# Human-Wildfire Interfaces Towards Wildfire Mitigation in Wildfire and the Wildland Urban Interface (WUI) Communities

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**ABSTRACT**

In recent years, wildfires have taken over our critical infrastructure, cities, and communities, and to date, efforts to mitigate wildfires are still unable to match the needs. More specifically, existing wildfire mitigation strategies in communities at risk do not prepare managers, authorities and emergency responders well to prevent or respond to such disasters. In this paper, we propose developing human-wildfire model interfaces that can assist responders, inspectors, and managers to better share and communicate wildfire risk and damage and change human behavior, from owners to emergency responders. The study of this interface will also explore the use of machine-aided digital twin experience aids pre-disasters that can assist emergency responders to make better decisions of evacuation or rescue to save lives. The goal of this research is to advance a new interface between the human, their environment during fire, and the perception of fire risk in the context of Wildfire and Wildland Urban Interface (WUI) using Augmented Reality (AR).

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## INTRODUCTION

Climate change has increased the frequency and intensity of wildfires globally, posing serious threats to both built and natural environments. In the context of infrastructure inspection, fires create hazardous conditions that impede visibility, limit mobility, and endanger personnel. Simulating such conditions in training environments has been challenging due to safety concerns and resource limitations.

Human-wildfire model interfaces can assist responders, inspectors, and managers to better share and communicate wildfire risk and damage and change human behavior. These model interfaces include visualizing flames, smoke, heat shimmer, and embers, providing a controlled, immersive environment for users to experience fire hazards in real time. This paper explores the use of human-wildfire model interfaces' use in transportation infrastructure inspection and disaster preparedness, with a focus on training, standardization, and risk mitigation.

## OBJECTIVES OF HUMAN-WILDFIRE MODEL INTERFACES

Training for Emergency Responders: Fire events can compromise bridges, tunnels, and roadways through thermal damage, spalling, and visibility loss. Training first responders to assess fire-related damage in a simulated environment improves their ability to act quickly and safely in real-world events. The AR system allows for repeated exposure to fire scenarios without physical risk.

Wildfire Preparedness for Emergency Responders: Emergency personnel can rehearse evacuation routes, firefighting coordination, and public communication strategies within the app. Simulated fire propagation models help responders understand how fires may spread across different terrains and under varied weather conditions.

Community Engagement and Public Education: The AR simulation tool can also be deployed in educational settings to raise awareness about fire risks, especially in high-risk rural areas. Color-coded threat levels and real-time propagation allow residents to simulate fire threats to their homes and understand early warning protocols.

## AUGMENTED REALITY TO ENHANCE FIRE UNDERSTANDING AND INTERFACES

The research team has used Augmented Reality (AR) in the context of increasing interfaces between humans and their changing environment, ranging from SHM applications [1], structural dynamics [2], industrial facilities [3], and robots' interfaces [4]. AR in the context of this research refers to the use of headsets that enable interfaces between the humans and their environment [5,6]. The AR generates a fire environment visualization that is overlaid around the environment of the users. In this paper, the authors present the use of AR for disaster understanding and planning with experts on wildfire assessment.

## HUMAN-WILDFIRE MODEL INTERFACE APLICATION

The human-wildfire model interface is an interactive AR application that allows the user to create virtual fire around his surroundings. The dynamic fire environment is useful to simulate the real world like environment in a virtual setting. The value it brings to first responders' community is that it allows to train first responders' for adverse environments during the fires. Hazardous environments like high gusty wind, heatwaves, smoke, and flame spread can increase the magnitude of fires. To see the effect of these environmental conditions is important to be able to simulate the fires in various conditions. We would like to quantify this without having to go out in the field and expose ourselves in those environments. With this application it is possible to achieve that in a closed environment. The future version of application can take the user analytics and see how different the user is able to navigate under different environment conditions. Ultimately, the goal is to create fires in different environment conditions. Figure 1 shows the spatial fire application with intensity menu.

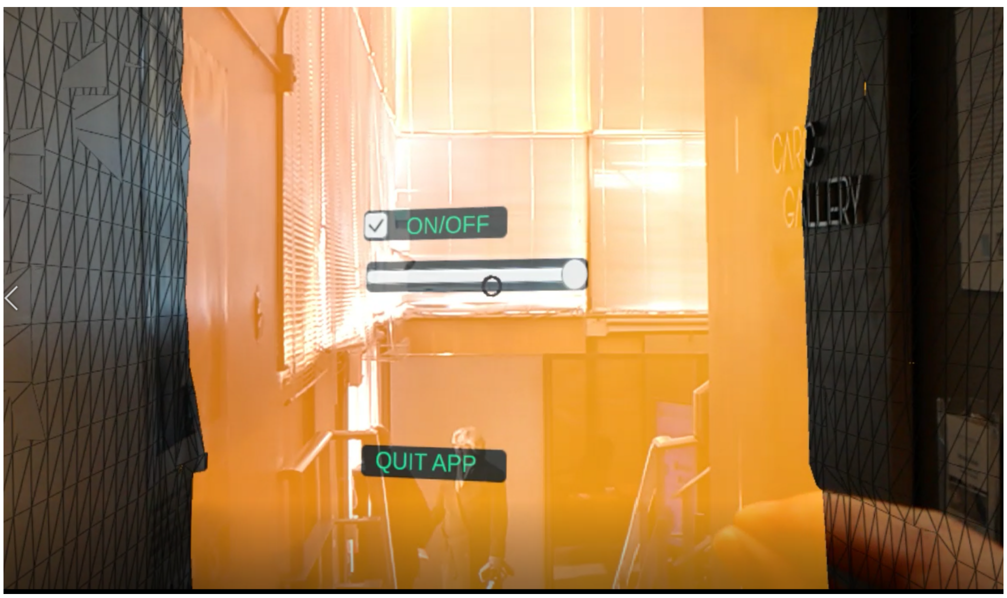

Figure 1. Human-wildfire mode interface understands your real surrounding environment and creates the simulated fire around it.

One of the most important achievements of this project is the successful simulation of fires within an AR environment. By integrating sensor data into AR visualizations, users can interact with and experience dynamic environmental changes in real-time. This capability is particularly valuable for disaster preparedness, allowing emergency responders, urban planners, and community members to visualize and respond to potential fire scenarios in a controlled, immersive setting. The ability to "experience" fires without physical risk creates an opportunity for safer, more effective training.

Moreover, the AR application bridges a critical gap in disaster preparedness by offering a tool that combines environmental data, user engagement, and scenario-based learning. This fusion not only improves understanding but also enables rural communities to make informed decisions during emergencies. For instance, the incorporation of user-defined flood thresholds and visual signals, such as color-coded severity levels, enhances the app's practical utility. These features enable users to simulate specific risks relevant to their geographic and environmental context.

We wanted to include the direction of experts in disasters to better understand the potential of this research to assist emergencies. We organized a 1h30m meeting with three experts on disasters in Native American communities. The research team (PI: Dr. Fernando Moreu, PhD candidates Kaveh Malek, Ali Mohammadkhorasani, and Dr. Jiwi Chong) organized a meeting on October 9th, 2024, with High Water Mark (HWM) LLC as shown in Figure 2. Attendees included CEO Phoebe Suina, along with environmental engineers Lauren Vigil and Joseph Ganeily. HWM specializes in emergency management, hazard mitigation, and environmental consulting, with a focus on flood recovery and mitigation in the Southwest, particularly in fire-impacted watersheds.

To ensure we collected feedback from HWM, we discussed the latest advancements in rain and sonar sensors developed in our lab and we collected their opinion from a practical perspective. These sensors are integrated into AR applications that simulate real-time rainfall and flooding scenarios using data collected from the sensors. The AR apps, running on Microsoft HoloLens 2 (HL2), aim to enhance disaster preparedness by providing immersive, real-time visualizations of flood conditions.

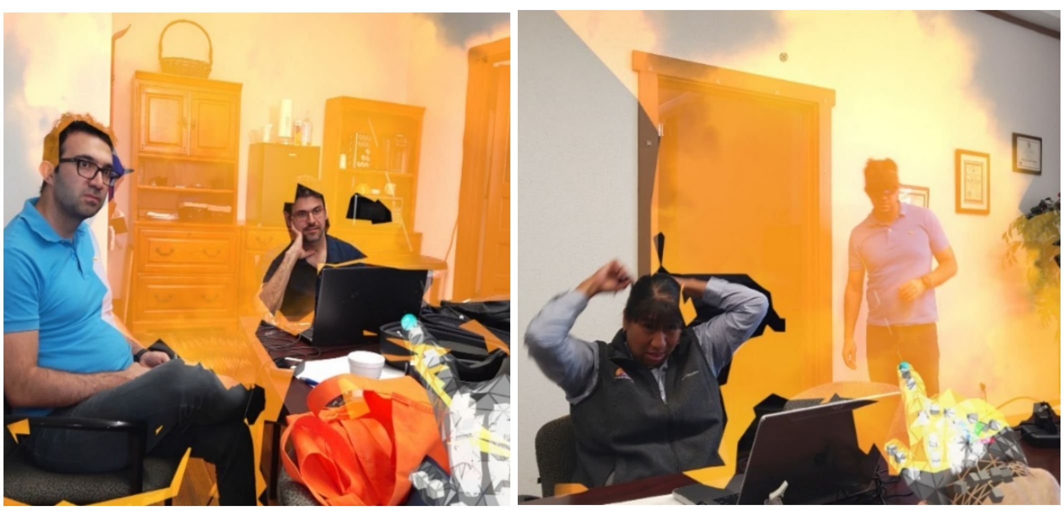

Figure 2. Meeting with High Water Mark (HWM) LLC on October 9th, 2024.

CEO Phoebe Suina provided professional feedback after discussing our advancement highlighting its strengths, weaknesses, and areas for improvement. Her feedback emphasized the AR potential for training purposes and its ability to visually represent the impacts of heavy rainfall and flooding. However, her team pointed out certain challenges that we need to address to simulate critical environmental and emergency situations, suggesting improvements in these areas. We also discussed a website that displays real-time data from sensors deployed in remote areas of New Mexico.

## EXPERIMENT RESULTS

A major accomplishment of this project is the accurate, real-time rendering of fire scenarios using AR. Users can experience heatwaves, smoke, and flame spread in their immediate environment, enabling high-fidelity training.

The system adapts fire behavior to local sensor data or user-defined inputs, offering a personalized training experience. This allows practitioners to simulate historical fires or anticipated risk scenarios for specific locations.

User interactions help quantify performance under fire stress conditions. This enables training institutions and agencies to benchmark skills and promote standardized inspection practices.

## FUTURE WORKS

Future works include integration with digital twin models of infrastructure, AI-enhanced fire propagation prediction, and collaborative multi-user simulations. This will improve group training for disaster coordination and enhance realism through data fusion.

## CONCLUSION

Human-Wildfire Model Interface's marks a significant advancement in AR-based training for infrastructure inspection and disaster preparedness. It enables users to safely interact with dynamic fire hazards, improving readiness and decision-making. As fire-related disasters become more common, tools like this will be vital in equipping both professionals and communities with the knowledge and skills to respond effectively.

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