Company Name: DeepScience Ltd

Application Title: Enhancing Real Emergency Outcomes through VIRTUAL: Virtual Intelligent Reality Technology Using Adaptive Loops

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Abstract

When we think of human-machine interaction in a first responder setting, we often think of the help that machines can provide to humans. This is a one-way flow of information, whether it be the oxygen readout on a SCBA pack, information from temperature sensors, or even the tools we may use to fight fires. Now let us develop that concept further. Imagine a feedback loop in which the human provides feedback to a machine that uses that information to inform where the human might go next, taking into account sensor data and chosen mission objectives. This is essentially the concept of VIRTUAL: Virtual Intelligent Reality Technology Using Adaptive Loops.

VIRTUAL will provide a unique competitive advantage by operating a real-time, AI-driven, adaptive feedback loop. Voice feedback from an HUD microphone coupled with current/historical sensor data and operational parameters guide the navigational and non-navigational decisions made by the AI, which in turn guides the firefighter who once again provides additional feedback. There will also be a self-rescue mode where the firefighter will receive visual reminders of necessary actions as well as prompts to get more information about the surroundings to inform routes for escape.

The proposed approach would have significant impact in achieving the goals of this challenge. That is because a firefighter can never be fully prepared for all events. That is why having an AI navigation and rescue assistant that can act as another set of eyes while providing constant guidance can improve a firefighter's level of preparedness, safety, efficiency, and chance of mission success. Ultimately, saving time on the fireground means saving both property and lives which we see as the real goal of this challenge.

References

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Project Description

1. Knowledge, Skills, and Capabilities at DeepScience Ltd

In this proposal, we will demonstrate how our approach is not only aligned with the goals of this challenge, but is responsive to the firefighter scenario and will have a significant real-world impact there when implemented. Before we describe our approach, let us provide a brief overview of our team and the knowledge, skills, and capabilities we bring to this project.

[Evaluation Point 2.1: Team] For the past 3 years, DeepScience has primarily conducted scientific research and development using the tools of artificial intelligence and AR/VR. We see AI as the select tool for turning data into actionable information and AR/VR as the means for a user to interact with that information. However, we have also investigated beyond this simple one-way flow of information. One of our key interests is the development of software that will support an AI-VR feedback loop, the central concept behind VIRTUAL. Through such a loop, a user's sensor and motor input in response to a VR environment would directly affect the decisions made by the AI, thereby changing the output available to the user in the VR environment and so on.

We are a small company led by 2 researchers/developers but we have won several innovation awards in the past 3 years, proving that we have the R&D skills necessary to be self-funding. For 2017 our project lead, Dahl Winters, was the 3rd top solver on InnoCentive, a network of 380,000 registered problem solvers tackling the most challenging problems in R&D. We have successfully followed through on several projects while maintaining ongoing research collaborations with large multinational companies such as AstraZeneca and RTI International. While we have not worked specifically in public safety, we have had a history of serving clients in the defense and intelligence community through development of AI software products. If selected to advance in this competition, we will have the availability and resources to address this project with a high chance of success.

[Evaluation Point 1.1: Strategic Alignment] We will now demonstrate the alignment of our approach with challenge goals and the likelihood of significant impact. Our HUD solution, VIRTUAL, will involve a fusion of our AI algorithmic work with our VR software development skills as well as our ability to perform hardware/software system integration. We aim to provide research-based advances in User Interface (UI) technology displayed in the HUD by powering the data display and visualization with AI that is responsive to user feedback. This type of adaptive system will enable first responders to always have the necessary information at hand without needing to find it. This will enable them to be able to complete their tasks efficiently, safely, and effectively, leading to significant measurable impact in real world outcomes.

[Evaluation Point 1.2: Technical Outcome] Our proposed approach will result in a significant improvement in commercially available technology as well as a technical outcome that will enable considerable progress toward the challenge goals. That is because as of today, there is no commercially available, adaptive, AI-driven VR system of the type described by VIRTUAL. Its development will mean that first responders will have their own personal AI constantly integrating user feedback and sensor data in a changing environment to provide the best possible strategy to meet mission objectives.

We recognize that the goal of this challenge is ultimately to provide a solution that saves time, money, and lives in emergency scenarios. A human cannot integrate incoming information as rapidly as an AI, yet it is the human who will be the one carrying out the necessary tasks to accomplish the mission. It is he or she who must perform the search and rescue for victims or control fires before they get out of hand. Thus, a solution that loops information between the human and AI is a technical outcome that would meet the goals of this challenge.

2. Current State-of-the-Art in the Relevant Field and Applications

In this section, we will ***demonstrate our knowledge of public safety requirements, missions, operations, and tasks*** as they pertain to ***firefighting.*** We will do so by addressing the key shortcomings, limitations, costs, and challenges faced and describe how the proposed project will overcome these.

How Firefighters Fight Fires: Public Safety Requirements, Missions, Operations, and Tasks
The basic goal of firefighting is to locate, confine, and extinguish the fire. To do this safely, firefighters must undergo extensive training beforehand. The state-of-the-art in firefighter training currently makes use of VR environments such as those made by Ludus and Flaimtrainer to train firefighters in fireground scenarios. The advantages are that training can proceed in environments that are inherently unsafe and difficult to reproduce, no longer possible to train in due to environmental, community and regulatory constraints, or that are expensive to train in. Firefighters must train on many complex tasks, to include reduced profile, full escape, swim, air conservation, hoseline following, rapid location of doors/windows, rapid clearing of window opening, rapid forcible exit of interior doors, wall breaching, first floor escape, head first ladder exit, second floor escape, rope escape via windows, and importantly the performance of search/rescue operations.

In 2016 there were 1,342,000 fires reported in the US. The most damaging of these fires in terms of fatalities and property damage were structure fires. Around that time there were 1,160,450 firefighters, 70% of whom were volunteer firefighters. It is a testament to their training that there were only 7 firefighter deaths that occurred while firefighters were operating at structure fires. However, there were 24,325 firefighter injuries sustained during fireground operations. Nearly 60% of those injuries were due to overexertion strain, falls/jumps/slips, or contact with an object. Thus, injuries are a significant hazard to firefighter safety worthy of prevention.

Key Shortcomings, Limitations, Costs, and Challenges Faced by Firefighters

Preparation: Even the best VR training cannot completely prepare a firefighter for unexpected fireground scenarios that might lead to injuries. **Physical Limitations**: With SCBA gear on the back and a water hose that must be brought in, there is not much room for additional gear there. Also, to stay in communication with other firefighters, at least one hand must be free to operate a portable radio which is not possible when lifting a victim. **Environmental Limitations**: A fire represents a dynamic situation that will play out differently depending on the type of construction, fuel load, size and location of windows, ventilation, and degree of fire suppression. Depending on the severity of the fire and its proximity, a direct path that would allow the firefighter to save a victim may not be the safest path due to temperatures, debris, and growth of the fire. **Cognitive Limitations**: A firefighter cannot act on more than a certain amount of information at a time. Overload raises the chance that a firefighter may "read the fire" differently, putting the firefighter in potential danger. **Costs:** The primary cost of all these limitations is time. The longer it takes to put out a fire, the greater the property damage and the more likely the rate of injuries or loss of life.

How Our Proposed Project will Overcome these Limitations
A firefighter can never be fully prepared for all events. That is why having an AI navigation and rescue assistant that can act as another set of eyes while providing constant guidance can improve a firefighter's level of preparedness, efficiency, and chance of mission success. To address **physical limitations**, the VIRTUAL system will not be back-mounted given the need to carry the SCBA there and to remove it during emergency egress through small openings. Instead, it will consist of a HUD connected via protected cable to a computer on the back of one upper leg and a power pack on the back of the other. This positioning frees the arms and back for other more important loads. To address **environmental limitations**, VIRTUAL will integrate real-time sensor input (oxygen levels, heart rate, internal and external temperatures) to make its recommendations of what actions to take next. To address **cognitive limitations**, VIRTUAL will present only information that is critical to have at a particular stage in the mission.

3. The Competitive Advantage Offered by Our Approach

VIRTUAL will provide a competitive advantage by operating a real-time, adaptive feedback loop. Voice feedback from an HUD microphone coupled with current and historical sensor data plus operational parameters guide the navigational and non-navigational decisions made by the AI, which in turn guides the firefighter who once again provides additional feedback.

Integration of Key Data into the HUD that Supports Key Elements of the Mission
VIRTUAL will **monitor voice communications** over portable radio and receive **voice commands** through the HUD microphone. The firefighter activates the system by saying "V," followed by the command category and finally the command. These commands are all short on purpose to ensure actions can be carried out quickly, but they are unlikely to be mimicked by other words. For example, *"V, Objective, Find Fire."* It will not speak back in response, eliminating the chance of interfering with potential radio communications. Voice input will go in but only visual input will come out in the form of navigation routes on the HUD.

Quality, Content, and Quantity of Data Elements Integrated Into the HUD
Besides voice input, sensor data will be integrated. Once collected, sensor data will be stored and tied to position through **simultaneous location and mapping (SLAM)** methods so as the firefighter moves around, a map is generated. Thus, previously risky areas can be avoided during subsequent routing. Sensor data display can be toggled through voice commands; even if off, alerts will still be visible if dangerous physiological limits are close to being reached. These and other operational parameters such as SCBA oxygen levels, temperatures, victim location, and hazard locations will be used in the AI's decision-making.

Use of Data to Enable Users to Make Decisions
The AI is responsible for integrating all incoming data to provide recommended actions to the firefighter. Most frequently these actions will be navigational decisions needed to meet a mission objective. The firefighter can choose to override the AI at any time or to change mission objectives through voice command if, for example, an injured victim is unexpectedly found.

How this Data Interfaces with Navigational and Non-Navigational Functions
In an emergency situation for the firefighter, the costliest element is time. In such an event, the firefighter can choose to voice activate the AI's self-rescue mode by saying *"V, Objective, Abort."* The firefighter will then be **visually reminded** to follow the necessary steps for rapid self-rescue: to keep calm even during a low air alarm, control breathing, radio for help, manually activate their PASS device for rescue, and to proceed with the best possible route to get out of the structure. The AI will use the incoming data to display several navigational routes to the firefighter to find an exit. These routes would present as green for fast and lowest risk and yellow for faster but greater risk.

In this mode, the firefighter will be reminded to stay low, maintain situational awareness, and respond to the **visual prompts presented by the HUD**. The prompts will be presented in a flowchart-like manner depending on the answers to earlier prompts. If the AI displays "Are there hose lines present", the firefighter simply has to respond "Yes" or "No" to move on to the next question which will be displayed as soon as an answer is received. Feedback will be integrated to update the displayed navigational routes. Most questions will be yes or no for time savings and speech recognition accuracy; for numerical questions (How many windows? What floor are you on?) the firefighter only has to speak the answer ("1," "2," or "higher"), for example.

4. Performance Metrics and Plan

[Evaluation Point 2.2 Plan] Below is our plan to manage the limited schedule, resources, project risks and other challenges, and produce high quality project outcomes in support of challenge goals.

Stage 2 WORKING CONCEPT AND HUD PROTOTYPE (2/5/18 – 3/9/18)

Stage	Description and Performance Metrics	Duration
Development – Generating Scenarios for AI Training	Generate synthetic operational parameter layers for use in a 2D simulation whereby a user needs to know multiple routes to complete multiple mission objectives with the least risk and time. Select the model with the greatest **% completion of mission objectives divided by runtime** for use in VIRTUAL.	2/5-2/12
Development – AI Output to UI	Use Cython extensions with the AI code to output data into a navigational UI for the HUD. Integrate operational parameters along with supplied mission objectives. Make the model fast enough to **run continuously** to update navigational routes without jitter as the user moves.	2/12-2/19
Development – Settings Menus	Integrate **2 menus**: 1) a settings menu for user to change display parameters and 2) a navigation menu to toggle different navigation settings (waypoint, breadcrumb, map, floor plan).	2/19-2/23
Development – Voice Controls	Develop voice recognition functionality; use the commands to drive the UI functions above with a **>95% success rate**.	2/23-2/28
Testing and Verification	Meet all checklist items on the **Unreal VR Checklist** for compliance testing, evaluate the software according to the **12 usability heuristics of VR apps** (Sutcliffe and Gault 2004), and evaluate efficiency, learnability, helpfulness, and control metrics using the **Software Usability Measurement Inventory.** Show **>95% satisfactory completion** of all checklist and evaluation items.	3/1-3/5
Completion	Assemble a portable VIRTUAL system configuration – power pack, portable computer running Unreal Engine 4, microphone, Vive VR HUD, and AI software	3/5-3/9

Stage 3 HUD PROTOTYPE TEST & EVALUATION ROUND 1 (3/19/18 – 5/11/18)

Stage	Description and Performance Metrics	Duration
Outline baseline capability	Integrate VR environment, scenario details, and operational parameters to interactively test and evaluate the prototype	3/19-3/30
Development	Meet all requirements for **UI/UX** and **functional navigation elements** (oxygen/time-based hazard and temperature)	3/30-4/13
Testing	Complete a series of suggested interactive tests and evaluations to improve the prototype	4/13-4/27
Refinement	Improvement of prototype, addressing any items that were not at least **95% satisfactory**	4/27-5/4
Verification	Re-testing on the interactive tests and evaluations to show **>95% satisfactory completion** of those tests	5/4-5/11

Stage 4 HUD PROTOTYPE TEST & EVALUATION ROUND 2 (6/4/18 – 6/9/18)

Stage	Description and Performance Metrics	Duration
Live Demo	Successful completion of live demonstration	6/9/18

Dahl Winters
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CEO/Co-Founder, DeepScience Ltd. (2015-present)

- ***AI-Driven Augmented Reality for Space-Based Maintenance (2018):*** Developed a concept design for an AR heads-up display driven by AI algorithms to guide astronauts' interior maintenance activities. Topic to be submitted for consideration under NASA's SBIR Program.

- ***Virtual Reality for Community Interaction (2017-2018):*** Built a prototype VR environment for a client interested in a private virtual meeting space for 150 members. The VR environment was built using Unreal Engine 4 and stored on Amazon Web Services (AWS) for potential use with GameLift to serve the environment to the necessary users.

- ***Artificial Intelligence and Augmented Reality for Visual Inspection (2017):*** Employed generative adversarial autoencoders in efficient anomaly detection for an early-stage NVIDIA Inception Program startup, Optar AI. Served as interim CTO of that startup to help them reach their minimum viable product. Researched and recommended uses of augmented reality for visual inspection. Also investigated multi-view CNNs for 3D model identification, fusion of multiple CNNs with image segmentation for anomaly detection, and deep reinforcement learning for unsupervised classification.

- ***Artificial Intelligence Optimization (2016-current):*** Performed research to understand how current deep learning systems can be further optimized and to find alternatives to deep learning that are much more energy efficient. Investigated biomimetic design as a way of producing more efficient and advanced AI architectures.

- ***Biomedical Design R&D (2016-current):*** Originated and coordinated a nearly 2-year research collaboration between two multinational research organizations, AstraZeneca R&D in the United Kingdom/Sweden and RTI International in Research Triangle Park, NC. Through this collaboration I have secured $125k in innovation-related awards to develop a patent pending biomedical implant for the treatment of type II diabetes.

- ***Physical Design R&D (2015)***: Developed an efficient and scalable solution to treat massive quantities of industrial wastewater from hydrofracturing. The solution utilizes hydrodynamic cavitation to remove organics as well as salts and boron, allowing the water to be returned to agricultural use.

Geospatial Big Data Architect, Monsanto (2016-2017)

- As a consultant under a business contract between DeepScience and Monsanto, designed cloud-based big data pipelines for drone and ground-based imagery analytics and led dev teams in their construction. Analytics included employing deep learning algorithms on multispectral imagery to classify ground objects and developing algorithms to perform image stitching. Directly managed a team of 2 geospatial big data engineers. Worked with a team of 20 to develop APIs interacting with GeoServer datastores to make data more accessible to clients.

- Administered Linux resources on AWS EC2 and Google Cloud Platform, developed Docker environments on ECS, and Elastic Beanstalk; used SQS, SNS, set up IAM roles for security and Elastic MapReduce for large analytics jobs on Hadoop and Spark.

- Used Pix4D and Agisoft PhotoScan for image stitching and performed modifications of open-source software (Map2DFusion, OpenDroneMap) for the same purpose. Employed the OpenCV computer vision library for algorithm development involving imagery using CUDA-based workflows.

Staff R&D Scientist at DigitalGlobe (2014-2016)

- Primary developer on a project involving satellite image mosaicking and information indexing at scale, done under a contract for IARPA (https://www.iarpa.gov/index.php/research-programs/finder). This software operated on about 20 machines using Hadoop and was successfully productized in my first year.

- Architected an image processing system that removes buildings and forest from terrain models to get the underlying surface elevation. Dockerized this program to run in our Geospatial Big Data (GBDX) cloud environment on AWS.

- Experienced in big data architecture using Hadoop ecosystem tools to analyze and process multi-terabyte datasets within a multi-petabyte corporate image archive. Actively worked with ENVI, ArcGIS (including Spatial Analyst), and QGIS.

- Developed and used machine learning algorithms for land cover classification and image mining. For small-scale work I used Weka and KNIME. For big data I used MLLib (Apache Spark). I have also explored deep learning using Caffe and Theano for applications in object recognition.

- Had opportunities to explore UI/UX and mobile development through collaboration with other teams. Have good knowledge of Android development as well as the hardware to do so. In previous work I designed the interface for RTI's synthetic population map viewer, visible at http://synthpopviewer.rti.org.

Education

M.S. Ecology, University of North Carolina at Chapel Hill | 5/1/2009
National Science Foundation Predoctoral Fellow for 3 years

B.S. Biology, Duke University | 5/1/2003
Reginaldo Howard Scholar, full tuition leadership/merit scholarship for 4 years

Previous Positions

RTI International, 11/1/2012 – 11/1/2014 | Environmental Scientist, Air Quality Engineering

- Performed data analytics and software development for EPA's Greenhouse Gas Reporting Program
- Spearheaded the development of software to automate the process of finding patterns in reported GHG emissions to assess the quality of the national emissions inventory.
- Made use of big data and machine learning tools for geospatial problem solving
- Environmental Professional Intern (EPI) certified from the Institute of Professional Environmental Practice (IPEP)

Sundogs Solutions, 5/1/2011 – 7/1/2011 | Solar Specialist

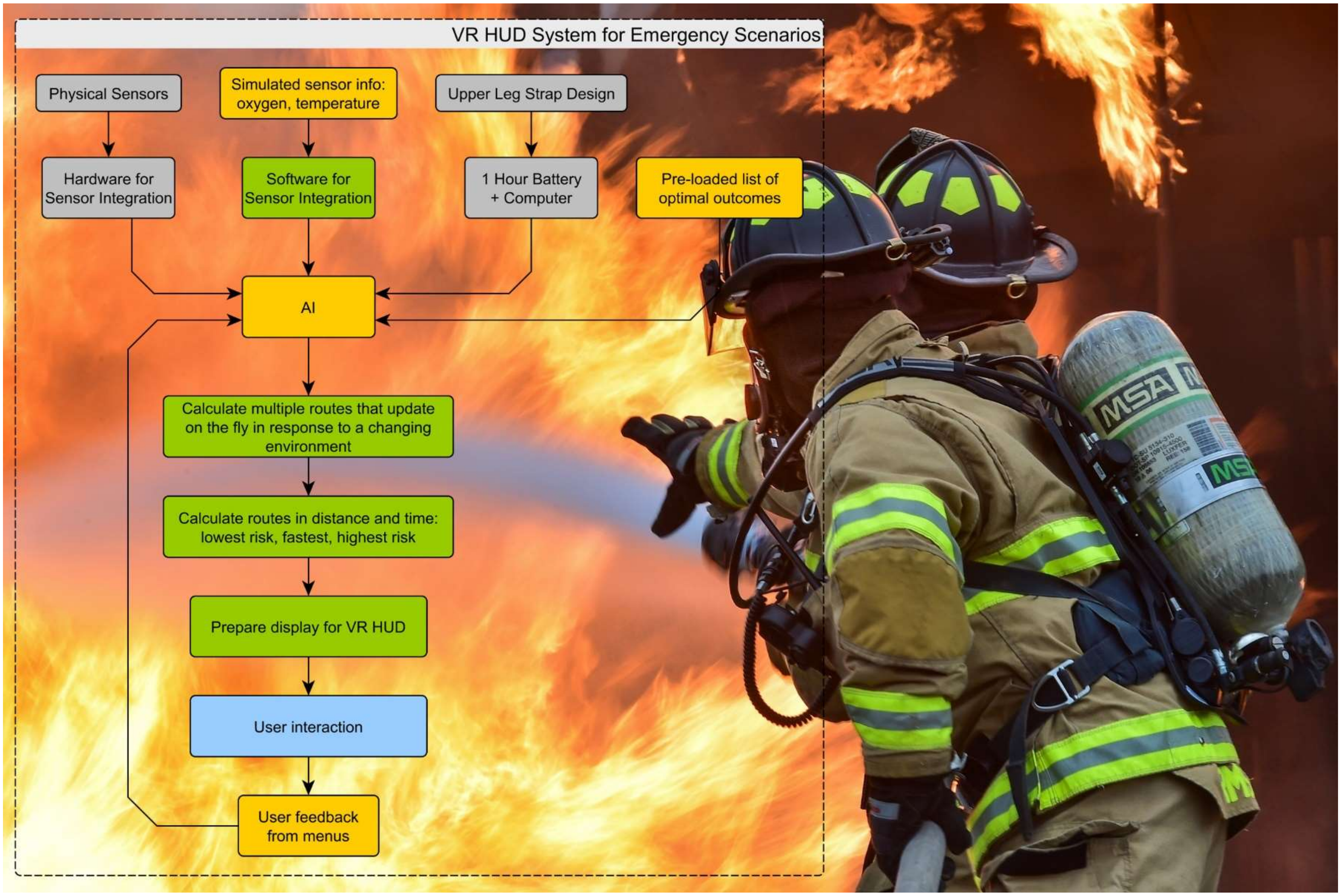
- Performed solar site analyses to determine shading and other characteristics affecting solar power systems
- Analyzed numerous factors (city building codes, requirements, and technical reports) to design plans that would receive city approval

University of North Carolina at Chapel Hill, 8/1/2005-5/1/2009 | National Science Foundation Predoctoral Fellow

Duke University, 8/1/2003-5/1/2004 | Professional Teaching Assistant

Duke University, 8/1/2000-5/1/2004 | Web Designer/Tech Support

Concept Sketch 1 of 3: The VIRTUAL Adaptive Loop



Our concept of an adaptive loop is shown above. Hardware (in gray) feed sensor inputs and operational parameters into the AI. The AI then performs functions through its software (green) that feed into the VR HUD. Once visible, the user can interact with the HUD and this user feedback from menus and voice commands will get re-integrated into the AI to guide its next decisions.

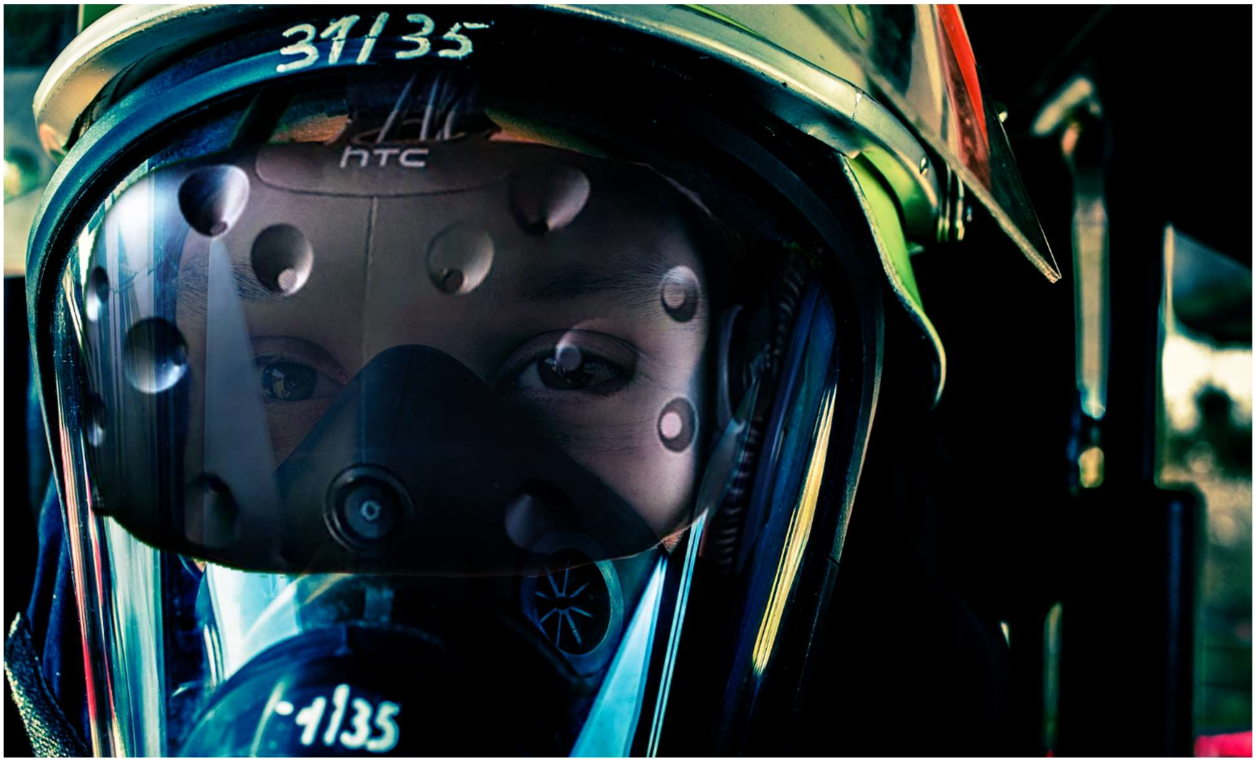
Concept Sketch 2 of 3: VIRTUAL's FireView Voice-Interactive Display

This is a view of the user interface through the HTC Vive. Key elements are on the left and right so as not to obscure vision of the ceiling (due to potential obstacles or entanglement hazards) or the floor (due to the potential need to navigate through debris).

The green navigation wedge always points in the direction calculated to best meet the mission objective, whatever it might be. In this case, VIRTUAL has received the "V, Objective, Find Fire" command. It thus plots a route toward increased temperatures. Note the transparency of the wedge, again made to not obscure objects that may be on the ground.

The sensor readouts to the right can be toggled on/off through the Display menu along with font sizes and colors. The Nav menu changes the type of navigation and will allow users to navigate toward waypoints, to leave breadcrumbs (made possible by SLAM), or just to view different route types (fastest, lowest risk, both).

Concept Sketch 3 of 3: The HUD and FireView Display Elements



Not visible: microphone for voice commands; cushioning between the HTC Vive and the helmet.

AI-Driven HUD Design - Live Feedback on Navigational / Mission Decisions

Interactive Display

	AI Inputs	Human Decision Points	AI to HUD Outputs	HUD Settings
User Views	View sensor information: oxygen levels, external and internal temperature	View calculated navigational routes and perform risk assessment to increase safety while meeting objectives	View guidance for navigating chosen routes	View changed display before changes applied
User Feedback	Toggle through objectives: find person or object, find location	Toggle through navigation settings: waypoint, breadcrumb, map, floor plan	Receive feedback on completing mission objectives	Settings menu to enable wearer to customize display

Columns represent the four types of display elements a user can view. For each of these, there are options for users to provide feedback. Toggling and any changes in settings are done entirely by voice commands. While there are headsets like Neurable that provide a brain-computer interface to interact with the Vive, we do not feel it can be used reliably under dynamic emergency situations due to potential inability to control one's thoughts. Thus, voice commands that can be understood even with the noise of a burning building is our choice for hands-free reliability.