Maritime Emergency Simulation System (MESS)
A Virtual Decision Support Platform for Emergency Response of Maritime Accidents

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Abstract: This paper presents a maritime emergency simulation system (MESS) for the improvement of emergency response skills of participants of search and rescue (SAR). Firstly, the system architecture, software and hardware system are proposed, and the components and function are also introduced. Thus the virtual environment based on virtual reality is established with the distinguishing advantages of immersive, intuitiveness, low-cost and interactive. Four main types of accident are implemented in this system, to accomplish this, five key technologies which have been introduced in MESS are also proposed, among these technologies, some could enhance the immersive such as the traffic flow simulation and accident logic, while some advanced technologies could improve the efficiency and feasibility if being applied to the actual SAR. Moreover, the application domain including skills improvement of participants in SAR, accident investigation, adaptive decision-making based on scenario analysis, human reliability in emergency response are also discussed. Finally, the conclusions and further research are remarked.

1 INTRODUCTION

Maritime transportation safety has captured a great amount of concern in the past decades (Montewka et al., 2014 and Prabhu Gaonkar et al., 2011). According to the previously research works, many effective and useful measures have been proposed in risk control. Unfortunately though these methods have benefited us a lot, many accidents still existed in waterway transportation. Passenger ship “SEWOL” sinks which has caused 475 people in distress according to the latest report in 16 April 2014. From the perspective of traditional causal analysis of accident, human error is the main causes among all of the possible reasons (Jin et al., 2005), Thus majority of measures focus on the improvement of seaman reliability and accident prevention. But few attentions have been paid to the improvement of the SAR skills once accidents happened. While in the abovementioned ship accident, the total loss could be reduced by reasonable ship disposition and effective passenger evacuation.

The safety situation in inland maritime transportation is more complex than open sea area owing to the strong relationship between navigational environment and safety situation. Four distinguishing features of inland waterway transportation could be briefly summarized. Firstly, the offshore structures may bring higher stress levels to the seaman, and in fact, many accidents happened in the bridge area (Svensson 2009). Secondly, the risk arises for the relative-close-range collision avoidance in restricted and narrow waterway (Mou et al., 2010). Thirdly, apart from the SAR in maritime accident, inland emergency response involves the traffic organization and accidental ship disposition. In our past research (Zhang et al., 2013), we have discovered that the ship accident many cause a detention if none efficient method has been taken in drought season. Finally, as many different types of ships navigate in the restricted waterway, the reason and consequence of different types of ships may vary from each other (Antão et al., 2008a, Antão et al., 2008b and Sormunen et al., 2013). Thus the feasible and reasonable method in emergency

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response becomes a challenging and motivating field of study.

Virtual simulation system has been proved to be a practical tool in the skills improvement of participants owing to its powerful characters of interactivity, immersive, inexpensive and low risk. And this advanced technology has been applied to many domains. For example, Maritime Simulation System (MSS) was utilized for the training of crew and pilot (Feng et al., 2012), and the car simulation (Yu et al., 2013), train simulation (Watanabe et al., 2011) and military domain (Rizzo et al., 2011). Moreover, a virtual emergency decision support system for crew has been proposed by Varela and Soares (2007). But few system targeted at the cooperation group decision-making for Rescue Coordination Centre (RCC), thus a maritime emergency simulation system (MESS) is required for the skills improvement of rescuers. MESS is different from MSS in the following aspects. Firstly, the participants being trained are different, secondly, the former focus on the cooperation of multi-person and the process modelling, while the latter one concerns more about the accuracy of ship motion. But the virtual environment is similar in these two systems.

2 SYSTEM DESIGN

2.1 System Architecture

This study presents a maritime emergency simulation system that can perform cooperative disposition among multi-person to represent different departments using virtual reality technology. The VR engine generally interfaces the three-dimensional virtual reality models with the logistic to undertake given tasks to control the virtual world. The system architecture of MESS is shown in figure 1.The system involves five components, the accident evolution and intervention logic, accident virtual environment, emergency training simulator, hardware-in-the-loop and human-in-the-loop. The function of each component is as follows.

(1) The accident evolution and intervention logic is crucial for this system as this system is targeted at accident disposition. This component involves the accident scenario and emergency response plan for accidents. In our system, four types of accident include the collision, grounding, contact, and fire has been developed, moreover, the accident would develop into intermediate states and final state over time, and traffic flow should navigate according to the regular and emergency traffic regulations. And the emergency response plan could be dynamic executed according to the development of accident.

(2) The accident virtual environment includes the geometric model and conditional model. This could provide the participants a close to real environment. The geometric model includes the building, topography, sky and other background environment by using a virtual reality technology, in our system, the OGRE engine is adopted. The conditional model includes the wind, current, channel, offshore structures, prerequisite condition for the occurrence of different types of accidents.

(3) Emergency training simulator is the essential component to provide a platform that the participants could interact with each other as well as the computer. The training control module could set up the condition to make sure the participants could cope with different scenarios. Training evaluation module could assess the performance according to the data log and replay module. Moreover, a man-machine interface module has also been designed in this system.

(4) Hardware-in-the-loop module provides the hardware utilized in the emergency response proceeding. The participant could input, edit or inquire the significant information by using mouse and keyboard. Specifically, the rudder and propeller is provided to manoeuvre the SAR ship. The projector and VGA are used to project display screen to the projection screen.

(5) Human-in-the-loop. There are three groups of participants in this system. One group is in the RCC who is in charge of the SAR. Another group is the marine patrol ship who is in charge of traffic organization and plucking people from waters. The accidental ship is in the charge of the third group, and the function of this group varies according to the accident type.

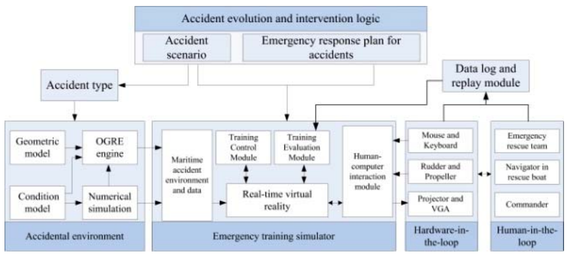

Figure 1: System architecture of MESS.

2.2 Hardware System

As shown in figure 2, the hardware system includes the projection screen system, RCC room and SAR vessels. Six computers which could simulate the different types of supervision methods of the RCC room in China, and the communication between the servers could be carried out via internet, the information displayed on the computer screens could be projected to the projection screen via projector and VGA. Two computers are used for simulation of SAR vessels. Specifically, the functions and composition of hardware system are as follows.

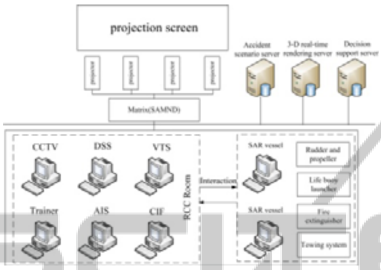

Figure 2: hardware systems of MESS.

(1) There are six computers in the RCC room to display the different software. The participants of each group could cooperate in emergency response in the charge of Commander-in-Chief (CIF); moreover, the RCC room could communicate with the SAR ships using radio communication or other effective methods.

(2) Two computers are used to simulate the SAR ships. Both of the two ships could be manoeuvred by using the rudder and propeller to control the course and speed. The marine patrol ship which could rescue the man overboard, thus the life buoy launcher is embedded into the software system.

(3) Three servers are used in this system, one is for accident scenario server which could set up the different accident scenarios, one is for the real time rendering to make sure the virtual environment immersive, the last one is for decision support which includes the workflow modelling and cooperation decision making in emergency response.

2.3 Software System

The software system of MESS could be categorized into four types according to the intents and purposes. They are system software, supporting software, training supporting system and simulation application system.

(1) System software is the system that could manage and operate the system resources. It includes the database management system, network management system and operating system.

(2) Supporting software includes the Visual C++, C#, OGRE engine, 3D max and MapInfo. Visual C++ is the widely used software for MESS; all of the algorithms are compiled by Visual C++. C# is unitized for the GUI of MESS, while the virtual environment adopts the OGRE engine. 3D max is applied to the three-dimensional modelling of objects, and MapInfo is the foundation of VTS (Vessel Traffic Service) and AIS (Automatic Identification System).

(3) Training supporting system is the system that could be directly used for simulation. And it is composed of geographic database, navigational environment database, emergency resource database, models, algorithms, accident scenarios and intervention. The function of the training supporting system is storage of the data, models and algorithms, thus it could be extended and developed once a new requirement is needed.

The models and algorithms which have been applied to MESS are emergency Workflow models, early-warning, human behaviour and rescue effect evaluation in emergency response. All these tools will be introduced in the following sections.

(4) Simulation application system is the system that has been developed and could be used in the process of emergency response. In the MESS, there are four types of simulation application system, specifically, the CCTV (Closed Circuit Television) system, VTS system, AIS system and DSS (Decision Support System).

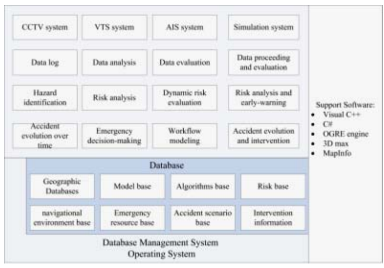

Figure 3: software system of MESS.

CCTV system: this system could monitor the navigation ships in the channel by using cameras, thus this system is a virtual environment and could be used for acknowledging whether a ship accident has happened. VTS system: this system could monitor the navigation ships according to the signals of Radar. AIS system: this system could give the predefined static and dynamic parameters of ship if the AIS are installed in the ship and available. DSS system: this system provides five types of significant information of emergency response, specifically, the navigational environment, the execution process of emergency plan, the available emergency resource, the rescue information and the parameters of accidental ships.

3 KEY TECHNOLOGIES FOR MESS

3.1 Traffic Flow Simulation Based on Multi-Agent

Multi-agent is a widely used method in traffic flow simulation. For example, de Oliveira and Camponogara (2010) have applied this technology to urban traffic networks control. While in waterway transportation, maritime traffic in piracy-affected waters is developed by Multi-agent (Vaněk et al., 2013 and Jakob et al., 2011). In a basic Multi-agent system, the agents could interact and communicate with each other which makes the traffic could be self-organized.

In MESS, if one ship accident happened in the channel, the traffic flow should initiatively deviate from the channel or heading to the anchorage to be far from the scene of accident, thus the traffic organization would be feasible and effective by using Multi-agent. The multi-agent system is shown in figure 4, in regular scenario, once a vessel leave the wharf, the vessel would interact with the berth, then navigate in the restricted channel, and make collision avoidance with the other vessels, then the traffic flow is established. While navigate from departure port to destination, the vessel would sail through the bridge, anchorage, berth and lock by interaction.

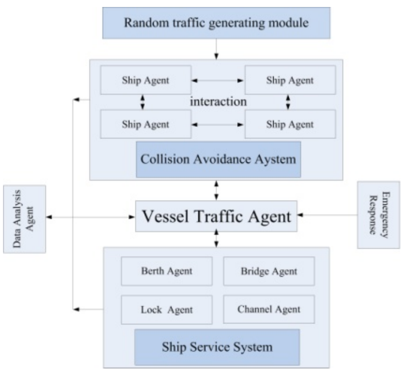

Figure 4: Traffic flow simulation based on Multi-agent.

Thus all these participants would be supposed as agents. Moreover, since the vessels would navigate according to the regulations of vessel traffic control department, and in this system, this would be supposed as emergency traffic organization, thus this participant would also be supposed as an agent.

3.2 Early-warning

Early-warning is crucial for incident reduction which has been widely used in the Yangtze River MSA (Maritime Safety Administration). This method divides the hazard into four grades which is identified as different colours. The principle of this method is essentially similar with risk assessment. The difference is that majority of risk assessment models are based on the historical accident data (Knapp et al., 2011 and Li et al., 2012) while early-warning requires the real time data. Mazaheri (et al 2013) presented that the risk should involve the probability, consequence and risk control option. This is similar with Formal Safety Assessment (FSA) (Wang 2001). Though this risk assessment is dynamic, and in our previously research; the risk option control method could be evaluated (Wang et al., 2013). Thus in our MESS, the early-warning tool had been embedded in AIS system which is shown in figure 6.

3.3 Accident Logic and Development

Mazaheri (et al 2013) proposes majority of the accident research focus on the initial state and final state of accident, but few research concerns about the intermediate state. In fact, the accident would develop into different intermediate states; moreover, the intermediate states would vary according to different intervention methods.

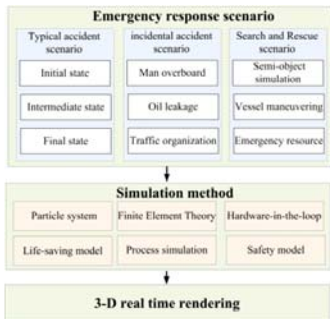

Figure 5: An accident scenario simulation in MESS.

For example, the fire accident would be extinguished if fire has been detected immediately and effective measures have been taken, but it would explode if none effective measures were taken. In MESS, the accident would develop according to intervention measures over time. The simulation of accident which includes accident evolution, rescue scenario is shown in figure 5.

3.3.1 Ship Collision Accident

Montewka (et al 2010) presents a new approach for the geometrical probability of collision estimation based on maritime and aviation experience. In his study, the historical accident data involves different types of ships, velocity, distance and course is used, from the result of simulation, this model has a good agreement with the practical data. Moreover, Goerlandt and Kujala (2011) propose traffic collision simulation based probability model. Ship type, ship dimension, ship speed are considered. And the consequence of ship collision is related with materials (Ehlers and Tabri 2012), speed, course and other factors. In our study, we have collected ship accident data in the recent years in China and data mining method has been applied to analysis the probability and consequence of ship collision. Furthermore, ship collision with offshore structures such as bridges has also been developed in MESS.

3.3.2 Ship Grounding Accident

Ship grounding accident is similar with ship collision. Thus some researchers have taken these two accidents into consideration in one method (Pedersen 2010). And the consequence analysis of grounding could also be carried out by Finite Element Method (FEM) (AbuBakar and Dow 2013). But if this method is adopted in MESS, the 3-D real time rendering would be challenging for this massive system, and even to impossibly accomplish. In MESS, we use the historical data to analysis the probability and consequence of grounding. But for further research, the data collected from the simulation result of FEM could be used instead of the historical data. Moreover, the stability, reserve buoyancy, sink-resistibility and overturn-preventing of grounding ship are also taken into consideration.

3.3.3 Man Overboard Accident

Life-saving is especially complex in emergency response if unavailable or incomplete information has been collected during the process. Thus many methods have been applied to life-saving in the open sea area. For example, the satellite-guided search-and-rescue-system has been proposed (Kurowski and Lampe 2014). Moreover, another essential part of life-saving tool is the drift distance estimation influenced by current and wind. Ni (et al 2010) presents an approach to predict the boat drift, moreover, an operational SAR model for the Norwegian Sea has also been proposed by (Breivik and Allen 2008). We have introduced the service lifecycle model in MESS, and drift model is based on the current and wind which has not taken the personal movement into consideration. For further research, the drift model based on uncertainty and inaccuracy information should be carried out in MESS.

3.3.4 Ship Fire Accident

Ship fire accident is a typical accident in maritime transportation. This accident would develop into cartography in a RoPax ship or dangerous goods ship. Thus there is a mandatory requirement on monthly drills of fire prevention in ocean-going ship. The fire accident may caused by electronic failure, human error or other reasons. Wang (et al, 2013) proposes a Monte Carlo method to predict the process time until the ship explode, and he has cauterized four different types of parameters to simulate the time of fire accident. Shichuan (et al 2012) presents a numerical computation approach in ship engine room. Since the MESS focuses on the cooperation emergency response of fire accident, the fire accident only takes the available time and different types of accident into consideration. But for further research, the people evacuation model should also be considered especially for RoPax ships.

3.4 Workflow Modelling

Workflow modelling is a powerful and practical tool for transaction management. Petri net is perhaps the most widely used method among all workflow modelling methods due to its well defined and easy-to-understand graphical feature (Salimifard and Wright 2001). Moreover, the graphical feature facilitates visual communication between the exactors involved in the process of execution. At present, continuous works have been done to cope with the rapidly changing requirements; however, majority of traditional workflow modelling technology could only deal with the predefined process. Moreover, a well-formed workflow technology should be intuitiveness and correctness verification. Thus the emergency workflow modelling which is used in incident command system becomes a motivating and challenging field of study. A Workflow Intuitive Formal Approach (WIFA) has been proposed by Wang (et al 2008). This approach defines the workflow into five-tuple. Specifically, this workflow is represented by task, precedence matrix, conflict matrix, precondition and initial state. This method is actually well-defined with the distinguishing characters of flexibility, intuitiveness and correctness verification. Moreover, this model could be easily modified according to the special requirements of different systems. The timeliness analysis, resource consume and decision-making are the basic problem which should be studied in emergency response .Timeliness workflow modelling (Wang 2012) and resource requirements modelling (Wang et al., 2009) are proposed for the purpose of timeliness analysis and resource analysis. In MESS, an improved WIFA is presented to meet the requirements of multi-executors and dynamic modification on emergency workflow modelling.

3.5 Cooperative Group Decision-making

Group decision-making plays an essential role in choosing a best or compromise option, and has been a keen research topic in the field of multiple criteria decision-making (MCDA). Unlike the classical MCDA model which only concerns the ranking of different attributes, group decision-making focuses on the coordination of the experts when they make different choices or even conflicting choices (Xu 2007) .This is very common because each expert may have their preferred orderings of the attributes. Moreover, the choice of a single expert may be not persuasive or feasible due to the inherent complexity or incomplete information in the process of decision-making. Thus group decision-making is widely used in order to integrate the experts' viewpoints and overcome the partial opinion of single expert. While applied to the maritime accident emergency response domain, there are multiple related departments in the process of decision-making after a maritime accident occurs, if the decision maker simply considers the problem from the perspective of his own department, the decision will be limited in feasibility. Thus all related suggestions from other departments should be taken into consideration to obtain a highly cooperative decision. Unfortunately, little research work concerns about the multidivisional cooperation within group decision-making. In order to address this problem, a multidivisional cooperation model was introduced in MESS.

4 SYSTEM APPLICATION INSTANCES

In this section, a collision accident is presented to be an instance for application of MESS. This accident happened near the Wuhan Yangzi River Bridge. The accidental ships are a container ship and a ferry, after collision a fire accident happened. The emergency response of this accident could be carried out as follows. There are eight participants for emergency, two are representative of marine patrol vessel and fire extinguishing vessel, and the others are in the RCC room and each participant is in charge of one computer.

Firstly, the AIS system discovered the accident happened in the channel by using early-warning tool, this tool is shown in figure 6. Then he reported to the CIF immediately, the CCTV system would check whether this accident happened according to the instruction of CIF. Once the accident was acknowledged, the CIF will ask the VTS system for ship's particulars of accidental ships. At this time, the CCTV reports that somebody was overboard.

Figure 6: Early-warning tool of AIS.

Secondly, the CIF will ask the DSS to inquire the available emergency resources, and then the CIF will ask the available SAR vessels heading to the accident scene by using effective communication methods.

Figure 7:a scene of emergency response simulation.

Moreover, the choice of closure of the channel is made by using the cooperative decision-making system.

Finally, after the fire has been extinguished and overboard man has been rescued, the evaluation of emergency response could be given. The scene of emergency response simulation is shown in figure 7.

5 APPLICATION OF MESS

5.1 Accident Investigation

The accident investigation method depends mostly on the evidence obtained by the investigator. Thus the recorded data plays an important role in analyzing the reason of the accident. But in fact, the experts made judgments mainly according to the experience and professional skills. If the virtual environment could be established, the experts could immediately make reasonable judgment. Though this technology may be still a matter of controversy for accuracy which mainly depends on the virtual model, but in future, this technology could be introduced as an auxiliary method in accident investigation.

5.2 Adaptive Decision-making Based on Scenario Analysis

The emergency decision-making in ship accident is crucial for damage control, but this is actually complex especially in restricted resources scenario. The ship condition, emergency resources and navigational environment could be assumed as available emergency resources; mostly the captain could only bear an acceptable damage instead of without loss. Since the accident investigation focuses on the causal analysis, adaptive decision-making based on scenario analysis could be carried out to find out whether a better method could be adopted. Through that the decision-making skills of emergency response could be improved.

5.3 Human Reliability in Emergency Response

Study on the human reliability is essential since majority of the accident are caused by human error. In the traditional investigation, the reasons of human error are roughly treated. But from the perspective of psychology, the human error may differ from different scenarios such as stress, fatigue, confidence etc. As the development of psychology analysis technology, the galvanic skin and electroencephalogram-graph could be introduced to research the human reliability in emergency response.

6 CONCLUDING REMARKS

The MESS is the pioneering which is targeted at skills improvement of SAR officers in emergency response. This system could provide a vivid virtual environment established by virtual reality for the participants, thus this system has the distinguishing advantages of immersive, intuitive, and interactive. Moreover, this system could provide different scenarios with the advantage of low-cost and random-scenario analysis. The accident logic and intervention method is based on the evolution and development of ship accidents, thus the emergency process for participants would effective and useful. Furthermore, the traffic organization and rescue of man overboard are also in line with reality, so this could be applied to the actual SAR in future. This system could also be used for research domain (i.e. accident investigation, adaptive decision-making, human reliability). For further research, the accident such as stranding should be carried out.

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