Designing Agent-based Modeling in Dynamic Crowd Simulation for Stressful Environment

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***Abstract*—In recent years, modeling and simulation technologies have been gaining tremendous momentum in investigating crowd dynamics. Various simulation architectures have been developed and virtual environment representations have also been constructed for crowd simulations. To represent the behavior of a crowd, a number of behavior models have been proposed with different types of modeling approaches, such as flow-based models and agent-based models. Crowd models may also concern different aspects of a crowd. In modeling stress response, a method based on well-established theory of Generalized Adaptation Syndrome (GAS) has been developed to simulate the dynamic behavior of the crowd. However, there is still lacking of method to address the way virtual agent interacts with the instant changing behavior of the crowd during stressful events. This study were review current work on modelling stress and stress behavior models and extends it into the area of crowd simulation to simulate the behavior of the stress response of virtual agent during stressful events. It attempts to look into the solution of the problem and utilized a method based on the psychological theory of GAS to develop an algorithm for responsive virtual agent under stressful events by determining the dynamic behavior.**

***Index Terms*—Algorithm; Responsive; Virtual Agent; Virtual Environment.**

I. INTRODUCTION

Several researchers have attempted to characterize how humans respond to stress in terms of both internal, physiological changes and external, behavioral changes. Early attempts to model how human behavior changes in different situations include the work of Francis and Cattell [1], which proposed a mathematical formula to predict human behavior as a function of personality and situation. More recently, James [2] have extended this work to the pedestrian behavior, modeling the increased aggression people exhibit when stressed. Berg, Guy, Lin and Manocha[3] incorporates personality trait theory into simulating heterogeneous crowd behaviors. Meanwhile, Kim, Guy, Manocha and Lin [4] have introduced a method based on psychological theory of Generalized Adaptation Syndrome (GAS) to simulate the dynamic behavior of the crowd where they used linearization model of GAS in accordance to the theories involved. However, there is still lacking of method to address the way of virtual agent interacts with the instant changing behavior of the crowd during stressful events. This study extends the previous work in the area of crowd simulation to simulate the behavior of the stress response of virtual agent during stressful events. This study attempts to develop an algorithm for responsive virtual agent under stress. The ultimate aim of this study is to determine the dynamic behavior of virtual agents under stressful events.

II. LITERATURE REVIEW

The area of crowd simulation and multi-agent navigation is an active area of research, with a wide variety of methods and results. Crowd modeling and simulation has now become a key design issue in many fields including military simulation, safety engineering, architectural design, and digital entertainment etc. Crowd simulations have been intensively used for real-time tactical military training, such as simulating the civilian behaviors and combat actions in peacekeeping scenarios.

Constructing a pool of human individuals and their behaviors in a virtual environment has been applied to identify possible risks or failures in a broad range of emergency situations and facilitate the architecture design to ensure safety. The simulation and control methods of crowd have been discussed by Pelecheno[5] in a broader coverage of the field. In this study, we primarily focus on interactive methods for modeling crowd behaviors under stressful events.

A. Agent-Based Model

Agent Based Modeling (ABM) is a model consists of collection of autonomous decisions-making agent where each agent assesses its situations and make decision based on set of rules where their effect on the system view as a whole [6], [7]. Important feature in ABM are repetitive competitive interactions between agent.

Figure 1 shows the structure of a typical agent [6]. There are three basic elements in an agent based model. First, a set of agent consists of their attribute and behavior. Secondly, a set of agent has relationship and methods of interactions where agents are connected to each other by using a topology. A topology will describe how and with whom agents interact and also the mechanism of the dynamics of the interactions. Thirdly, the agent environment that provides information on the spatial location of an agent relative to other agent may also have its attributes and methods.

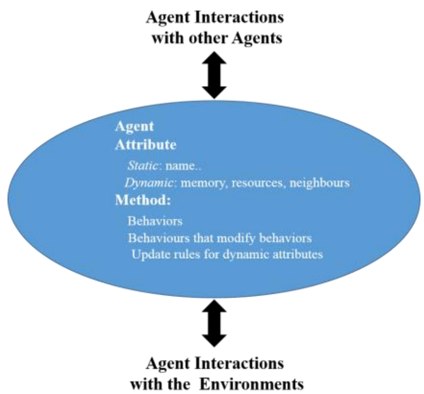

Figure 1: A typical agent structure (adapted from Makal and North [6])

ABM has been widely used to capture emergent phenomena in various areas. The Basic Immune Simulator use to model interaction between cell of the innate and adaptive immune system [6][8]. In ecology, an agent based model for predator - prey relationship between transient killer whales and threatened marine animal in Alaska have been develop by Mock and Testa. An agent-based model was used to simulate evacuation behavior for a Chinese supermarket and an international university in the Netherlands [9]. The TRansportion Analysis SIMulation System (TRANSIMS) created by Los Alamos National Laboratory (LANL) was used to simulate the movements of individual vehicle on a regional transportation network and estimate air pollution created by vehicle movement [7]. Axtell and Epstein developed ResortScape which provide an integrated picture of the environment and all interacting elements in a theme park.

Benefits of ABM are its ability to capture emergent phenomena. Agent may be capable of evolving , allowing unanticipated behavior to emerge [7]. Generally, they cannot be reducing to the system parts because the properties are decoupled from the properties of other part making it difficult to understand and predict. Example , putting a pillar just before the exit of confined space like cinema or theatre hall will reduce the number of injured people and increase the flow during fire escape situation [7].

Secondly, ABM provides a more natural description and simulation for a system composed of behavioral entities. Sometime individuals behavior cannot clearly be define through aggregate transition rate or individual's behavior is complex. Eric Bonabeau said rather than come up with equation that rule the dynamics of the density of shoppers it much easier to describe how shoppers move in a supermarket [7]. From the shopper behavior not only the density equations result will appear, will also enable user to study aggregate properties.

Thirdly, ABM is flexible. If level of description or complexity of agent is not known and require some time for finding ABM will be the solutions because provide a natural framework for tuning the complexity. It has the ability to change level of description and aggregation [7].

B. Dynamic Crowd Simulation

In terms of dynamic crowd simulation, there are several frameworks proposed for simulating and rendering large number of crowds. The Virtual Dublin project simulated crowds in an urban simulation at interactive frame rates [10]. Yersin, Ma and Thalmann[11] proposed a method of using pre computed crowd patches to populate a large scale virtual environment for real-time simulations. Parallel GPU-based algorithms have also been proposed for both crowd simulation and high-quality rendering [12]. Recently, Chen had introduced new hybrid approach of modelling & simulation based on hierarchical Grid simulation architecture for handling huge crowd upon [13]. This approach was successfully implemented for handling a high density of the crowd in the urban area. Besides that, the crowd simulation method based on a biologically motivated space colonization algorithm also being introduced [14].

Many real-time techniques have also been suggested for goal-directed multi-agent simulations. Among them is the HiDAC system which able to simulate various behaviors[15]. Reciprocal Collision Avoidance based methods have been successfully applied to simulate crowds [3]. An interactive algorithm based on navigation fields, where users can directly control the crowd movement are proposed by Patil, Berg, Curtis, Lin and Manocha[16]. Many researchers have used psychological factors in crowd simulation. For example, the simulation of different way finding behaviors of trained/untrained leaders and the followers in emergency situations is done by Pelechano, Brien, Silverman and Badler[17]. These behavior patterns are chosen based on the given role, and may not change during simulation. Sakuma proposed a local collision avoidance method that switches discreetly between smooth and urgent avoidance behaviors based on the urgency of collisions [18]. Besides that, the system which models the effects of psychological factors by using artist derived rules to change behaviors when the agents are fearful, fatigued or happy introduced by Master and Stockholm [19].

C. Stress Behaviour Model

Besides that, in terms of stress behaviour model, Selye proposed a broad framework for understanding how the response to stress changes over time [20]. His General Adaptation Syndrome theory presents a non-specific, non-unique model of stress response to stimuli. Since this work, other studies about stress in a broad aspect have been performed, investigating its relationship to general activities, physiological effects, emotional, behaviour, and cognitive performance [21], [22]. The connection between stress and aggression has been particularly well established and holds across a variety of stressors [23]–[27].

Kim has introduced a method based on psychological theory of Generalized Adaptation Syndrome (GAS) to simulate the dynamic behaviour of the crowd where they used linearization model of GAS in accordance to the theories involved [4]. Figure 2 shows the GAS theory (upper) and its approximation based on assumption of linear and accurate stress(below). Figure 3 shows the crowd simulator which indicates crowd reaction to the external stressor. Crowd, in this case is being assigned with predetermined path reaction.

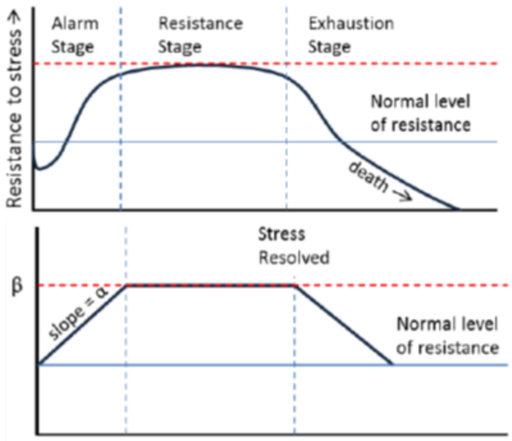

Figure 2: General Adaption Syndrome and approximation (courtesy: Kim et al. [4])

Figure 3: Evacuation scenario. Agents evacuate an office building in the presence of a fire stressor and crowding stressors (adapt from source [4])

Figure 4 shows Kim overall system [4]. It has three main components. First the stressor provides a source of stress for the agents.Four different prototype stressors are used in the system. There are time pressure, positional stressors, environmental stressors, and interpersonal stressors Second, the stress accumulation function which is determined by the GAS model. Third, a multi-agent simulation algorithm that is capable of changing an agent behavior by increasing its aggressiveness and impulsiveness.

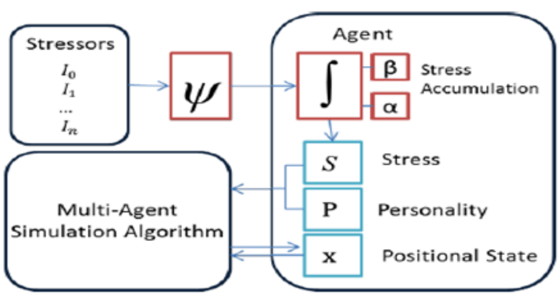

Figure 4: System Overview (adapt from source [4])

Ingram and David has introduced Vulnerability-stress model in order to explain crowd behaviour during stressful event [28]. It explain how genetic traits, biological, physiological, cognitive and personality interact with stressors to produce reactions.

This study approach will be based on these works to model dynamic crowd behaviours. Its ultimate aim is to identify the possible algorithm for virtual agents to react in a stressful environment as there are dynamic behaviours of a large crowd. Other stress behaviour models such as vulnerability-stress models will be emphasized upon [28]. This stress behaviour model could be integrated into dynamic crowd behaviour to produce new algorithm.

Cognitive models of depression that rely on diathesis model show that substantial life stress also occur before the proses of depression [28]. According to Beck's Cognitive Theory of Depression, depressed people have unrealistic negative way of thinking about themselves, their experiences and their future due to their emotional and physical symptoms. Combination of pessimism and helplessness will lead to a lack of motivation [29].

D. Fear Modelling

Panic disorder and fear concept is characterized by sudden episodes of uncontrollable anxiety accompanied by a variety of cognitive and physiological symptoms. Psychological theories of panic and anxiety usually imply directly or indirectly that pathological anxiety is associated with an intentional bias towards threat cues. It is common to see that fleeing from the immediate situation; freezing, choking and smothering sensations are quite frequent as well. In addition, there are four elements of panic; a) hope to escape from limited resources, b) contagious behaviour, c) aggressive concern about one's own safety, and d) irrational illogical responses [36].

To model these behaviours, a number of formal modelling techniques have been introduced, namely; cognitive modelling, formal logic, probabilistic model, differential equation and agent based model [36]. For example, Dynamic Bayesian Networks has been used to model passenger's panic during a ship fire. The concepts of probabilistic and dynamic elements were used to demonstrate how panic can dynamically vary from passenger to passenger with different scenarios and conditions. Similar scenario also being used in pedestrians behaviours during the evacuation processes from metro stations.

Differential equation and agent-based model were used to model panic conditions among trapped individuals incorporated with accident investigation [39]. Concept of fear modelling in emergency aircraft evacuation also has been investigated to establish an aircraft emergency evacuation model to reflect the resulting selfish behaviour of those panic passengers.[41]. Schlake[44] developed a mathematical model to analyze panic among pedestrians using a set of ordinary and partial differential equations. Special focus was given to study existence and uniqueness of local solutions from simulated patterns based on trends and motions. Social force theory was incorporated to design such model under related homogeneous flow scenarios.

Panic modelling during catastrophic events also received special attention from several other researchers. For example, a differential equation to analyze panic behaviours based on SIR model was developed by Verdiere et al [46]. The model covers different concurrent behaviours in catastrophic situations (i.e. earthquake, tsunami) and processes of transition from one behaviour to the other during the event. This includes behaviours such as reflex, panic, and controlled behaviours with their propagation mode.

From another perspective, Fava and Morton [42] developed a panic disorder model based on important constructs from related theories in psycho-dynamic, cognitive and neurobiological literature. The causal modelling approach has been used to generate important patterns that later were evaluated with important cases in panic modelling. Recently, a multi-agent model receives more attention in developing model for panic behaviour in crowds. Normally, the main focus of multi-agent models is to represent culturally-based human groups that behave according to well-established and institutionalized rules or known as "collective behaviours". For example, Franca et al., developed panic behaviour by utilizing related information in contagion theory [43]. The model describes the structure of and operation of collective panic in a systemic and computable ways, from its genesis up to its execution apex.

The agent based approach has also been used to analyze patterns in crowd behaviour involving contagion of mental states [45]. Form this approach, the results show the inclusion of contagion of belief, emotion, and intention states of agents results in better reproduction of the incident than non-inclusion.

E. Accumulative Stress

Stress is an automatic state that results when the body is told to make change in order to adapt to any demand. According to Hans Selly stress is the nonspecific response of the body to any demand [30]. Stress can be categorize into two there are Eustress, the positive stress and Distress, the negative stress [31]. Eustress motivate and improve one performance while Distress will causes anxiety and decrease performance.

There are several causes that can trigger stress [30], [32],[32]. There is fear and uncertainty, for example, talking to a stranger, news about threat of terrorist, global warming, and unfinished project. Attitudes and perceptions on how individual react toward situation or news may create a different. Unrealistic expectations or perfectionist expectations may also cause stress. Life changes, for example from marriage to divorce and from securing a job to jobless are also part of causes that may trigger stress. All of these events when combine will lead to stress and will create symptoms like anxiety, depression, fear, anger and frustration.

III. METHODOLOGY

This study adapts the Design Science Research Methodology (DSRM) which was originated from the work in engineering and computer science disciplines [34],[35]. The DSRM emphasizes on the need for constructive research methods, which allow the disciplined, rigorous and transparent building of a software or system (for which the generic term in Information Systems is referred to as an Information Technology artifact) as outcomes and to distinguish the work from an ordinary practice of developing an application. Figure 5 shows the research methodology for this study.

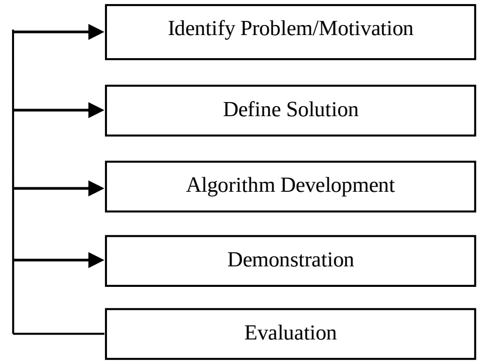

Figure 5: Research Methodology

In phase one, problem statement and/or motivation of this study is derived from existing literature and previous works. Content analysis will be used to form solid argument. Second phase involve identify requirements for responsive virtual agent in a stressful virtual environment. Requirement analysis and interview with domain experts will be used in defining both virtual agent and stressful virtual environment requirements. Based on the requirements identified in second phase, algorithm for responsive virtual agent in a stressful virtual environment will be designed and developed in third phase.

In forth phase the demonstration phase, a virtual environment with responsive virtual agent will be designed and developed based on the algorithm in third phase. Activities involved in this phase are scene modelling, character modelling and the integration of both. Lastly is evaluation phase. Both verification and validation will be conducted in this phase. What-if analysis is used as basis during simulation in various scenarios in order to get a solid and robust algorithm.

IV. RESULTS AND DISCUSSION

In recent years, many researchers have studies in dynamic crowd simulation and agent based model technologies. There is various simulation techniques have been developed and using virtual environment representations in order to create a dynamic crowd simulation. Table 1 shows the review of crowd simulation from year 2005 until year 2014 from the other researchers that implemented their crowd simulation in different situation and techniques used. There are about crowd simulation and the techniques used to create crowd simulation integrating with the psychological behavior such as stress and panic behavior of the models.

The review of crowd simulation paper, there are differences theories and techniques that are researchers focuses for panic or emergent situation in crowd simulation behavior. Most the researchers such as Kim, Guy Monacha and Lin, Sharbini and Bade and Pelechano, O'Brien, Silverman and Badler are studies about how to stimulate crowd simulation where the behavior panic or stress are involved in the crowd simulation. As for reviews, Kim, Guy, Mohacha, Lin and Sharbini using a psychological theory of GAS to simulate the dynamic behavior of the crowd and Kishi, Kitahara, and Kubo using Dijikstra's algorithms techniques to applied in refuges simulation for tsunami disaster. Pelechano et al., papers refer that they studies are implemented two different techniques approach which are first in 2005 is Model HiDAC and next two years in 2007 the combination of MACES and PMFserv are used but both of them are for agent behavior in crowd simulation. There are various environments that are using for crowd simulation in the research with different situation. For example, from the review there are several environments or situation for crowd simulation such as emergency aircraft evacuation, crowd refuge simulation from tsunami disaster, crowd simulation in emergency in shopping mall and crowd simulation for Hajj. However, there is still no researchers come out with method to address the way virtual agent interacts with the instant changing behavior of the crowd during stressful events.

Table 1
Review of Crowd Simulation from 2005 – 2014

Author(s)	Objective	Technique(s)
(Wang et al., 2014)	To proposes a hybrid approach to guide crowd movements by constructing a navigation field and local collision avoidance simultaneously	The crowd can take use of navigation field which records the optimal path and local collision test keeping them off obstacles with modified vector to reach their desired destinations.
(Kishi, Kitahara, & Kubo, 2013)	To discusses the crowd refuge simulation from tsunami disaster.	The refuge simulation is calculated by multi-agent system, Dijikstra's algorithm is applied for calculation method of route selection.
(S. Kim, Guy, Manocha, & Lin, 2012)	To simulate dynamic patterns of crowd behaviors using stress modeling	A method based on psychological theory of Generalized Adaptation Syndrome (GAS) to simulate the dynamic behavior of the crowd where they used linearization model of GAS in accordance to the theories involved.
(Sharma, Otunba, & Han, 2011)	To identify the sense of presence in a virtual environment as a possible way of validating human behavior and crowd simulation models.	Aircraft evacuation Virtual Reality framework for validating crowd behavior simulations.
(Mulyana & Gunawan, 2010)	To simulate the hajj crowd based on the development on intelligent agent and intelligent agent is able to adapt and show rational behavior, to recognize the environment, and to do action.	The intelligent agent was implemented using ActionScript with object oriented paradigm
(Sharbini & Bade, 2009)	To analyze on the bona fide of human relationship in aiding the decision making process during the simulation in panic situation and further discussed on the theories stated**.**	Physics and sociopsychological forces in order to describe the human crowd behavior in panic situations.
(Pelechano, Allbeck, & Badler, 2007)	To simulating the local motion and global way finding behaviors	Model (HiDAC: High-Density Autonomous Crowds) where crowds moving in a natural manner within dynamically changing virtual environments
(Pelechano et al., 2005)	To integrate a psychological model into a crowd simulation system in order to obtain believable emergent behaviors.	Architecture is proposed that combines and integrates MACES and PMFserv to add validated agent behaviors to crowd simulations.

V. Conclusion

Even though there are works have been done related to the development of dynamic crowd simulation agent-based model, the lack is still there, particularly related to dynamic crowd instant changing behavior when facing stressful environment. Therefore, this study attempts to look into the solution of the problem and utilized a method based on the psychological theory of GAS. Previous works have shown the relevancy of the theory in simulating the dynamic behavior of the crowd.

Those previous works will be a base to this study for developing the dynamic crowd behaviors. A possible algorithm for virtual agents to react in a stressful environment as there are dynamic behaviors of a large crowd is the conclusive purpose of this study. Besides, other stress behavior models such as vulnerability-stress models also will be emphasized upon. These models are important and could be assimilated into dynamic crowd behavior to produce new algorithm.

Acknowledgment

The authors would like to express their sincere appreciation to Ministry of Education Malaysia for funding this project under Fundamental Research Grant Scheme (FRGS).

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