self-defense training for users in their own homes. The immersion is enhanced through the use of hand-tracking. In place of hand controllers, the user's physical hands are tracked and rendered for the self-defense simulation. Our contributions include: a virtual environment appropriate for encounters in a small town, integration of the Leap Motion Controller to an Oculus Rift CV1 headset, a Unity-driven experience, interviewing members of law enforcement for locations of violent crime, and a framework for investigating external evaluations of the impact of virtual reality simulations in future works.

Key Words: Human-computer interaction; virtual reality; simulation; training; self-defense simulation.

1 Introduction

Central Michigan University made national headlines in February 2018. During spring break move-out, a 19-year-old student shot and killed his parents in his dorm room causing the campus to go on lock-down [20]. More recently, in February 2020, a 19-year-old freshman student at Central Michigan University went to Wayside Central, the local night club, on a Saturday night and stabbed three attendees during an altercation [13]. These events seemed significant at the time, but crime has become increasingly more common and more likely to occur in this area. NeighborhoodScout ranks Mount Pleasant, Michigan as a 29 out 100 on safety, meaning Mount Pleasant is safer than only 29 percent of cities in the United States with roughly 20 crimes happening per 1,000 people per year. With nearly 15,000 students taking on-campus classes in Fall 2019, that equates to nearly 300 students becoming victims to some sort of crime during the academic year [4]. Although property crimes are lower than the national average, a Mount Pleasant resident is twice as likely to be murdered, four times as likely to be raped, and seven times as likely to be robbed than the average United States citizen [10].

While crime rates have substantially decreased over the past two decades a study found many victims are not reporting crimes. According to the Pew Research Center study, as many as two-thirds of crimes may be going unreported [6]. To continue to lower crime rates and empower victims of crime who do not feel confident reporting crimes to police, a self-defense class in virtual reality, dubbed KickVR, was created to simulate scenarios where self-defense might be necessary. When conflict resolution skills are not sufficient in de-escalating a conflict, successfully employing self-defense techniques is necessary to protect vulnerable populations like young women. One study at the University of Oregon found positive benefits for female college students who completed a self-defense class [15]. In fact, a national self-defense program which has had over 60,000 people complete their class reported that 97 percent of their graduates were able to fight off their attacker [9].

Using these programs as a model for the ideal self-defense class, we partnered with the Mount Pleasant Police Department to identify aspects of self-defense training that would contribute to successful skill development. Police Officer Justin Nau recommended teaching Krav Maga fighting techniques as they are the techniques that are used in many police and military organizations and are currently taught to sororities that opt-in to training offered by the Mount Pleasant Police Department. He also identified high-risk areas for crime in Mount Pleasant that we could virtually recreate including the local bar called O'Kelly's Sports Bar & Grill, Main Street which hosts a large majority of Central Michigan University's fraternities and sororities, and walking back to the car at night from the library or grocery store. These scenarios were generalized for a wider audience to use for skill development nationwide in hopes that anybody could download KickVR and learn skill development to defend themselves or assist others from becoming victims of violence.

2 System Design

KickVR is a virtual reality simulation, which is "a simulated experience that can be similar to or completely different from the real world" [14]. In this situation, the virtual reality

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simulation is meant to be as real as possible to master a difficult, potentially life-threatening task in a safe environment. During the creation of KickVR, it was easy to access resources necessary to develop the virtual reality simulation, but it was difficult to access the technology required to run and test the simulation. The Oculus Rift CV1 requires the user to have the following minimum system requirements: Intel i3-6100 / AMD Ryzen 3 1200, FX4350 or greater processor, NVIDIA GTX 1050 Ti / AMD Radeon RX 470 or greater graphic card, and 8GB+ RAM. However, to maximize the graphics and processing speed of the Oculus Rift CV1, the user must have the recommended system requirements: Intel i5-4590 / AMD Ryzen 5 1500X or greater processor, NVIDIA GTX 1060 / AMD Radeon RX 480 or greater graphics card, and 8GB+ RAM [5].

By default, the first generation of Oculus Rift headsets comes with two hand controllers. While they are easily tracked within the play-space the user sets up through the Oculus' Guardian System, it reduces the immersion and realism of the simulation. In a real-world situation where self-defense may be necessary, the user will not have hand controllers. The absence of hand controllers in combination with quality, supported hardware systems will allow for deeper immersion and a more quality experience. Instead, KickVR utilizes a Leap Motion Controller mounted on the Oculus headset which tracks the movement of the user's hands in real life to project in the simulation. One limitation of the Leap Motion Controller is that tracking is very limited to only in front of the user's headset. This was an acceptable limitation for this simulation since most self-defense moves are meant to be performed head-on and only used enough to incapacitate or escape the conflict. However, the Oculus Quest 2 that was released to the public in October 2020 solved many of these limitations. The Oculus Quest and Quest 2 has built-in hand tracking and an SDK that allows developers to use hand-tracking in their software. Both Quest headsets have four cameras on the four corners of the headset which is much more accurate than the one forward-facing sensor in the Leap Motion sensor. While there are only three default gestures currently supported by v12 Quest software, combining hand tracking and head mounted virtual reality display should reduce latency and thus improve realism [11].

KickVR also uses applicable, real-life scenarios with instructions from certified Krav Maga experts to guide the users to successfully learn self-defense techniques. The user interface is simple but informative as to not interfere with immersion. Additionally, there are several modules of varying difficulty levels and skill development objectives. The easier modules were developed first with more difficult modules being added incrementally. The module will be comprised of a training portion, an application scenario, and an evaluation of skill development upon completion of the training module with short statistics on that scenario in American society to further enrich and motivate skill development as seen in Figure 1.

The following technical requirements added or being added to KickVR is shown in Table 1 & Table 2. These requirements were prioritized on a three tier system. The first, level 1 requirements, denoted requirements that were implemented by May 2020. The next level, level 2 requirements, denoted requirements that were implemented by December 2020. The final, level 3 requirements, denotes requirements we are either currently working on or planning for future work.

3   User Experience

Hand tracking and hand gestures triggering logic in the simulation are one of the most impressive features of KickVR. Using a Leap Motion Controller mounted to the front of an Oculus Rift CV1 headset, key points like joints and the palm of the hand are found in real life and those positions are replicated in the virtual world. A hand mesh is then projected on those points to make the hand appear in the simulation as seen in Figure 2. Latency between hand movements in real life versus the virtual world were a concern while developing KickVR because small delays in visualization of movements can cause disorientation and motion sickness. Many factors play into response time of hand tracking including hardware, software, and graphics card constraints [1]. The Leap Motion Controller is configured to track a user's hands using three different settings: High-Speed Mode, Balanced Mode, and Precision Mode. High-speed mode focuses on maximizing frames per second while minimizing resolution which is good for games like Drunkn Bar Fight where graphics are not necessary for quality game-play. On the other hand, precision mode focuses on precise hand movements at the expense of frame rate which would be important for simulations that may require the user to interact with objects in the environment. Balanced mode is the middle ground between the two modes and is the default scanning mode.

At the hardware level, there could be as much as a 15 millisecond time difference between using a USB 2.0 versus USB 3.0 port for data transferring [1]. At the software level, the Leap Motion client on the user's PC handles all processing of data transferred from the USB port and cannot be sped up from the user's perspective. For visualization, latency can be affected by hardware components such as operating system, graphics card, monitor resolution, and physical circuitry of the monitor [1]. The average total processing time for the Leap Motion Controller alone is around 60-70 milliseconds since the Leap Motion Controller only uses USB 2.0 speeds [2] which is satisfactory to prevent motion sickness. More settings can be changed to optimize latency including disabling vertical synchronization in graphics card settings and using a higher refresh rate monitor [2].

Complete system latency is a much larger issue when combining two separate hardware systems to achieve the same goal. While the Leap Motion Controller is used for hand-tracking, the Oculus Rift CV1 is in charge of updating what the user sees in the virtual space based on their real world
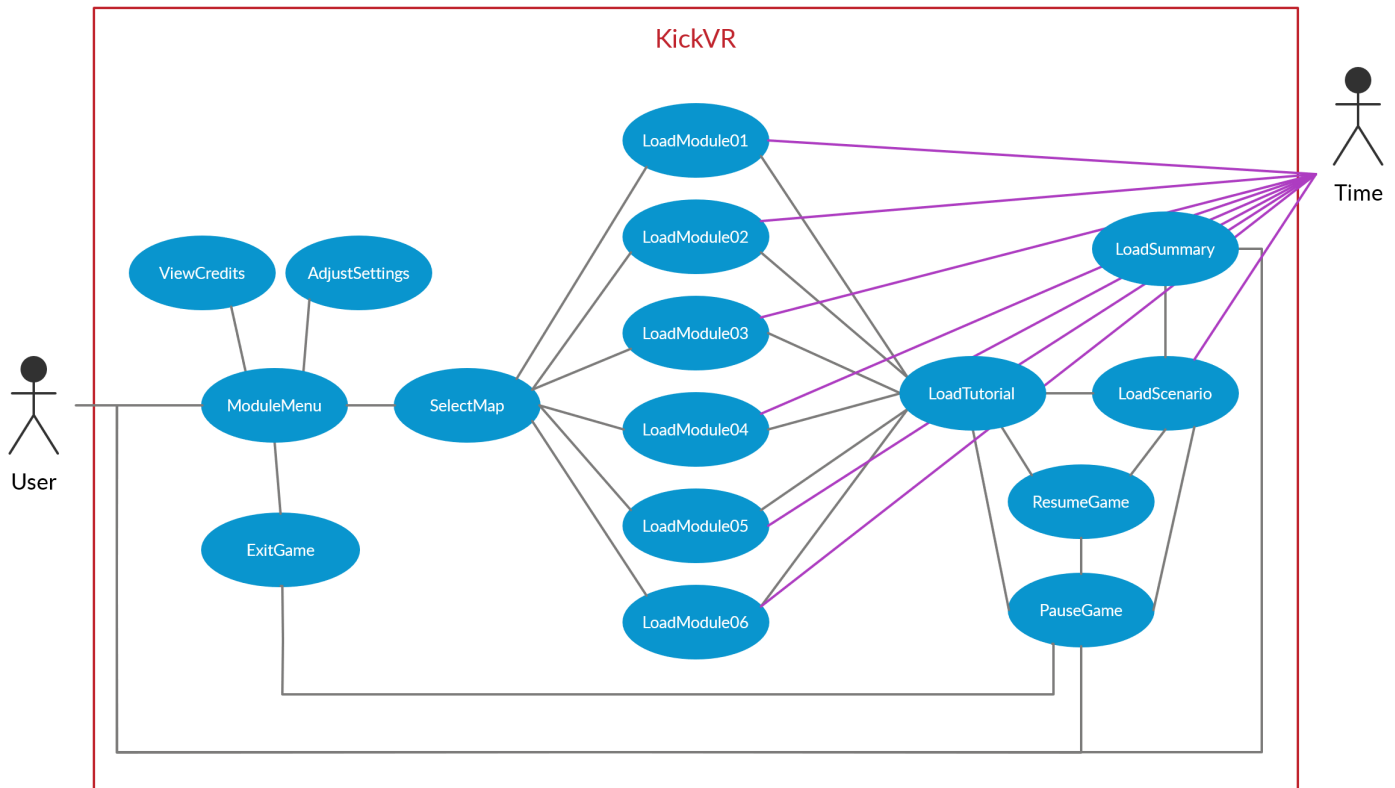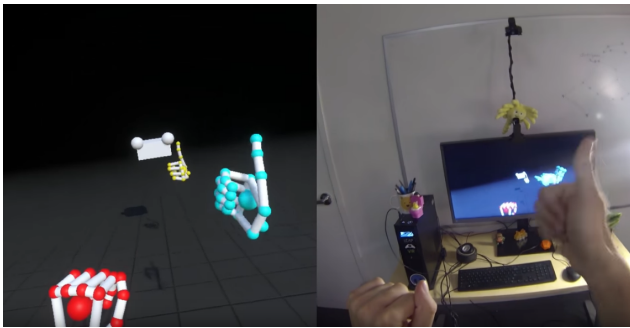
Figure 1: Use case diagram for kickvr

Figure 2: A screenshot of leap motion developers using hand tracking from leap motion's unity core assets[8]

movements. Figure 3 refers to how the user and their Oculus Rift CV1 interact with the KickVR simulation. When actions are made to update the model, view, and controller in KickVR, latency is a factor. The latency between the controller and model via an update request, such as seeing a button appear in the virtual space and the user's hands reacting by moving their hand to click the button, is unavoidable. A joint research project between Microsoft Research and University College London found that the average reaction time when performing a task on a computer was 335 milliseconds whereas the average reaction

time on the Oculus Rift S, the more updated version of the first generation Oculus Rift used for KickVR, was 422 milliseconds [7]. The reaction time of 85 milliseconds was attributed to the average total processing time for the Oculus Rift S alone.

When combined with the latency of the Leap Motion Controller, there could be nearly two-tenths of a second delay between movements the user makes in the real world and movements in the virtual world which increases risk of motion sickness and decreases immersion and realism. As a result, future virtual reality simulations would benefit from an all-in-one virtual reality and hand tracking head mounted display to reduce latency. In December 2019, hand tracking was added to the Oculus Quest and was enabled upon released for the Oculus Quest 2 in October 2020. Cross-platform development for the Oculus Quest and Oculus Quest 2 platforms should be a high priority for KickVR and other virtual reality simulations that use hand tracking to reduce latency and ultimately enhance the user experience.

The user must configure two pieces of hardware for the system. First, the user configures the Leap Motion Controller. Second, the Oculus Rift CV1 "guardian system" is configured, independently from the Leap Motion Controller. Finally, the user executes the simulation, and loads into the virtual hub which acts as a three-dimensional main menu. In this scene, the user can choose which training module and thus which self-
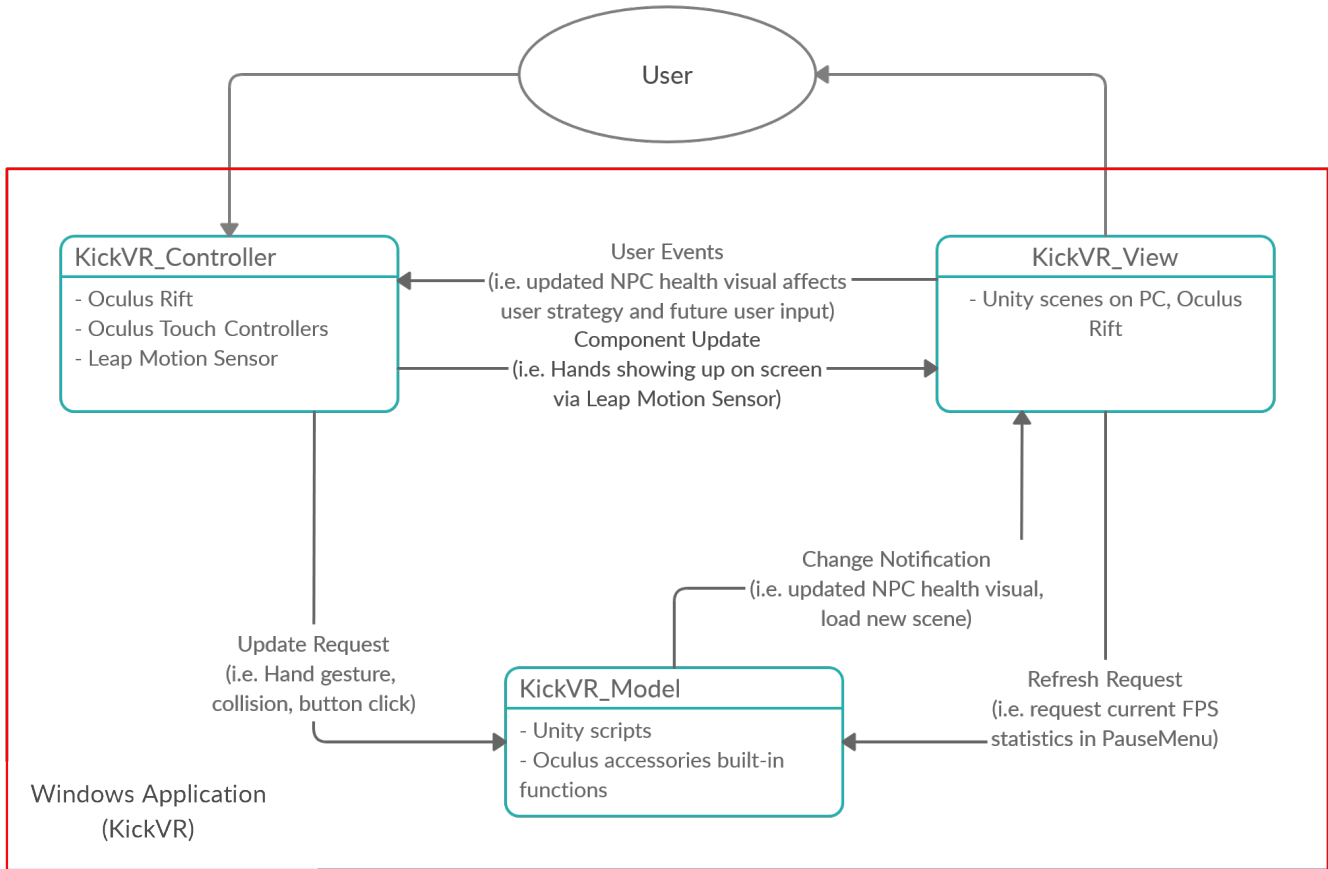
Figure 3: Model-view-controller diagram for kickvr

defense technique they would be interested in learning and can select an environment they would like to apply their skills in as seen in Figure 4.

In each training module, the user completes two segments: a skill development and a skill application segment. The skill development portion is completed first which can be seen in Figure 5. The user will learn that module's skill from a certified Krav Maga expert via video and be able to endlessly practice those skills in a safe gym environment. When they are ready to move on, they use the Leap Motion's hand gestures which take them to the skill application environment they chose in the virtual hub.

There are three environments as seen in Figures 5 and 6: a street scenario at night, a store parking lot scenario at night, and an indoor bar scenario. Additional environments could be added in the future for other common experiences, like being attacked inside a house by an intruder, for user's to have experience with hand-to-hand combat in a wide variety of scenarios. Upon loading into the scenario, the NPC loops through fighting animations such as punching, guarding, and elbowing. The user applies their fighting skills from that training module and previously completed scenarios. The user

is meant to guard themselves from incoming attacks and also attack the NPC when they are vulnerable to a counter attack. The skill application segment ends when the user or NPC loses all of their health. From there, the user is taken to a summary scene which is seen in Figure 7. In this scene, the user can understand all hits they dealt and received via a scoreboard. The point tally is meant to show efficiency of skill application and skill mastery. Higher scores indicate that the user more efficiently utilized their self-defense skills.

The efficiency score is computed via the trigger areas and colliders on the NPC and user models as seen in Figure 8. Trigger areas activate a script when an object comes close to its interaction zone. Colliders, which are slightly smaller than trigger areas, are used as a barrier so models, like the user's hands, do not visually clip into other models, like the NPC's body. Each collider has one trigger. The user has one body and two hand colliders. The NPC model has several colliders including two hand, two arm, one abdomen, one chest, one groin, and one head collider with respective trigger areas. Unless blocked by the user's hand colliders, the NPC deals 50 damage per hit to the user. When a collider on the NPC is struck by the user's hand, a collider script determines which on

Table 1: Functional requirements

Requirement	Priority	Description
FR01	1	The simulation must initially load up to a start screen or main menu.
FR02	1	The user must be able to exit the simulation.
FR03	1	The simulation must have a menu from which the user can select training modules.
FR04	1	The user must be able to control a character in each training module.
FR05	1	The user must be able to receive directions in each training module via signposting and colored visual cues.
FR06	1	The simulation must provide a tutorial and an application in each training module.
FR07	1	The user must receive additional information on that module's self-defense technique or a statistic related to self-defense.
FR08	1	The user must be able to see their physical hands projected virtually in the simulation.
FR09	1	The simulation must have a tutorial training module.
FR10	1	The simulation must have an open-hand strike or punch training module.
FR11	1	The simulation must have an acknowledgment list to give credit to its authors, advisors, and resources.
FR12	2	The simulation should have sound effects and haptic feedback in peripherals to enhance training.
FR13	2	The user should be able to pause and resume their training modules.
FR14	2	The simulation should have a closed-hand strike training module.
FR15	2	The simulation should have an elbow strike training module.
FR16	2	The simulation should grade the user on the effectiveness of their self-defense techniques at the end of each training module.
FR17	3	The user may be able to select the environment they would like to test their skills in during the application portion of their training module.
FR18	3	The simulation may have a grappling training module.
FR19	3	The simulation may have a knee strike training module.
FR20	3	The simulation may have background music samples.
FR21	3	The simulation may have accessibility options to adjust the volume.
FR22	3	The simulation may feature an endless survival mode.
FR23	3	The simulation may feature interactive, physics-driven objects.

Table 2: Non-functional requirements

Requirement	Priority	Description
NFR01	1	The simulation must be playable on Windows platforms.
NFR02	1	The simulation must be developed in Unity.
NFR03	1	The simulation must be compatible with the Oculus Rift/Quest virtual reality system and peripherals.
NFR04	1	The simulation must be compatible with the Leap Motion Controller.
NFR05	1	The simulation must have a functional, aesthetic user interface.
NFR06	2	The latency for loading scenes should not exceed 30 seconds.
NFR07	2	The simulation should have a frame rate of at least 30 frames per second to prevent virtual reality sickness.
NFR08	3	The simulation may be used and enhanced with a haptic vest.
NFR09	3	The simulation may be playable on MacOS platforms.

Figure 4: Module menu (top) and map selection (bottom) in the virtual hub in kickvr

the NPC was struck and increments the respective counter to deduct NPC health. For example, if the user strikes the NPC in the head, it will result in an 80-point decrement of NPC health. Since the head is the most vulnerable part of the human body, which the user learns in the tutorial training module, 80 damage

Figure 5: Training environment in the tutorial module (top) and street scenario (bottom) in kickvr

Figure 6: Store parking lot scenario (top) and bar scenario (bottom) in kickvr

is the most damage the user can deal with damage scaling down for each body part with the minimum damage dealt being 10 if the user hits the NPC's hands.

To improve the user experience and gauge effectiveness of the virtual reality simulation on skill development, a study was created and approved by the Central Michigan University Institutional Review Board in February 2020. In the study, a user would be given an informed consent form and a pre-test of quantitative survey questions to complete as seen in Table 3. Then, the user would be instructed on how to use the virtual reality equipment and how to exit the simulation if they were to experience motion sickness. The user would start the simulation while investigators observe and ensure they do not exit their play space. Upon completion of the simulation, the user would be given a post-test of both quantitative and qualitative survey questions as seen in Tables 3 & 4. However, due to COVID-19 restrictions at Central Michigan University, this study has been postponed until Central Michigan University deems it safe to study human subjects in an enclosed space.

4   Background

While there are many self-defense resources available over the Internet, none combine the educational, realism, and entertainment components of KickVR. There are plenty of services that offer self-defense training such as free videos on social media platforms like YouTube while other mediums come

Figure 7: Skill development summary scene in kickvr

at a price such as physical classes. KickVR combines the benefits of both types of services. With a virtual reality self-defense class, consumers can train through self-paced realistic simulations in the comfort of their own home. Training through the simulation is available 24/7 and users get better, more interactive practice than what passive videos provides. KickVR brings the defense class into living rooms nationwide and help train users to better protect themselves while keeping them in their comfort zone. A survey of our peers found that interest is high in a product like KickVR since self-defense videos garner millions of views and there are many self-defense facilities located around the world. Classes can also be very expensive whereas this product might have a one-time smaller fee similar to a video game or could be a free product.
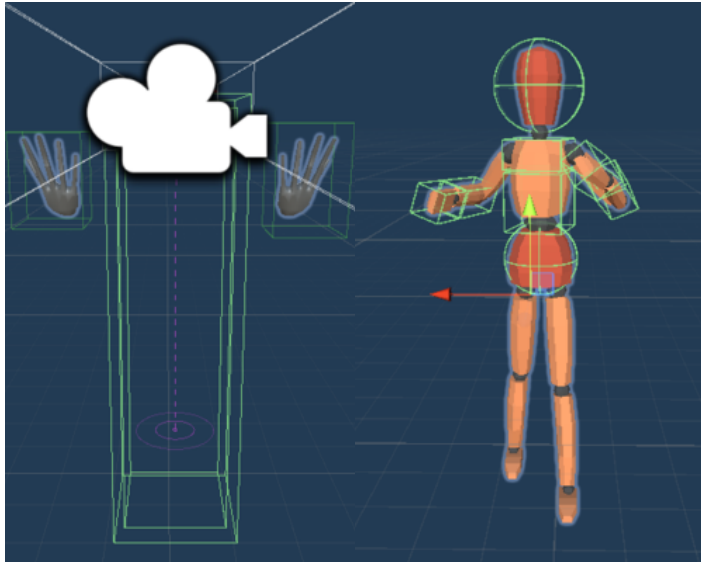
Figure 8: User colliders (left) and npc colliders (right)

Table 3: Quantitative survey questions

Item	Statement
1	I learned something about self defense.
2	I was able to complete the module.
3	I enjoyed the game.
4	I felt challenged by the game.
5	I felt motion sick.
6	I enjoyed the first module.
7	I enjoyed the second module.
8	I found the tutorial to be helpful.
9	I felt the hand tracking was accurate.
10	I enjoyed the combat part of the game.
11	I felt the scoring system was fair.

Table 4: Qualitative survey questions

Item	Question
1	What did you enjoy about the game?
2	Do you see value in virtual reality as a method of training?
3	Do you feel more confident in your ability to defend yourself?
4	What changes would you make to the game to increase your enjoyment?
5	What changes would you make to the game to increase you skill development?
6	Is there any other feedback you would like to add?

Video game marketplaces like Steam feature many self-defense games, but the only similar self defense class that combines gaming and education would be Self-Defense Training Camp, a Microsoft Kinect title that puts players in specific situations and has them mimic the actions on screen to progress through the game. Other video games like Creed:

Rise to Glory and Drunkn Bar Fight seen in Figure 9 bridge the education and video gaming gap, but miss key elements. Creed features realistic boxing combat and boxing technique training, but the goal of the game is to fight for sport and competition. In a real scenario, there are no regulations and someone who is vulnerable needs to be able to protect themselves and counter attacks with every resource available when deescalation is not possible. Drunkn Bar Fight features realistic combat through ragdoll physics and grabbing items in the environment to fight with, but does not teach the user how to properly employ self-defense techniques, solely focusing on video game entertainment. The primary competition are the real physical classes such as Spartan Krav Maga [16] that teach self-defense, and videos that teach self-defense techniques over the Internet. Virtual reality games could also act as secondary competition since this product doubles as a game that is enjoyable to play while informative about self-defense.
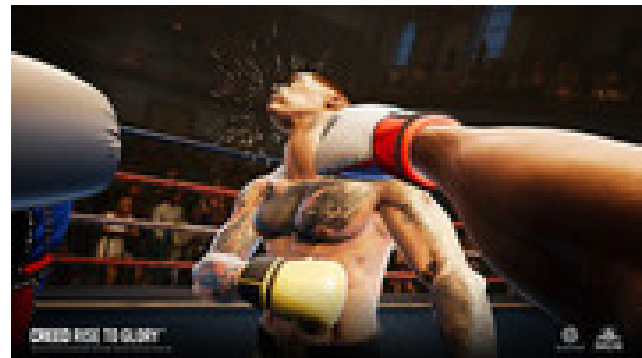

Figure 9: Screenshots of creed: rise to glory [17] (top) and drunkn bar fight [18] (bottom)

On the other hand, self-defense videos are easy to access and can be found online for free. However, they lack real practice or simulation. Viewers might practice the moves shown on screen, but without a scrimmage partner or accountability from an instructor simulating the technique in a realistic scenario, the technique is not developed properly. Physical classes are great for this reason as you can practice the moves taught to participants on other students or the instructor. It can show the user how these self-defense techniques actually work in the real world and let the participant truly practice them. However,

classes can be expensive, require participants to form a schedule around them, show up in person which is difficult in the wake of COVID-19, and can be intimidating for some people, especially those who rarely step foot in a gym or dojo. Our virtual reality self-defense class will let the user choose when to train, and from the comfort of your own home, just like a video. Then, similar to a traditional class, users can practice real-world scenarios through the immersive virtual world. In the end, the virtual reality self-defense simulation doubles as a fun video game and a potentially life-saving course.

Unity and Epic Games' Unreal Engine make virtual reality simulation development possible for most developers. Since Central Michigan University teaches Unity development and has resources and faculty members trained for Unity, KickVR was created in Unity. Unity offers many advantages for VR development including a high definition render pipeline for realistic graphics, spatial audio for positional sounds in the virtual space, and most importantly the ability to build the application for multiple platforms including Android, iOS, Windows, HTC Vive and Oculus Rift [19].

5   Future Work and Conclusion

In this paper, we discussed the motivation for creating KickVR, the development process, our findings, our contributions, and its strengths and limitations. In addition, we reviewed the hand-tracking capabilities of the software and offered some insight: providing a mixed-methods interview rubric approach for how virtual reality simulations can be used for training. We strongly believe that self-defense skill development should be prioritized in society. In addition to the physical benefits of self-defense training, it also provides many psychological benefits. One preliminary study found that self-defense training produced increases in self-esteem, perceived control, and confidence while decreasing anxiety, fear, and avoidance behaviors in women who took a self-defense class [3]. KickVR can satisfy both self-defense competency needs and psychological safety needs.

For future work, we are interested in adding features such as new training modules and environments, like the inside of a house. In addition, building an Oculus Quest-compatible simulation is a major priority for better hand-tracking. Hand-tracking was the most difficult part of developing KickVR because of the need to integrate communications between two hardware devices. The Leap Motion Controller was also prone to visual glitches or lack of accuracy due to smudging on the sensor or competitive calls to the CPU. In December 2019, Oculus announced that they have released in-house hand-tracking capabilities for the Oculus Quest through a software update [12]. This reduces overhead price of running KickVR for consumers since there would be no need to purchase a Leap Motion Controller and it would reduce overhead processing power necessary to run both the Oculus Rift CV1 and Leap Motion accessories simultaneously. This could be implemented by updating the Oculus Integration asset package in Unity and

replacing the Leap Motion hand-tracking GameObjects and script logic with the respective Oculus Integration hand-tracking GameObjects.

To increase realism, we are also interested in implementing inverse kinematics (IK) through Unity's physics engine. IK enables the NPC to be effected by a force applied by the user's hand via a punch. For example, a punch to the left side of the NPC's head would result in the NPC's head moving right while not effecting any script logic. We hope to eventually publish KickVR on Steam for widespread public availability.

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