# VRescuer: A Virtual Reality Application for Disaster Response Training

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October 31, 2019

# *VRescuer*: A Virtual Reality Application for Disaster Response Training


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***Abstract*—With the advancement of modern technologies, Virtual Reality plays an essential role for training rescuers, particularly for disaster savers employing simulation training. By wholly immersed in the virtual environment, rescuers are capable of practicing the required skills without being threatened of their lives before experiencing the real world situation. This paper presented a work-in-progress Virtual Reality application called *VRescuer* to help trainees get used to various disaster circumstances. A scenario of a city was created with an ambulance rescuer and several rescuees in the scene. The intelligent ambulance rescuer was introduced as a rescuer/guider to automatically search and find the optimal paths for saving all rescuees. The trainee can interfere in the rescuing process by placing obstacles or adding more rescuees along the ways which cause the rescue agent to re-route the paths. The *VRescuer* was implemented in Unity3D with an Oculus Rift device, and it was assessed by twenty users to improve the proposed application.**



***Index Terms*—Oculus Rift, Virtual Reality, Disaster Response Training, Simulation Training, Intelligent Agent.**


## I. Introduction

According to the Department of Homeland Security [1], United States had severely suffered from natural disasters and catastrophes within a twenty-year period (from 1995 to 2015) which cost 16.1 billion dollars insured losses. Floods and storms accounted for the majority of common disasters (71 percent of all incidents). More recently, Hurricane Harvey (2017), Hurricane Irma (2017), Hurricane Maria (2017) continued threatening people's lives in this country. Thus, the demand for quick responses to these unexpected events has increased than ever before. One such important response is to rescue people within a sufficient time and cost.

A number of preparedness efforts have been established for disaster response training based on the conventional training methods [2], including classroom-based training, web-based training, tabletop training and real-life drills. In the classroom setting, the instructor provided necessary information to the trainees whereas web-based training allowed rescuers to watch pre-recorded videos or sessions as many times as they wanted to at their own pace. The latter method, that is tabletop training and real-life drills, enabled trainees to discuss a simulated emergency situation or put their hand on real-life circumstance. These traditional methods pose several challenges due to the lack of realism as in classroom-based and web-based training or inconsistency and varying scale as in tabletop and drills exercises. To address the existing challenges, there is a need to have a uniform training across all methods.

Virtual Reality (VR) is an emerging trend in the preparedness of natural disasters because of its cost-effectiveness, efficiency, comprehensiveness, safety, scalability, and customization. Being immersed in a controlled environment, trainees can take advanced tactical training, repetitively practice with chaos until they master the required skills without threatening their well-being. Also, critical thinking will also be enhanced through a series of mental challenges such as finding the most sensible solutions or optimal alternatives to a circumstance. Thus when they face a real-life strike, their actions will be automatically triggered. Another important aspect of VR is that VR allows a user to navigate through the subconscious mind in which it is sometimes difficult to process a huge amount of information. Many efforts have been done to learn and introduce VR to a wider range of audience [3], [4]

To take the advantages of VR, several case studies and applications have been conducted and developed in both government [5], [6] and education sectors [7], [8]. Although VR is still in the early stage of development due to unavailability of standardized VR software package, the outcomes of these training offer a unique realistic quality and gain a high level of acceptance. Each of these training focuses on different aspects of disaster management. The need to have a training application to optimally rescue multiple people is not fully addressed, which in turn can help rescuers to act quickly in real-life situations.

Thus, this paper presents *VRescuer*, a VR application to train rescuers on disaster response in a simulated environment. The contributions of this paper are as follows: (1) It proposes an approach to optimally rescue people who are geo-located in complex settings, (2) it provides a demo of the proposed approach with a VR application, and the effectiveness of the proposed approach is assessed by five volunteers to improve the application.

The rest of the paper is organized as follows: Section II summarizes similar studies with our approach in the literature. The application design and its description are presented in Section III. Section IV shows the a user study of the application. Our paper is concluded with future work in Section V.

## II. Related work

In 2001, Freeman et al. [9] conducted a problem-based training experiment for users to watch the virtual patient in a high fidelity world. Both traditional flat screen and three-dimensional virtual reality were used to repeated enhance user experience by the clinical algorithms. The performance of the training was assessed through the lens of the trainee. Farra et al. [10], on the other hand, presented a longitudinal experimental design to evaluate the effectiveness of using virtual reality on learning outcomes and retention of nursing students. Students are randomly separated into two groups and a traditional web-based training was first introduced to both groups. The treatment group takes a further step with a virtual reality experiment. Their positive study results showed that VR can reinforce learning and increase student retention. Andreatta et al. [11] compared the impact of using standardized patient (SP) with fully immersed virtual reality (VR) environment for training emergency medicine (EM) residents. Hsu et al. [2] reviewed several applications of virtual reality based disaster preparedness and response training in the United States, taking into account of government agencies and academic settings. Besides the advantages of VR applications, this study pointed out the two most common challenges: familiarity with VR applications for the trainees and the initial VR training development costs. Li et al. [12] introduced a system called ERT-VR to train the emergency rescue commanders. This system was designed for the earthquake emergency rescues. Trainees are completely immersed in the virtual environment equipped with a head-mounted display, these commanders will be trained by taking the role of the characters in the scene to control their actions and observe the outcomes.

The above studies emphasize on different parts of disaster rescues using VR applications, overall they analyzed and provided the benefits of being immersed into virtual environment that can enhance the learning outcomes. However, the perspective of optimizing rescue routing is not fully addressed and touched, which is the main objective of our paper.

## III. The *VRescuer* design

### A. The VRescuer approach

*VRescuer* is developed using Unity3D. The primary goal of *VRescuer* is to create a VR application that presents rescuers or trainees a high-level view of the rescuing process. To meet these goals, this paper proposes several features that are implemented in *VRescuer*:

– **Overview Display (F1)**. Display an overview of the scenario.
– **Details Display (F2)**. Present details of the rescuing paths.
– **Interfere the agent (F3)**. Place obstacles on the rescuing paths or add more rescuees to the scene.
– **Navigation (F4)**. Move to different places in the scene.

### B. The VRescuer components

Based on the outline features, *VRescuer* consists of three main components: 1) Fig. 1(a) contains the grid-based system of the virtual environment, 2) Fig. 1(b) presents the intelligent agent and the rescue, and 3) Fig. 1(c) displays overview from the training observer eyes.

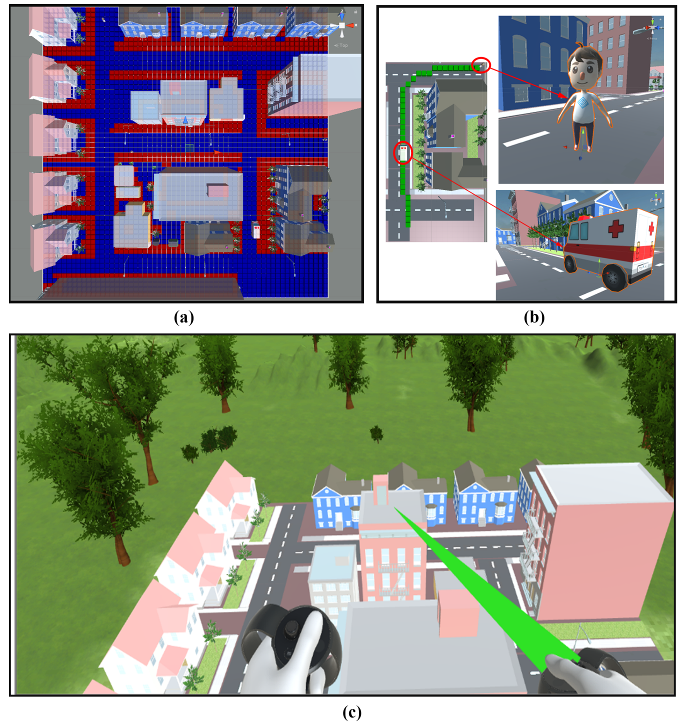


Fig. 1. (a) The grid-based system, (b) The intelligent agent and rescuees, (c) The training observer

*1) The grid-based system (F1):* The *VRescuer* architecture uses the two-dimensional grid-based system to generate routing paths from the intelligent agent (i.e., the ambulance) to the rescuee. It was constructed based on the intersections between the vertical and horizontal lines (i.e., the $x$ axis (pointing right) and $z$ (pointing forward) axis in Unity coordinate system). The center of the grid is positioned at the point (0,0). Each node on the grid carries information whether it is reachable (blue point) or unreachable (red point) as depicted in Fig. 1(a).

*2) The intelligent agent and rescuees (F2):* The intelligent agent (i.e., the ambulance) Fig. 1(b) plays an important role in the training process. During the training session, the ambulance will automatically locate all rescuees presented in the scene, find the shortest paths to each rescuee then start saving the nearest rescue until all rescuees are saved. The number of rescuees and their positions in the scene is configurable. For finding the shortest path between any two given points, the *VRescuer* adapted the $A^*$ search algorithm from Hart et al. [13]. To optimally save the rescuees in order, we approach the traveling salesman problem (TSP) with *dynamic programming* [14]. Since the number of rescue points in our application is relatively small (less than 20), we do not consider other optimization methods. The TSP algorithm is shown in Alg. 1 where $d_{ij}$ is the shortest distance between $i$ and $j$ using $A^*$ search, $C(S, k)$ is the cost of visiting each point in $S$ once, from 1 to $k$.

**Data:** $N = \{1, 2, 3, ...n\}$
/* 1 is the starting point, the rest is rescuees' positions */
**Result:** Optimal rescue path
Initialization: $C(\{1\}, 1) = 0$;
**for** $s \leftarrow 2$ **to** $n$ **do**
  **for** *all subsets* $S \subset N$ *of size* $s$ *and containing 1* **do**
    $C(S, 1) = \infty$;
    **for** *all* $j \in S, j \neq 1$ **do**
      $C(S, j)=\min \{ C(S - \{j\}, i) + d_{ij} : i \in S, i \neq j\}$ ;
    **end**
  **end**
**end**
**return** $\min_j C(N, j) + d_{j1}$

**Algorithm 1:** Our rescue path algorithm

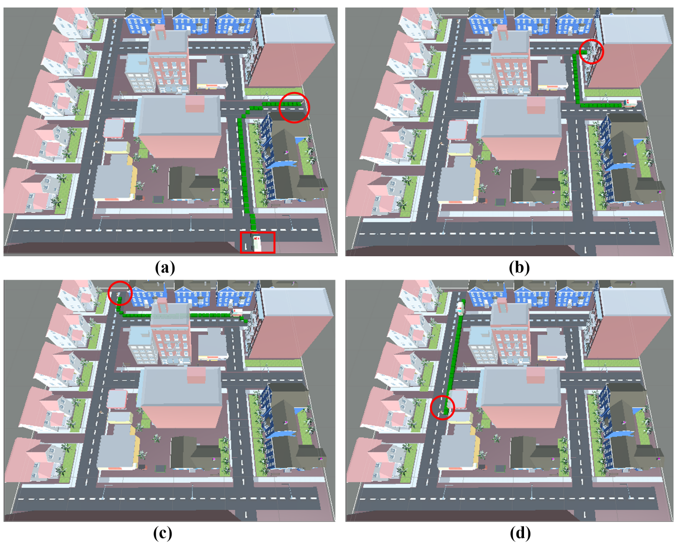


Fig. 2. The ambulance automatically locates and saves all rescuees in order (a)-(b)-(c)-(d). Red circles denotes rescuees and red rectangle is the starting position.

The algorithm is demonstrated in Fig. 2. The ambulance first locates all available rescuees' positions in the scene (four red circles). Then it starts following its optimal path which is (a)-(b)-(c)-(d) from its starting point (red rectangle).

*3) The training observer (F3, F4):* This component is the most important part of the *VRescuer* design since it enables trainees to be fully immersed in the virtual environment for practicing the required skills. By wearing the Oculus Rift head-mounted display with two touch controllers, trainees can look at and experience the behavior of the ambulance from multiple perspectives.

**Navigation (F4)**: They can navigate in the scene by natural movement (walking), teleport (suddenly move to a given point) or moving with the ambulance. The navigation is performed via the two touch controllers. Natural movement is carried out by using the joystick. Moving with the ambulance is controlled by the left touch controller.

**Watching the ambulance behavior (F3)**: In addition to normal rescue points that have been initially set up in the scene. Trainees are also able to practice and experience new circumstances. For example, when the ambulance is following its path to the nearest rescuee, if the obstacles are accidentally placed and blocked its way, the intelligent agent will stop and find a new path to its destination. At this point, two cases can occur: 1) the new path is still the optimal path to the current rescue point and 2) the new path to the current rescue point is not the optimal path. In the first case, the ambulance continues following its new path to the destination whereas in the second case, the ambulance changes its direction to follow the optimal path. Besides adding obstacles in the scene, trainees can place more rescuees, each time a new rescue is presented in the scene the ambulance will re-route its map to achieve the optimal solution. Adding an obstacle in the scene is performed by the right touch controller where the saver points the controller to a place then hits the button (i.e., defined by button A). Similarly, placing a new rescuee is done by pressing by another button (i.e., defined by button B). Fig. 3 illustrates three cases in the scene, Fig. 3(a) presents the normal route to the rescue point, then the trainee places an obstacle to block part of the road as in Fig. 3(b). When the obstacles have completely blocked the way, the ambulance recalculates its path as in Fig. 3(c). Fig. 3(d) shows a new path when a new rescuee is presented.

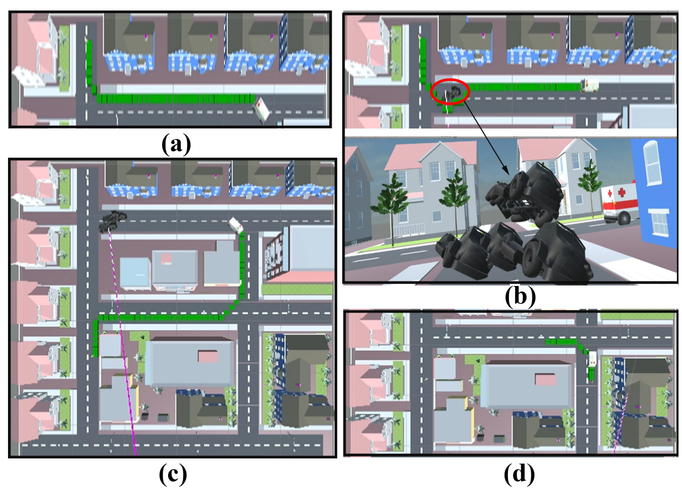


Fig. 3. Re-routing paths: (a) Default route, (b) Re-route with few obstacles, (c) New path, (d) New rescuee

## IV. User Study

A number of assessments has been proposed in the literature to evaluate a visualization design. A review conducted by [15] summarized these methods into the two main categories including quantitative and qualitative method. His study indicated that qualitative method should be conducted as part of the design process to continuously refine the application. Observation and interview are the two main techniques that often used in this category. In the observation technique, observer tries to watch user's behavior and take notes unobtrusively whereas interview technique requires interactions between an observer and users. In our study, we combined these two techniques to 1) gain an understanding of users' behavior on the usability of the application, and 2) get feedback from users to improve the *VRescuer*.

**Procedure**:

Before being immersed into VR world, users were introduced the purpose of the study, the Oculus Rift device and the available functions on the touch controllers. Each user would play the *VRescuer* in 15 minutes. The application was tested on Windows 10 64bit, 64Gb RAM, Graphic Card NVIDIA Quadro P4000. All free 3D models in the scene were imported from Unity Asset Store. The application demo is accessible on YouTube[1]. The experiment was conducted in both the author's lab and at the institution lecture room. There were two phases during the study. In the first phase, five users did the experiment at the author's lab, responses from users' feedback were collected then the application was modified and improved accordingly. The re-designed application was shown again at the institution lecture room as a showcase. Users' feedback was collected through observations and interviews by taking notes. Notes taking on observations were recorded in terms of how users start the application? which feature of the VR application did users most likely to focus? and How did users interact with the application? Interview questions focus on understanding the aesthetic design such as color use, ease of interactions, 3D model size, and suggestions for improvement.

**Result**:

Overall, users quickly got used to the navigation system in about 3 minutes, interactions took a little longer due to the use for the first time and to memorize the buttons. The users' feedback includes: 1) the scenario should be the real world place and bigger, 2) more intelligent agents should be included to rescue unreachable positions (e.g., helicopter), 3) point of interaction in the scene should be highlighted and 4) when walking in the scene, a thumbnail map should be include to show user's position and direction.

*VRescuer* showed some drawbacks in the study experiment. First users felt dizzy during nature walks, they responded that walking on the road was not necessary because they wanted to see the overview of the map. Second, the initial position of the trainee was too high (on top of the highest building), it may cause fear to users who have the phobia of heights. This problem can be alleviated by lowering or creating buildings with various elevations.

## V. Conclusion and Future work

This paper presented the *VRescuer* to help trainees practice various disaster events. Users were able to practice the rescuing paths by observing the intelligent agent behavior. Obstacles and rescuees were dynamically added to the scene through the user's controllers. Users' feedback was collected to improve the *VRescuer* continuously. In future work, the contributions of this paper will be extended by integrating a real-world scenario (e.g., OpenStreetMap, Mapbox, auto generated terrain [16]) and multiple agents for better rescuing strategies. Sensors on smartphone device can be utilized [17] to measure user's physical response after experiencing the application. Future research will involve a comprehensive user study of *VRescuer* to further improve user experience and acceptance using the extended technology acceptance model with the components of task technology, perceived visual design, perceived usefulness, perceived easy of use, self-efficacy, and intention to use.

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