FireHUD

Virtual Reality Heads-Up-Display Navigation Challenge

Submission Stage 1
Firefighter Scenario

NextGen Interactions LLC
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Abstract

Future firefighter heads-up displays (HUDs) have the potential to enhance public safety significantly. However, such HUDs and related augmented reality (AR) technologies are still at an early experimental stage and are not yet ready to be used. Even in the cases where the technology is ready, it can be difficult to evaluate and optimize their use in the context for which they will be deployed. However, we can more easily prototype HUD /AR technology and simulate the environment in which that technology will be used by using today's virtual reality (VR) technologies.

FireHUD will be a VR interface for firefighters that utilizes visual, auditory, and vibrotactile cues to propel HUD development, usage, and evaluation of future HUDs in realistic simulated contexts for which they will be used. The solution aims to maximize comfort, ease-of-use, and navigation through environments without distraction. In addition to having a typical HTC Vive interface, we will focus on the following:

- Thermal imaging, seeing through smoke, and x-ray vision
- Issuing commands, changing interface mode, selecting objects, and placing markers
- Navigation
- Use of appropriate reference-frames to maximize comfort and usability

We believe our interface will have a significant impact on the future of public safety. The results of this system could be used across a broad range of use cases that focus on navigation through dangerous environments. Most notably, knowledge gained from experimenting with these VR prototypes could be incorporated into future firefighter technologies, such as HUDs, smartwatches, and communication tools. For example, our binocular–occlusion solution could increase eye comfort in future AR systems, our hand reference frame interface could correspond to smartwatch implementations, and real-time placement of markers could inform other first responders of important items at their location in the environment.

FireHUD—Project Description

1 Strategic Alignment

1.1 Approach

Today's state-of-the-art VR systems and interfaces can be quite compelling, and they have enormous potential for simulating firefighting scenarios and for training. However, even today's best VR systems and their implementation have their challenges. In addition, a VR project cannot possibly be completely defined in advance; VR implementations very much depend on factors, such as use case, targeted audience, and goals. Therefore, we will take a highly agile/iterative approach that we have developed over the years for several different VR projects, along with feedback from firefighters. We will focus on creating comfortable and highly usable HUD interfaces that can be utilized in various firefighting scenarios.

1.2 Real-World Application

VR has enormous power when interactions do not necessarily match reality. Unrealistic interfaces can work well for a game, but they may not work so well for simulating the real world or for evaluating performance and training applications where results and skills from the simulation do not transfer to the real world. For example, teleporting long distances can be useful in a VR game, but it is probably not a good technique if the intent is to deploy the results to real-world firefighters in the field. We will design our HUD interface to correspond to real-world applications and/or for simulating HUD/AR displays that could be expected to be deployed in the field in 5–10 years.

Ecological validity is the degree to which results approximate real-world application. Performance metrics should not only consider best possible scores (e.g., lowest time-to-completion) but should also take into account how well those measures apply to real-world performance (i.e., the measures should have ecological validity). For example, a firefighter with a basic VR interface could simply flip a virtual switch to put out a fire immediately. However, a firefighter trained to flip a virtual switch would not necessarily perform well in a real-world fire scenario. In addition, there could be problems of more general external validity; experimental results showing that one interaction technique is better than another technique might only apply to a specific scenario, the type of user, or the specifics of the VR system. Therefore, we will first use constructivist approaches to iterate upon our solutions. *Constructivist approaches* construct understanding, meaning, knowledge, and ideas through experience and reflection upon those experiences rather than try to measure absolute or objective truths about the world. This approach focuses more on qualitative data, emphasizing the integrated whole and the context in which the data is collected. Most importantly, the constructivist approach will be based on obtaining feedback from subject-matter experts: firefighters.

Once we have refined the interface for firefighter needs, we will collect objective measurements, such as task completion time, number of errors made, and goals achieved. Such objective measures will be valuable for comparison between the interaction techniques after those techniques are refined.

2 Technical Outcome

In addition to a standard Vive implementation (i.e., a room-sized VR experience with hand tracking and audio/visual/vibrotactile cues), we will focus on the challenges and solutions for a firefighter scenario as described below. Note that we may not be able to deliver all of these features given the short time and limited resources. We will prioritize features based on feedback from firefighters.

2.1 Thermal Imaging, Seeing through Smoke, and X-Ray Vision

We plan to simulate thermal imaging by enabling seeing through smoke by replacing the real world with virtual geometry (Sketch 1) and to augment human vision by drawing visual cues that would normally be obstructed by real-world objects (i.e., a type of "x-ray" vision, Sketch 2). For seeing through objects, overlaying information on top of virtual geometry (for VR) or real geometry (for AR) can be a problem due to occlusion depth cues not matching binocular cues (*binocular–occlusion conflict*). The HTC Vive Chaperone is an example of such a conflict occurring: The safety grid fades in, even when the grid should be occluded by geometry in front of the grid to avoid binocular–occlusion conflict. This can be subtle but confusing and uncomfortable for users. We will solve this by using custom-built shaders to project navigation cues that would normally be occluded (e.g., breadcrumbs or a victim) onto the surface of the occluding geometry, which will effectively enable firefighters to see comfortably through walls and other geometry.

Today's VR systems appear optically at a single depth, even though the eyes naturally converge to different depths (*vergence–accommodation conflict*). Although this cannot be completely solved using today's consumer head-mounted displays (HMDs), we can minimize its effect by putting HUD elements at a distance from the user since this conflict is most problematic at close distances.

2.2 Issuing of Commands, Changing Interface Mode, Selecting Objects, and Placing Markers

We will implement different interface options so that those different options can be compared. We hypothesize that a hand-held panel will be best for changing interface modes and entering commands and that pointing with a hand will be best for selecting objects and placing markers.

2.3 Navigation

We would like to better understand navigation requirements from PSCR before deciding upon specific navigation techniques. For example, is virtual navigation needed, or will the environment be small enough to fit within a Vive-tracked space? We suspect we will use a limited form of teleportation (to minimize motion sickness) where teleportation distances are not to exceed what could reasonably be achieved by physical steps to improve ecological validity. If matching the real world is not important, then we will investigate integration of other techniques, such as teleporting to locations defined by pointing at a world in miniature, such as a 3D map, held in the non-dominant hand.

2.4 Use of Appropriate Reference Frames

A *reference frame* is a coordinate system that serves as a base to locate and orient objects, and an appropriate usage of reference frames is important for creating comfortable and usable interfaces. We will consider placing interface elements in the following reference frames when iterating upon our solution.

Head Reference Frame. The *head reference frame* is based on the point between the two eyes and a reference direction perpendicular to the forehead. For a HUD implementation, the head reference frame is equivalent to the HMD screen coordinate system. Systems that only allow for placing information in the head reference frame are often called AR displays, but they are more appropriately called information displays (e.g., Google Glass), since the displayed information does not spatially correspond to objects in the real world. Advantages of using this reference frame include information always being visible and the use of head-gaze selection, which may be quite important for firefighters who need to keep their hands free for other tasks. Disadvantages include visual information getting in the way and excessive use of this reference frame can cause nausea and eye strain. For cues in the head reference frame, we will make them large enough to be easily perceivable/readable, but small enough to not be obtrusive. We will also minimize the number of visual cues to not be annoying or distracting, put cues at an appropriate peripheral distance, give the cues depth so other objects occlude them properly, and place the cues at a far enough distance so that there is not an extreme vergence–accommodation conflict. In addition, we will explore making the cues translucent.

Hand Reference Frames. Hand-centric visuals are especially important when using a phone, tablet, or VR controller. A smartwatch's pose can be estimated by putting it on the back of the hand (Sketch 3); it would be better to put a simulated watch in a wrist reference frame, but most VR systems do not track the wrists. Placing signifiers, such as labels or icons, in the hand reference frame that point to interface elements will be especially helpful to new users, but experienced users will be able to turn off those signifiers. Although both the left and right hands can be considered separate reference frames, the non-dominant hand is useful for serving as a reference frame for which the dominant hand to work.

Torso Reference Frame. The *torso reference frame* is defined by the body's spinal axis and the forward direction perpendicular to the torso. The torso reference frame is especially useful for interaction because of proprioception, most importantly the sense of where one's hands are felt relative to the body. Just like in the real world, tools in VR can be attached to the body, so they are always within reach no matter where the user goes. This not only provides the convenience of tools always being available, but also takes advantage of the user's body acting as a physical mnemonic, which helps in the recall and acquisition of frequently-used control mechanisms. Examples of mnemonics in the torso reference frame are pull-down menus located above the head, tools surrounding the waist as a utility belt (Sketch 4), navigation options at the user's feet, and deletion by throwing an object behind the shoulder (and/or object retrieval by reaching behind the shoulder). The default HTC Vive system does not provide torso tracking, although the torso pose can be estimated from head and hand tracking. A Vive tracking puck can be used to track the torso, which can dramatically improve the usability of an interface by placing interface elements more accurately in the torso reference frame.

Virtual World Reference Frame. The *virtual world reference frame* matches the layout of the virtual environment and includes geographic directions (e.g., north) and global distances (e.g., meters) independent of how the user is oriented, positioned, or scaled. Cues enhancing the visibility of the simulated world (e.g., the outline of a doorway) or things in the world, such as a victim (Sketch 1), as well as environmental wayfinding aids, such as footprints (Sketch 2) and waypoints, should be placed in the virtual world reference frame.

Real-World Reference Frame. The *real-world reference frame* is defined by real-world physical space and is independent of any user motion (virtual or physical). The Vive Chaperone system is displayed in the real-world reference frame when the user approaches a physical boundary, decreasing the likelihood that the user will get hurt by bumping into the real world. We will use the Vive's default Chaperone system, but, otherwise, we do not plan to utilize the real-world reference frame for this project.

3 The Team

NextGen Interactions has created VR experiences on most major VR platforms and has worked with market-leading clients, such as AT&T, Logitech, and Oculus. Recent projects include MakeVR—an immersive modeling program in partnership with HTC, Sixense, and Digital ArtForms, which has been HTC Viveport's best-selling non-game app; DinoDigger—an educational game incorporating physical touch in partnership with Merge VR and Jack Horner's World of Dinosaurs; and VR Apocalypse—a game that works with the Virtuix omnidirectional treadmill that was demonstrated on ABC's *Shark Tank*. NextGen Interactions recently won the NIST Virtual Public Safety Test Environment Challenge.

The project will be led by **Jason Jerald, PhD**, one of the world's leading authorities on VR. Over the last 20+ years, Jason has personally worked on over 70 VR projects with over 40 organizations, including Valve, Oculus, Virtuix, Sixense, NASA, AT&T, General Motors, Raytheon, Lockheed Martin, three U.S. national laboratories, and five universities. Jason's work has been featured on ABC's *Shark Tank*, on the Discovery Channel, in *The New York Times*, and on the cover of the MIT Press journal *Presence*. He has held various technical and leadership positions, and he has served on the ACM SIGGRAPH, IEEE Virtual Reality, and IEEE 3D User Interface Committees. Jason earned a Bachelor of Computer Science with a computer graphics emphasis and minors in mathematics and electrical engineering from Washington State University. He earned a Master's and a Doctorate in Computer Science from the University of North Carolina at Chapel Hill, focusing on perception of motion and latency in VR. Jason has authored publications and patents directly related to VR, most notably the best-selling book *The VR Book: Human-Centered Design for Virtual Reality*.

Although NextGen Interactions has expertise in VR, we do not have expertise in firefighting. Therefore, we will work with **Edmund Blake Boyd, Interim Fire Captain, Cary Fire Department** to help define the solution and iterate upon it from a firefighter's perspective. Mr Boyd will also invite his firefighter contacts to try the system in order to obtain further feedback.

4 Plan

We have developed agile processes over the years that are specific to VR. Regardless, each VR project is unique and poses specific risks. The greatest challenge for this project will be to build and iterate upon the proposed concepts in a short time. Another challenge is the lack of publicly available Unreal Engine assets compared to Unity in that most non-standard components will need to be created from scratch.

Below is a description of some of the most important points for directing and managing the project that will lead to the project's success.

4.1 Design with and Feedback from Firefighters

Working with the intended audience and subject-matter experts is essential for any project. Fortunately, the target audience is obvious for this project (firefighters), and we have interest from multiple firefighters who will help design the interfaces and provide feedback on prototypes.

4.2 Prioritization of Features

Given the short amount of time, we may not be able to implement all of the features described in Section 2: Technical Outcome. We will prioritize the features based on input from firefighters.

4.3 Issue Tracking and Daily Meetings

All issues will be tracked in a JIRA backlog and Kanban board. We will have short daily meetings, where team members will discuss their progress, their challenges, and their next tasks.

4.4 Version Control

We store all code and assets in a Bitbucket Git repository. Our branching flow consists of groupings that correspond to components defined in our tracking system. Branches within those component groupings consist of epics, small groups of issues, and individual issues. We will aim for weekly releases (sprints) with each release receiving a new version. Those versions will be tagged, so we can return to those working versions to maintain stability and to test consistently on specific implementations.

4.5 Testing

Testing is essential for VR development since there is much that can go wrong with even seemingly minor changes. Our tester will spend approximately 10 hours/week cycling through test cases, while focusing on testing the latest changes. All bugs will be entered into our system, and they will automatically appear in the backlog, where they will be prioritized and selected for fixing.

4.6 Evaluation

We will wait to define the specifics of what the evaluation will be since we expect that to be more clearly defined by PSCR. We suspect the evaluation will consist of measures, such as time-to-completion, number of errors made, and goals achieved.

Jason Jerald, PhD

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Citizenship: U.S.

EXECUTIVE SUMMARY

Dr. Jerald is Co-Founder and Principal Consultant at NextGen Interactions, is Adjunct Faculty at Duke University, serves on multiple advisory boards of companies focusing on VR technologies, and speaks about VR at various events throughout the world. Jason has been creating VR systems and applications for over 20 years. He has been involved in over 70 VR-related projects across more than 40 organizations including Valve, Oculus, Virtuix, Sixense, AT&T, NASA, General Motors, Raytheon, Lockheed Martin, three U.S. national laboratories, and five universities. Jason's work has been featured on ABC's *Shark Tank*, on the *Discovery Channel*, in the *New York Times*, and on the cover of the MIT Press journal *Presence*. He has held various technical and leadership positions, and has served on the ACM SIGGRAPH, IEEE Virtual Reality, and IEEE 3D User Interface Committees. Jason has authored over 20 publications and patents directly related to VR, most notably *The VR Book: Human-Centered Design for Virtual Reality*.

PRIMARY POSITION

NextGen Interactions (2012-Current)
Co-Founder and Principal Consultant
Consulting and contract services for virtual reality

EDUCATION

Ph.D., Computer Science, UNC-Chapel Hill (2009)
Dissertation: Scene-Motion- and Latency-Perception Thresholds for Head-Mounted Displays
Under the direction of Frederick P. Brooks, Jr.

M.S., Computer Science, UNC-Chapel Hill (2003)
Latency Compensation for Head-Mounted Virtual Reality

B.S., Computer Science, Washington State University (1998)
Computer Graphics Specialization, Minors in Mathematics and Electrical Engineering

PROFESSIONAL & RESEARCH EXPERIENCE

NextGen Interactions (2012-Current)
Co-Founder and Principal Consultant
Consultant for strategic/technical business advising, team lead for building systems and applications, and lead curriculum designer/instructor for professional VR courses. Clients/partners include Oculus, AT&T, Sixense, Merge VR, and Virtuix.

Duke University, Pratt School of Engineering (2016-Current)
Adjunct Assistant Professor
Investigation and reduction of VR sickness.

Digital ArtForms (2009-Current)
Chief Scientist & Senior Software Engineer
Started as a Senior Software Engineer before transitioning to Chief Scientist. Past work includes:
-Developed software for various projects focusing on next-generation human-computer interfaces.
-Original primary investigator on an NIH funded SBIR grant titled "Motion-Controlled Gaming for Neuroscience Education."
-Conducted user studies that illustrated Digital ArtForms' technology is 4.5-4.7 times as efficient as the mouse and keyboard for fundamental 3D tasks.

-Delivered systems to Valve Software, University of Maryland Medical School, and Wichita State University
-Technology presented at ACM SIGGRAPH, IEEE 3DUI, and RSNA.
-Led proposal writing.
-Participated in partner/client relations and strategic business planning.

Waterford Institute of Technology / TSSG (2015-2016)
Adjunct/Visiting Professor
Advised the university on commercializing virtual reality technologies through TSSG (Telecommunications Software and Systems Group).

UNC Chapel Hill (2001–2009)
Research Affiliate, Effective Virtual Environments Research Group
Investigated what makes immersive environments effective. Activities included modeling, real-time rendering, system integration, human computer interaction, software and hardware development, latency reduction / compensation, user studies, and demonstrations.

NASA Ames Research Center (2005)
Researcher, Advanced Display and Spatial Perception Laboratory
Designed, implemented, ran psychophysics studies, and analyzed data for real and simulated motions in virtual and augmented reality.

HRL Laboratories (1998-2003)
Research Staff, Human-Centered Systems Department
Researched and developed interactive computer graphics applications.
Projects included Distributed Design Review In Virtual Environments (DDRIVE), Eye Gaze Correction for Videoconferencing, Human Computer Symbiotes, Virtual Immersive Environments with Windows (VIEW), Immersive Visualization for Computational Electromagnetics, a PC CAVE cluster, and setup and maintenance of the world's first re-configurable CAVE.

Washington State University (1998*)*
Research Assistant, Imaging Research Laboratory
Developed volumetric/implicit surfaces software (as a Maya plug-in), that takes a "skeleton" and grows "skin" by expanding to an implicit surface. The surfaces are smooth and get rid of the bulge problem evident using other methods.

Argonne National Laboratories (1997)
Intern, Mathematical and Computer Sciences Division
Designed software to be used in the CAVE (CAVE Automatic Virtual Environment).
Integrated custom software, OpenInventor, the CAVE Library, and the I_COLLIDE library from the University of North Carolina.

Battelle Pacific Northwest National Laboratories (1996)
Intern, Immersive Virtual Environments Laboratory
Collaborated with a small team on the design, implementation, and improvement of a virtual medical environment
Work included the intertwining of volumetric data along with traditional polygonal-based modeling.
Responsibilities included the majority of programming for the virtual environment.

Westinghouse / ICF Kaiser Hanford (1993-1994)
Intern, Design Services
Created visualizations to support solutions of waste storage problems.
Evaluated software releases such as 3dStudio and AutoCAD.

ADVISORY BOARDS

Burnout Game Ventures (2014-Current)
Strategic advice for a virtual reality startup company still in stealth mode.
CI Dynamics (2014-Current)
Strategic advice for a startup focusing on real-time simulation for virtual reality, gaming, and film.
Sixense Entertainment (2012-Current)
Provide advice on motion-tracking software and hardware for entertainment.

Edmund Blake Boyd

ACCOMPLISHMENTS

- Home Fire Prevention Campaign Coordinator – Multiple Smoke detector installation drives in Wake County with the American Red Cross
- Presidential Volunteer Service Award
- Star Spot Award for excellent job performance during 2015 Accreditation
- Center for Public Safety Excellence Fire Officer Designation in 2016
- Attending the Managing Officer Program at the National Fire Academy

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CERTIFICATIONS

- Instructor 3 – 10/2015
- Fire Officer 3 – 11/2014
- Fire and Life Safety Educator 2 – 01/2016
- Rescue Technician VMR, Ropes – 12/2005

DESIGNATIONS

- Fire Officer – Center for Public Safety Excellence – 2/2016
- Managing Officer – National Fire Academy – Currently Attending

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PROFESSIONAL EXPERIENCE

INTERIM FIRE CAPTAIN, CARY FIRE DEPARTMENT

2000 – Current

COMMUNITY PARTNERSHIP COORDINATOR, AMERICAN RED CROSS

2015 – Current
Lead coordinator for the Home Fire Prevention Campaign in Wake County

DISASTER ASSISTANCE TEAM RESPONDER, AMERICAN RED CROSS

2015 – 2016
Responded to homes damaged by fires and floods to conduct damage assessments and aiding families in need through initial financial assistance

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EDUCATION

FAYETTEVILLE STATE — BS FIRE AND EMERGENCY SERVICES ADMINISTRATION

GPA 3.923 — Chancellor's List Honoree — Graduated 12/2016

COASTAL CAROLINA CC — AAS FIRE PROTECTION TECHNOLOGY

GPA 3.903 — Presidents List Honoree — Graduated 12/2014

Strategic Alignment

- Enhance public safety through new firefighting interfaces
- Evaluate and optimize new HUD technologies and their use
- Focus on ecological validity of interfaces—design to correspond to viable future technologies
- Improve training that better matches the real world resulting in better training transfer
- Inform what interfaces are best suited for different firefighting tasks

Technical Outcomes

- Thermal imaging, seeing through smoke, and x-ray vision
- Issuing commands, changing interface mode, selecting objects, and placing markers
- Navigation aids
- High comfort and usability through the use of appropriate reference frames

Team

- NextGen Interactions, a VR/AR firm consulting and contracting firm, was founded in 2012
- Clients include AT&T, Logitech, & Oculus
- Built VR applications on most all major VR platforms
- Primary Investigator Jason Jerald, PhD, has 20+ years building VR systems & applications

Plan

- Design with and obtain feedback from firefighters
- Prioritize features
- Track issues
- Short daily meetings
- Version control
- Testing
- Evaluation

NEXTGEN Interactions
Consulting & Contracting Services

FireHUD

January 23, 2018

Jason Jerald
NextGen Interactions LLC
3701 Rolston Dr
Raleigh, NC 27609

Re: VR HUD Navigation Challenge

Dear Dr. Jerald,

I am writing to give my enthusiastic support in working with NextGen Interactions for the NIST PSCR VR HUD Navigation Challenge. I am especially excited about work to implement VR into the operations of the fire service from multiple aspects. I see the possibility of these advances dramatically changing how we evaluate our service delivery, current processes and procedures, and how we conduct training to not only be more effective but consistent and safer overall.

My primary contribution will be to serve as advising subject-matter expert on firefighting. Specifically, I will help to define how the system will be useful for firefighters and provide feedback on prototypes. Given my extensive firefighting experience and being a HTC-Vive VR user, I believe my input will be quite valuable in what will result in a competitive system for the contest.

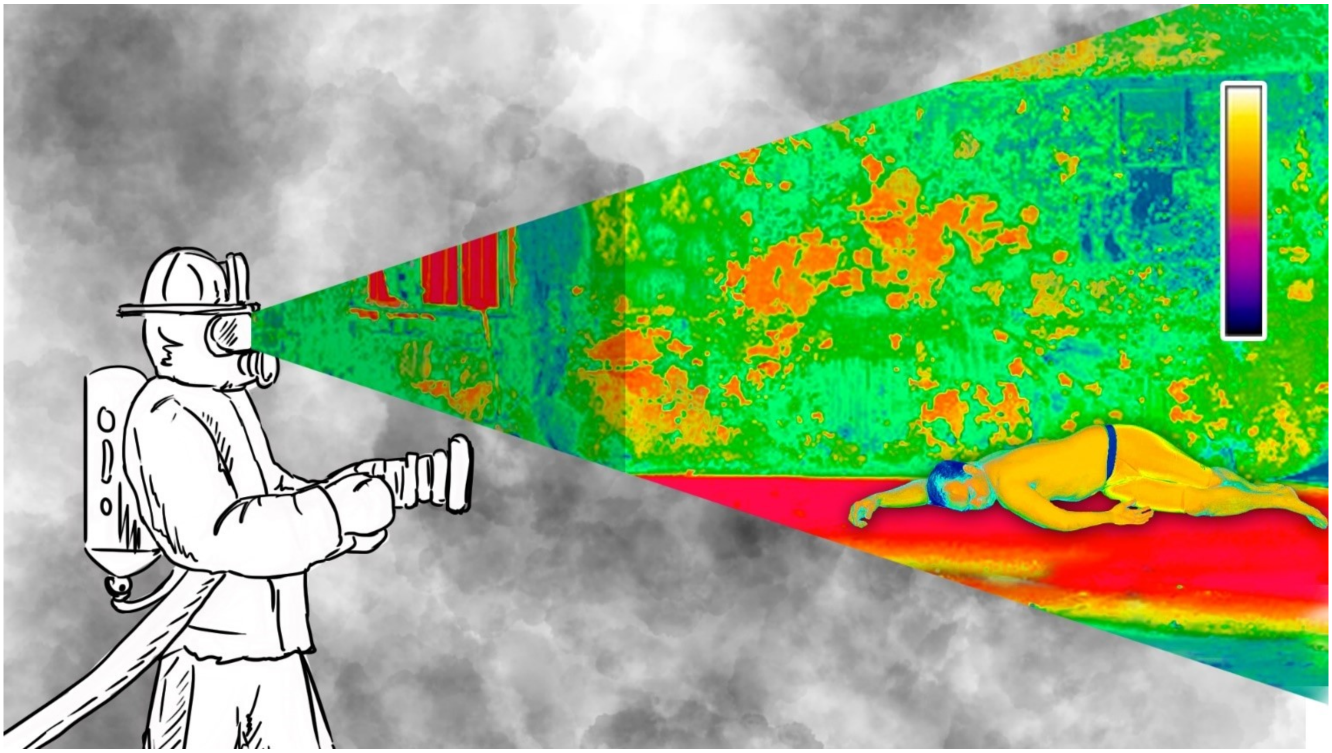
I hope to continue our efforts to iterate and even revolutionize how VR technology will change public safety for the better. If you require any additional information in processing this proposal, please do not hesitate to contact me directly at caryfd227@gmail.com.

Best regards,

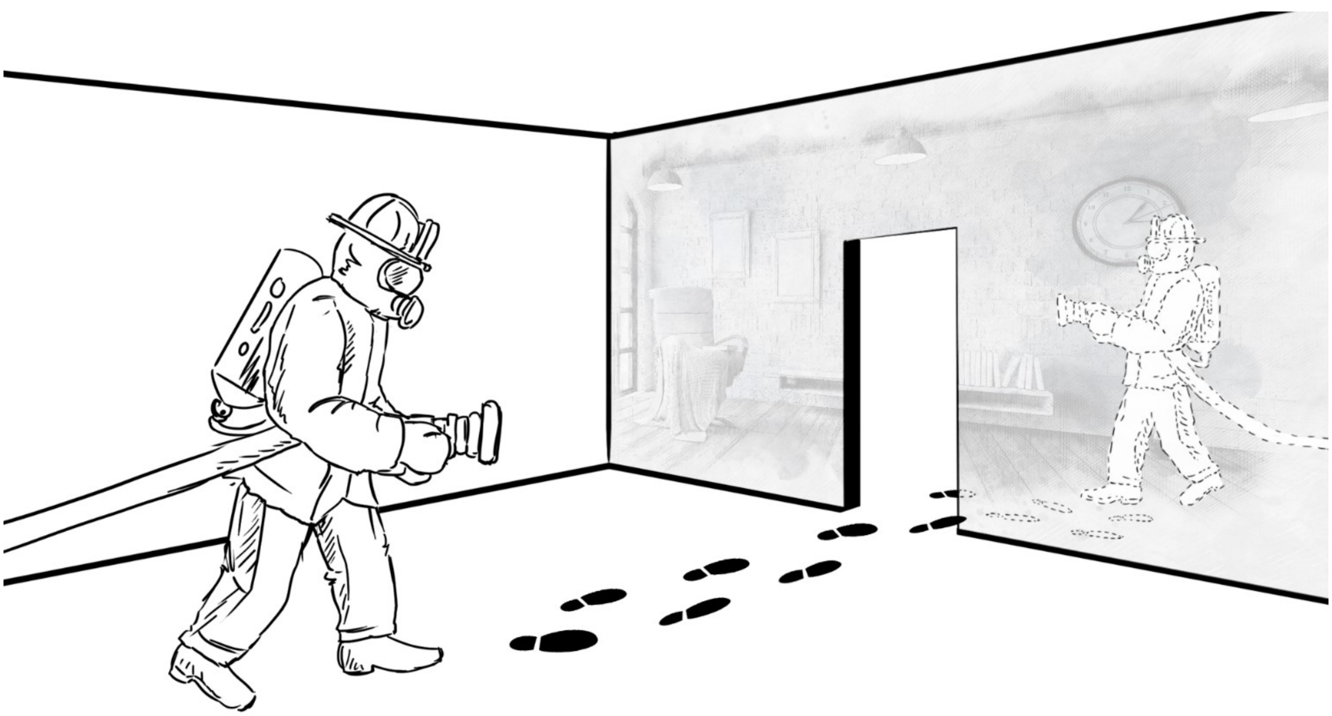
Blake Boyd

Interim Captain
Cary Fire Department
Station #1 – C-Shift Ladder 1

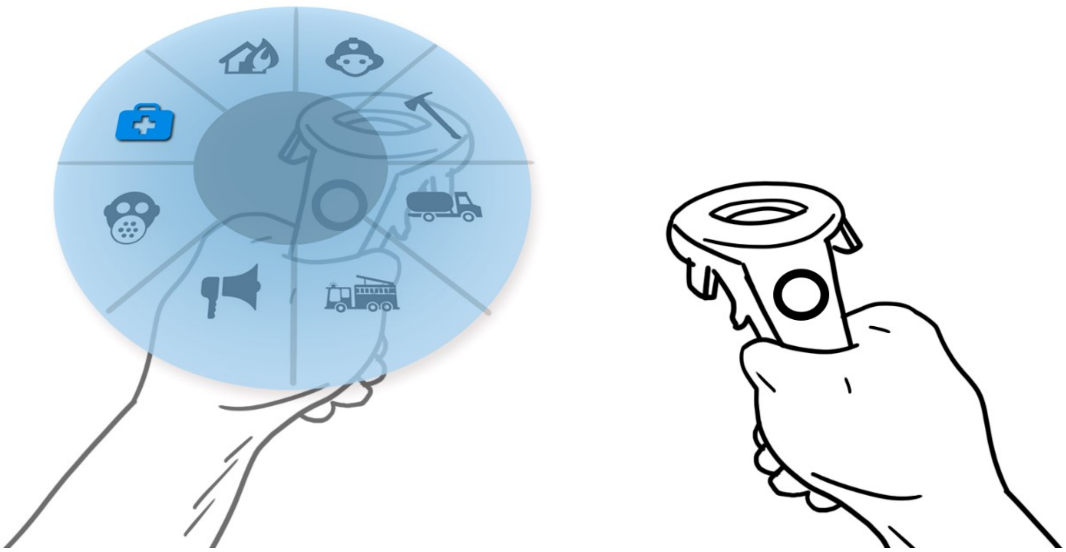
105 Ridge Lake Drive
Apex, NC 27539



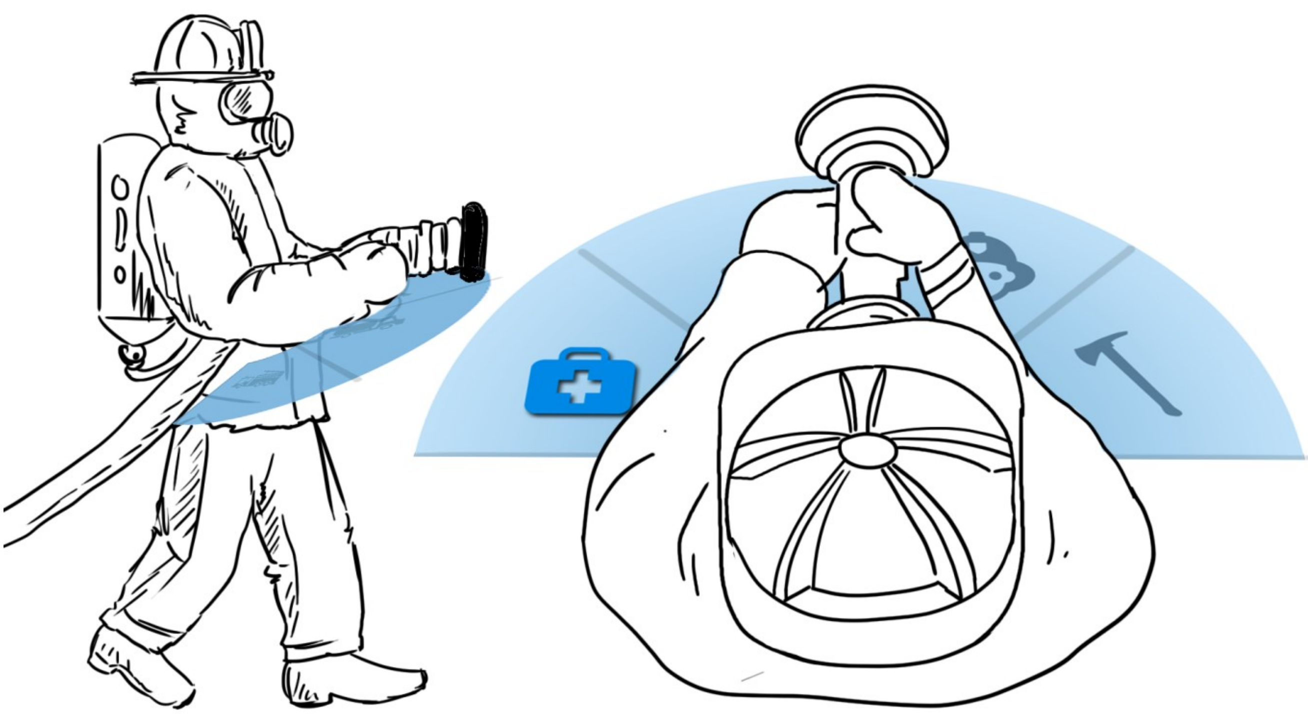
Sketch 1. *Directly viewing thermal imaging. In contrast to typical thermal systems that are on a hand-held device, thermal images could be directly mapped to the world from the perspective of firefighters. We could compare performance with this version with a version simulating a hand-held thermal imaging display.*



Sketch 2. *X-ray vision with occluded cues drawn on the walls to prevent binocular-occlusion conflict. By projecting occluded objects on the walls instead of drawing them behind the walls, we expect firefighters to have more comfortable and less confusing experiences.*



Sketch 3. *Circular Interface above the non-dominant hand reference frame. The user could interact by the touchpad on the Vive Controller, by pointing with the Vive controller in the dominant hand, or looking at the icon of interest and pushing a button.*



Sketch 4. *An interface in the torso reference frame. The interface travels with the user without getting in the way when looking in the forward direction. The firefighter could select tools by pointing with the Vive controller and pushing a button or by looking at the tool and pushing a button.*