# MULTI-USER COLLABORATIVE VIRTUAL EMERGENCY DRILL SYSTEM FOR URBAN ROAD EMERGENCIES

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**KEY WORDS:** Urban Road Emergencies, Emergency Drill,Multi User Collaboration,Computer Simulation, Virtual Reality.

**ABSTRACT:**

In order to comprehensively improve the coordination and emergency response ability of road emergency commanders and rescuers to various road emergencies, analyze the problems faced by road emergency personnel in rescue training, and propose a simulation drill method combining virtual reality visualization technology with emergency rescue training content to form an interactive drill system.This paper elaborates the key technologies, architecture system and functional design of the system in detail, introduces and implements a complete set of virtual emergency drill disposal process based on the case of landslides blocking urban roads in flood season. The Internet and virtual reality technology are applied to build road emergency scenes. The emergency drill personnel carry out remote interactive virtual collaborative emergency drills in the same virtual environment, so as to realize the repeated deduction drills of road emergencies, and design the emergency disposition of scientific assessment system for drill personnel to evaluate objectively the disposal process, It effectively improves the emergency response and rescue ability of emergency personnel, and solve the problems faced by the current road emergency practice drills, such as less times, high cost, single scene and subject, etc.

## 1. INTRODUCTION

In recent years, due to the impact of infrastructure and natural disasters, urban road emergencies have occurred frequently, which has brought serious harm and impact to people's life safety and social economic development (Qi Manfei et al.,2021;Chen Yujie,2019). Emergencies are characterized by suddenness, complexity and high uncertainty, which bring great challenges to urban traffic managers in emergency handling.After road emergencies occur, rapid and effective emergency rescue can reduce subsequent injuries and economic losses(Zhang An,2021).This requires road emergency personnel to have good emergency response capabilities and coordination capabilities.

At present, most of the traditional practical exercises are used to strengthen the tacit understanding of the cooperation of various departments, the familiarity of emergency procedures and the emergency operation ability of rescue personnel.This training method has disadvantages such as high cost, low efficiency and poor repeatability. Before actual combat drill, it is necessary to organize a large number of manpower and material resources to arrange the drill scene, and most of the resources used for the drill are disposable consumables, so each drill will consume considerable time and economic cost. Due to the high cost and low frequency of drills, it is difficult to effectively improve the coordinated emergency response ability of emergency personnel. Therefore, there is an urgent need for an efficient drilling platform to comprehensively improve the collaborative emergency response ability of emergency rescue teams and the proficiency of emergency procedures.

The continuous development of virtual reality, computer simulation, Internet and other technologies provides the possibility to solve the above problems.Virtual reality technology is used to construct various emergency scenarios and conduct coordinated emergency drills in the virtual environment, which breaks the limitation of time and space, greatly improves the efficiency of emergency drills and reduces the economic cost of actual combat drills.In developed countries, virtual reality technology has been widely used in the field of emergency. The United States Naval Research Laboratory has developed a virtual fire training system, which can train users on their operation and reaction, and the operation level of firefighters can be significantly improved through training (Jiang Meiqi,2018). In Sweden, VR was applied to forest fire in the early stage. Rego Granlund developed a forest fire rescue system, which can be used to train various roles, including firefighters, commanders and staff officers (Jiang Meiqi,2018).Domestic researchers have also carried out relevant studies. Author Jin Hao used virtual reality technology to build a simulation system for water emergency rescue, enabling rescuers to conduct virtual drills in the form of interaction and improve their emergency rescue ability(Jin Hao et al.,2021). Author Liu Dunwen constructed a virtual scene for the emergency situation of tunnel fire, enabling rescue workers to conduct fire emergency drills in an immersive manner, and improving the enthusiasm of firefighters and their emergency handling ability(Liu Dunwen et al.,2019).

There are few researches on the application of virtual reality technology in road emergency response, and the concept of multi-level and multi-type emergency personnel cooperation drill is lacking in virtual emergency drill. Therefore, virtual emergency drill for road emergencies based on Internet multi-user remote cooperative participation is a new attempt. We can use the internet and virtual reality technology to construct the drill scene, and multi-level and multi-type emergency personnel can conduct remote interactive cooperative emergency drill through the same virtual scene, so

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as to realize the repeated deduction and drill of road emergencies and feedback the evaluation of the drill effect, which can effectively improve the emergency response and rescue ability of emergency participants.

## 2. RELATED TECHNOLOGIES OF THE SYSTEM

The construction goal of the virtual emergency drill system for road emergencies is that the drill personnel can log in to the system through the network in any area and carry out collaborative emergency drills in realistic virtual drill scenes. The realization of this goal requires the real-time communication technology between the client and the server, and the 3D scene simulation technology.

### 2.1 Real time communication technology

At present, the most commonly used application layer communication protocols are HTTP and Websocket. HTTP is a short connection and one-way network protocol(Li Kang,2021). After establishing a connection, only the browser is allowed to send a request to the server, and the server returns the corresponding data. Implementing instant messaging requires AJAX polling at specific time intervals (such as 1 second), resulting in too many unnecessary requests, wasting bandwidth and server resources ( e.g. Figure 1).WebSocket is a full-duplex communication protocol provided by HTML5 on a single TCP connection, which makes the data exchange between the client and the server simpler, allowing the server to actively push data to the client(D'ANGELO et al.,2018). The browser and the server only need to complete a handshake, and the persistent connection can be directly created between the two. Two-way data transmission is also carried out to effectively avoid the resource waste caused by polling ( e.g. Figure 1).Therefore, We use Websocket to realize the real-time communication of the client, so as to achieve the purpose of cooperative drill.

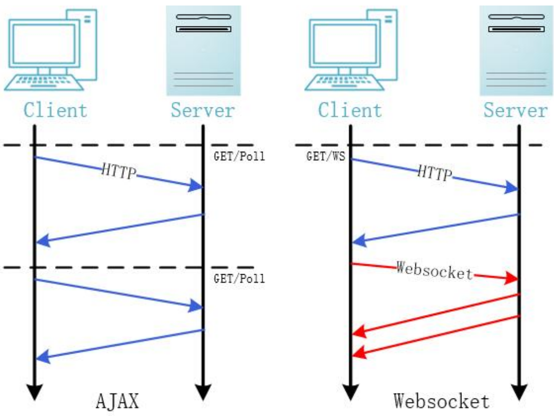


**Figure 1.** Mechanism of HTTP and Websocket

### 2.2 3D scene simulation rendering technology

The drill system needs to carry out virtual construction of the accident scene. Currently, there are many platforms that can be implemented: Cesium, Unity3D, Unreal Engine 4 (UE4), etc. Cesium uses the map engine of WebGL to provide multi-dimensional earth and real terrain display, which can locate specific positions according to latitude and longitude coordinates and support loading of models in various formats(Wang Jinna et al,2021).Compared with the more advanced game engine, cesium has a weaker rendering effect on the scene. Unity3D and Unreal Engine 4 (UE4) are currently popular game development engines, which can achieve realistic rendering of 3D scenes with more realistic effects.Unity3D is more suitable for lightweight development, preferring mobile terminal and mobile game development, while UE4 prefers PC terminal development, and the rendering effect of the scene is better than unity3d (Wang Hao et al,2021;Zhang Xiaoting et al.,2018;He Jiang et al,2021). Therefore, considering the business scenario and equipment requirements of the actual emergency drill,this system adopts the form of Cesium combined with UE4 to construct the virtual drill scene, which not only ensures the real geographical environment, but also achieves high-precision scene rendering effect.

## 3. SYSTEM ARCHITECTURE AND FUNCTIONS

We use the scene rendering technology of the Cesium and UE4, combined with Websocket two-way communication technology to build a virtual collaborative drill platform,so that emergency personnel of various departments can complete the whole virtual drill in different geographical areas in a coordinated way, and strengthen their familiarity with the rescue process of different types of road emergencies and emergency handling ability.

### 3.1 System architecture

The system adopts a multi-layer structure system, which is composed of data model layer, application layer, communication service layer and user layer( e.g. Figure 2).

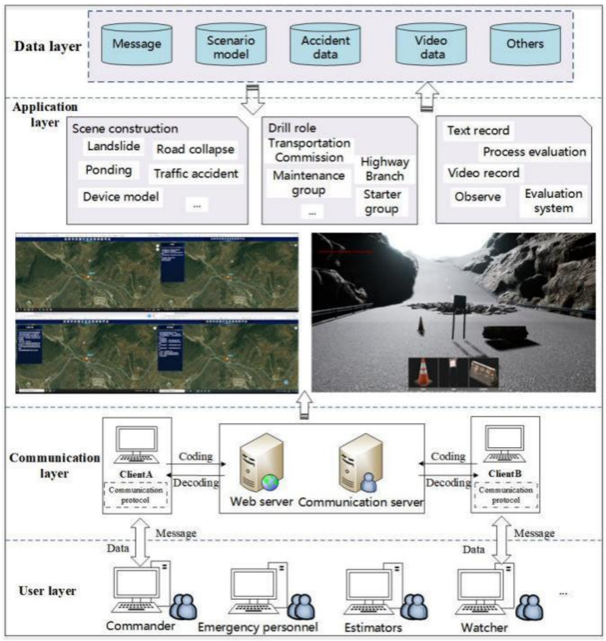


**Figure 2.** System architecture

**3.1.1 Data model layer:** As the basic layer of the system, it is used for the storage of data and models. Including emergency plans, scripts, scene models and other data, which are stored in databases or cloud servers and can be quickly retrieved and applied when needed. The data and drill records generated by the application layer will also be stored in this layer for subsequent reference.

**3.1.2 Application layer:** It is the interaction layer between users and virtual environment, which provides users with natural human-computer interaction. This layer uses Vue front-end framework to build the whole system, including the design of drill content, the rendering and integration of drill scenes, etc. The drill personnel conduct collaborative virtual emergency drill through this layer.

**3.1.3 Communication service layer:** As one of the core of the system, the communication service layer guarantees the real-time synchronization of the emergency operation of the emergency drill personnel, which is the fundamental of the cooperative emergency drill. After receiving emergency operation data sent by users, the server immediately sends the data to other users to complete virtual cooperative drills by receiving and sending data at multiple times.

**3.1.4 User layer:** Users composed of commanders, emergency personnel and evaluators can log in to the system through user names and passwords in any geographical area to conduct virtual collaborative emergency drills.

### 3.2 System function design

The system function is designed according to the system realization goal and service object, which roughly includes five functional modules: login module, scene setting module, collaborative exercise module, exercise evaluation module, observation and learning module. The realization of the main functions of the system will be introduced below.

**3.2.1 Virtual drill scene construction and rendering:** At the macro scale, the system uses Cesium platform to simulate the overall process of road emergency drill, including the display of road emergencies and the location of emergency teams, the patrol in the early warning stage, and the dispatch of personnel and resources in the response stage. However, the defect of Cesium is that the model rendering accuracy is not high, and the rendering effect of dynamic things is not real enough. Therefore, on the micro scale, the system adopts the UE4 game engine to construct the virtual drill scene according to the real scene in the form of "small world". Through UE4 PhysX physics engine and Niagar particle system, the scene rendering effect is more similar to the real world.

**3.2.2 Connection between Cesium and UE4:** UE4 is usually integrated into the web by pixel streaming.This method has complex operation and poor rendering effect, and frames are often dropped(Figure 3).So we adopt URL protocol to realize the call of UE4 drill scene on the web side. This method effectively avoids the poor rendering effect and frame dropping of pixel streaming( e.g. Figure 4), and then improves the user experience effect.

**Figure 3.** Pixel Streaming

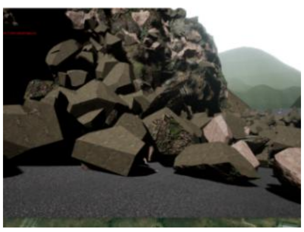

**Figure 4.** URL Protocol

**3.2.3 Implementation of disposal action and collaborative operation:**There are many roles and positions involved in the drill, which can be divided into command and execution, including commanding personnel and emergency personnel of various emergency departments(Niu Kun et al,2021).The design of each drill role is not randomly set up, but made after investigation and study of emergency plans and emergency scripts. According to the emergency response plan and script, the method of "scenario-response"is adopted to extract the emergency handling steps and actions that the drill role needs to execute(Guoyiyuan,2016; Chen Bo et al,2021).We use Cesium and UE4 engines to perform virtual reproduction of role actions, such as patrol and investigation of the area under the control of various departments before the arrival of extreme weather, and reconnaissance of the scene by UAV. The system uses Websocket protocol to realize the cooperative operation among all roles( e.g. Figure 5).Each role communicates with the server before the virtual drill. When the role performs the drill, it sends data to the server. After receiving the data, the server immediately distributes the data to other roles.

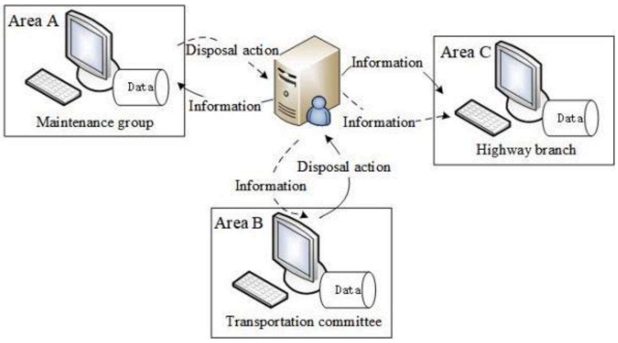


**Figure 5.** Cooperative operation mechanism of users

**3.2.4 Drill record and review:** We uses the RecordRTC to record the drill personnel's operations in this system. After the drill is complete, it generates text and video records. They are used for commanding personnel and experts to evaluate and summarize after the drill, and They are convenient for drill personnel to analyze and review the drill process.

**3.2.5 Drill process evaluation:** The evaluation function of the drill process is designed in the drill system. Based on the evaluation of the drill personnel by several emergency experts, we constructed the evaluation system of emergency response. The emergency rescue process is divided into six stages: emergency preparation, monitoring and warning, information reporting, emergency response, investigation and evaluation, and aftermath disposal. Each stage is carefully graded, and a three-level evaluation system is formed according to the work content of the performers. For example, the evaluation index of the emergency response stage of a certain performing role( e.g. Table 1)

**Table 1.** Example of evaluation index system

| Level indicators | Secondary indicators | Three-level indicators |
|---|---|---|
| Emergency response | Command and dispatch | Lead on-site command and coordination |
| | Emergency disposal | Put up traffic signs to divert traffic |

We use different methods to determine the weight of each level of evaluation indicators, so that the final evaluation results are more authentic and reliable. The evaluation indexes of the first two levels adopt the analytic hierarchy process to determine the weight(Pang Dongdong et al.,2021;Kramar U et al.,2018), and the process is as follows:

(1)By pairwise comparison, the judgment matrix is constructed, and the matrix elements meet the following requirements:

$$A=\left(a_{ij}\right)_{n\times n}=\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix} \quad (1)$$

$$\text{s.t. } a_{ij}=\frac{1}{a_{ji}}$$

where $A$ = the judgment matrix
$a_{ij}$ = index element score

(2) Calculate the importance of each indicator.

(3) Judgment matrix consistency verification(2-4).

$$CI=\frac{\lambda_{\max}-n}{n-1} \quad (2)$$

$$RI=\frac{1}{n}\sum_{i=1}^{n}CI_n \quad (3)$$

$$CR=\frac{CI}{RI} \quad (4)$$

where $CI$ = consistency indicators
$\lambda_{max}$ = the maximum eigenvalue of the matrix
$n$ = matrix dimensions
$RI$ = random consistency indicators
CR = consistency test results

When CR < =0.1 passes the consistency test, the weight is reasonable; If CR>0.1, it will not pass the consistency test and return to correction.

The weight of each evaluation indicator at the third level is calculated by the Comprehensive weight method combining Entropy weight method and Critic method (Wang Haoyu,2020;Iovi M et al.,2020;Deng Honglei et al.,2019). Finally, the weight expression of the indicator is determined by the product normalization method (5), and its correlation and stability are verified.

$$W_{hj}=\frac{W_{zj}W_{kj}}{\sum_{j=1}^{n}W_{zj}W_{kj}} \quad (5)$$

$$\text{s.t.} \quad 0\le W\le 1,\sum_{j=1}^{n}W_{hj=1}$$

where $W_{hj}$ = index component j of comprehensive weight method
$W_{zj}$ = index component j of subjective weight method
$W_{kj}$ = index component j of objective weight method

After the weight determination and the example verification, the evaluation system has good scientific and practical, can evaluate the emergency drill process, and the results have high reliability.

## 4. THE IMPLEMENTATION OF THE DRILL SYSTEM

The system carries out scene simulation and construction for a variety of road emergencies to realize virtual collaborative emergency drills, including mountain landslides, road collapse, ponding under the bridge, large traffic accidents and other cases. This paper only selects mountain landslides blocking road traffic events in flood season as a specific introduction.

### 4.1 Cases of mountain landslides blocking road traffic in flood season

This paper is set in a mountain area in XX District of Beijing. Due to continuous heavy rainfall, there was an accident of mountain collapse blocking road traffic. As the rain intensifies, secondary landslides are easy to occur. The units participating in the performance include the Municipal Transportation Commission, the Highway Branch Bureau and the maintenance group. The main tasks to be completed by each participating unit are as follows:

(1)Commanders: According to the specific situation of the disaster,study and judge the development trend of the landslide. Allocate resources, deploy rescue forces, and guide the rescue work.

(2)Emergency personnel: Cooperate with each other to rescue trapped people, clear stones, silt, etc. Restore road order.

(3)Assessor: According to the execution of each drill personnel to score, give suggestions.

The technology and implementation method introduced above are used to construct a virtual scene for the event of landslide blocking road traffic in flood season, simulate the emergency rescue process, and realize the virtual cooperative disposal drill.

### 4.2 Model construction of the drill scene

In order to make the virtual scene more close to the real environment. By consulting the text and image data of mountain collapse events in Beijing over the years, select the events with larger collapse scale and more complicated rescue work to build a three-dimensional scene model. It mainly includes static environment models (such as mountains, highways)( e.g. Figure 6), and dynamic target models (such as rescue vehicles, UAV, rescuers) ( e.g. Figure 7). We use 3DMax to make 3D models, use Cesium and UE4 to load models to complete 3d scene rendering, model loading and virtual rehearsal scene presentation. At the same time, We use the PhysX engine and Niagar system of UE4 to render the landslide process, UAV flight and other special effects to improve the experience of the drill personnel.

**Figure 6.** Static models

**Figure 7.** Dynamic models

### 4.3 Collaborative virtual drill and evaluation

Collaborative virtual drill is a simulation of the whole emergency rescue process, from the early warning stage to the end of the disposal work( e.g. Figure 8). At the same time, it is also an assessment of commanders and drill personnel to examine whether the emergency measures taken for various problems are reasonable and effective, and whether they are familiar with the emergency process and plan.

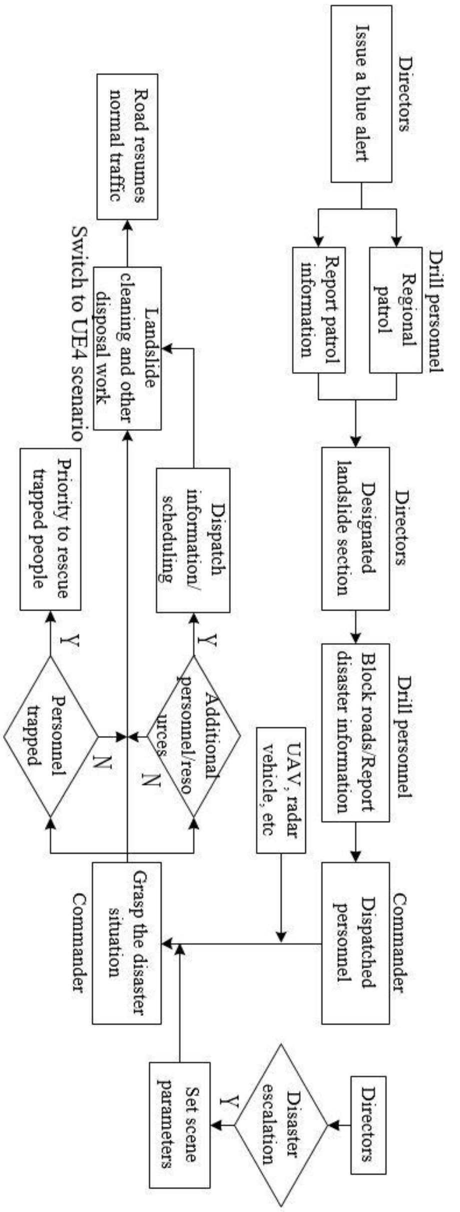


**Figure8.** Collaborative drill process

**4.3.1 Early warning stage:** Blue warning issued for flood season, and personnel in all regions need to take patrol measures. The director team selected a mountain road section as the location of the mountain collapse, set specific disaster information and tasks, and distributed them to each drill role.

**4.3.2 Disposal stage:** The drill commander receives the drill task information, and the system displays the location of the mountain collapse and the surrounding emergency teams (maintenance group, highway branch), emergency resources, and road distribution on the cesium platform in a visual way. The commander shall dispatch an emergency team to the scene to deal with the accident according to the specific situation of the disaster. After receiving the dispatch task, the emergency personnel shall select the emergency rescue equipment to be carried and rush to the scene of the accident. Commanders at all levels guide emergency work and dispatch drones to investigate the accident site to obtain specific conditions(e.g. Figure9). According to the disaster information provided by the system (collapse scale, area, people trapped), judge whether it is necessary to increase rescue personnel and resources. After that, the rescuers entered the UE4 scene, blocked the road, selected the corresponding rescue equipment for detailed rescue work, cleared the falling rocks, repaired the road, etc(e.g. Figure10). During the drill, the system instantly synchronizes the emergency rescue operations of each drill member, and has voice communication function, which facilitates the coordination between various roles, completes the cleaning of landslides, and restores road traffic.

**Figure 9.** Accident site investigation

**Figure 10.** Block the road and clean up the scene of the accident

**4.3.3 Evaluation and analysis:** During the drill, the commander and examiner can watch the cooperative operation information of the drill personnel in real time on the command platform.The assessors will judge by watching the playback video and the drill report, which includes the cooperative rescue action and execution time of the drill role. The assessors will score on a 5-point scale according to whether the execution action of the drill role is accurate and whether the execution time is fast, and point out the problems of the drill personnel. Then the system calculates the final score of each drill member according to the scoring results of the assessors and the evaluation system introduced above. Combined with the evaluation results, the drill personnel strengthened the practice of weak links and improved the emergency response ability.

### 4.4 Optimization of emergency plan

The virtual emergency drill system designed in this paper can deduce and review the emergency plans or scripts of various types of urban road emergencies. Through repeated drills, the key nodes in the process of emergency treatment and the deficiencies of rescue countermeasures were found out, specific improvement measures were put forward, and the emergency treatment process was constantly optimized to make the emergency plan more scientific and efficient, and strengthen the road emergency personnel's grasp of the key information nodes in the rescue process. Finally, the system will store the optimized road emergency plan or script data in the system database, and update the historical emergency plan database, which is convenient for subsequent emergency rescue personnel to read and learn.

## 5. CONCLUSION

In this paper, we propose and implement a multi-user collaborative exercise system based on Internet, computer simulation, virtual reality technology and road emergency actual combat drill. It solves the practical drilling problems faced by the road emergency team and the single problem of drilling personnel in previous studies, and breaks through the constraints of time, space and scene construction cost. The personnel participating in the drill can log in to the system in different geographical areas and enter the same virtual scene for remote interactive virtual collaborative emergency drill, so as to realize the repeated rehearsal of various road emergencies, effectively improve the emergency response and rescue ability of emergency participants, and optimize the emergency plan for road emergencies.

At present, the system is not perfect in the setting of virtual scene of road emergencies. The next step is to use computer simulation technology to develop richer drill scenes, strive for virtual collaborative drill scenes and diversified contents, and strengthen the research of evaluation system and methods to make the evaluation of drill process more scientific.

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