NAVIGATING EMERGENCY CROWD EVACUATION USING MAS-GIG MODEL

Dinh Thi Hong Huyen¹, Hoang Thi Thanh Ha², Michel Occello³

¹Quy Nhon University
²Da Nang University of Economics, The University of Da Nang
³Grenoble Alpes University
dinhthihonghuyen@qnu.edu.vn, ha.htt@due.edu.vn, michel.occello@lcis.grenoble-inp.fr

ABSTRACT: In this paper, we consider the problem of modeling complex systems at several levels of abstraction. We proposed MAS-GiG, a multi-level multi-agent model for modeling crowd navigation systems. Our approach is based on the formation of different levels to enhance the effectiveness of managing distributed multi-level systems. The mechanism of formation of levels is carried out from the bottom up. Thanks to the multi level observation, the complexity of the system is reduced on each level, and the system can also provide instructions that guarantee an effective monitoring. For experimentation, the MAS-GiG model was applied in the case of navigation the crowd following the safe path for minimizing the number of casualties.

Keywords: Complex system, multi-agent system, crowd navigation, emergency evacuation.

I. INTRODUCTION

Over the past several decades, complex systems have been the subject of extensive research in various approaches. The concept of “complexity” is defined depending on the field of study. Some examples such as: human brain, world economy, ecology system, internet, human society, global climate, power grid, transportation system, crowd move. In these systems, there are always some characteristics that make the study of it more and more challenging, such as: many participants, heterogeneous components, the system is always changing, diverse and special is its multi-level, multi-proportionality. It is because of such properties that in complex systems there are always unpredictable phenomena arising from local interactions that can affect the whole system [24]. Local interactions between parts give rise to spontaneous activity. This can be a process that is not controlled by any external agent. This process is completely decentralized, distributed in the system.

Modeling complex systems allows us to understand the system and predict its changes. According to Michael Batty et al [1], the author argues that it is not possible to take a holistic view of a complex system to reproduce its diverse behaviors. Therefore, many studies are performed and simulation based on partial representations. Multi-agent systems (MAS) provide a suitable model for modeling such complex phenomena.

The passenger system at locations such as train stations, airports, and shopping malls is also considered a complex system. This system has a large number of passengers whose behavior is constantly changing, a very large number of interactions including passengers interacting with each other and they interacting with the environment. If there is an emergency situation such as a fire, each passenger does not know the environment well, so he panics, he tries to get out at all costs, he may jostle and trample with others. That's why the death rate is high. As for the emergency management agency, they could not guide individual evacuation, because of the large number of evacuees, plus the panic. Automated guidance systems are not effective. Therefore, the problem of managing and navigating the crowd according to each level in an emergency situation is really necessary.

From the characteristics of complex systems, specifically the crowd system, we choose the MAS approach to model the system for a number of reasons such as. First, MAS uses separate entities to represent components such as autonomous, intelligent, flexible, interactive agents. Specifically, agents interact with their neighbors or with the environment to gain knowledge. Then the agents use their knowledge to decide and perform an action on the environment to solve the assigned task. Second, MAS is a kind of intelligent distributed system in which autonomous agents exist in a world without global control [2]. Third, MAS describes the system in a natural way, specifically describing pedestrian behavior. At any given time, each agent in the MAS is situated at any location in the environment and is capable of acting autonomously in that environment. Example, an agent can move to another location by changing its current location or it can change its state such as move to another place, return to the previous position etc.

Another advantage of MAS is that it can use multi-level organization. Conte et al [3] argue that for a given complex system, expert knowledge is available at different levels of detail depending on the domain. The author also argues that expert knowledge is largely unusable if we consider it only at the micro level. In MAS models, entities corresponding to different levels of abstraction will be represented by agents at different levels in the MAS organization [4].

In this paper, we propose the MAS-GiG multi-level multi-agent model to model the crowd. The main problem of the research is to build different levels in the model to control and manage the system at each level. The
organizational structure in the model is determined by the group structure and the interaction relationships. The model is applied in crowd navigation during a fire in a flight lounge. The experimental results include the total evacuation time and the total number of people unable to get out of the dangerous place to the safe place. If the smaller the total evacuation time and the remaining number of evacuees then the model is more optimal.

The paper is organized as follows: Section II, related works to multi-level multi-agent models. Section III, our approach to building the MAS-GiG model. Section IV, experiment the proposed model for crowd navigation when the fire occurred in a lounge with a structure similar to lounge 5, floor 1st, Danang International Airport. Finally, Section V, focuses on our conclusions and discussion of the results obtained and future research.

II. RELATED WORKS

According to Wood et al [5], the authors proposed a methodology for the design of multi-agent systems, with a simple approach of building a MAS through an entire software development life cycle. From problem description to implementation including 6 steps: Capturing Goals, Apply Use Cases, Refining Roles, Create Agent Classes, Build Conversations , Assembling Agent Classes. The authors do not mention groups and multi-level structures. Nahid Salehi et al [6], proposed a velocity-based method to simulate the actual behavior of the moving group. From the initial position to move to the common destination, in the process of moving, agents in a group must try to maintain the formation and cohesion of the group. Groups are created by combining multiple agents in a specific shape based on adjusting their orientation and position. Each group has a leader and followers. The authors did not mention multi-level structure. Noureddine et al. proposed a multi-agent model with AGR (Agent/Group/Role) architecture [7,8] with three concepts: agent, group and role. An agent is an entity that acts, communicates, has a role, and is a member of a group. A group is a set of agents, the group structure is an abstract representation of a group described by a set of roles. A role is an abstract representation of an agent's position and function in a group. Navarro et al. [10] studied the multi-level on MAS to increase simulation speed. In this model, only one level is active at a time while other levels in the same model do not co-exist (virtual). In the model, the author does not mention the group. Nguyen Thi Ngoc Anh and et al. proposed a synthetic model that combines a mathematical model and a multi-agent model [13]. In this model, the authors combine many types of heterogeneous models to represent several levels. Agents are synthesized and routed using equations of fluid flow. Interaction between levels allows the combination of models with information sharing functions. This model did not use the concept of group. The experiment of the model was applied for tsunami warning. Thomas Huraux et al. proposed a method to construct a holonic multilevel MAS [4]. In the model the agents are organized as nested groups, but the author does not mention the structure and formation of groups. The levels in the model all exist during the simulation. Stefania Bandini et al. proposed a multi-level model that combines three different MAS, including a cognitive MAS (MASC) is at the tallest level, a reflex MAS (SMAR) is at the lowest level, and a recursive MAS located in the middle level [14]. Recursive MAS communicates between SMACs and SMARs. Hoang Thi Thanh Ha and et al. proposed a multi-level multi-agent recursive (MAS-R). The purpose is to increase the effectiveness of monitoring distributed multi-level systems [15]. The levels in the model are virtual abstraction, only the base level is real in the model. Afra Khenifar et al. presented the background of a multi-agent multi-level model [16] to solve the problem of cooperation between groups of multi-agent to observe and control collective products. In this study, the collective product is the result of the interaction of different agents.

We appreciate the collective products in complex systems that are merged from interaction from multi elements. We are interested in the group’s behavior because group members usually have make collective decisions and actions. In this paper we propose a multi-level multi-agent model (MAS-GiG) with the purpose to enhance the effectiveness of managing distributed multi-level systems that are suitable for multi-scale complex systems. Our model emphasizes the group structure; group formation; multi-level formation and interaction. The group structure at each level consists of a group leader and members, the members of the group at the upper adjacent level are representatives of the groups at the lower adjacent level. The different levels in the model are closely related. We firstly apply this model for modeling the human crowd. Therefore, the MAS-GiG model has some more features than existing models: group formation based on social relationships. This is a main feature of the public crowds. We created the group based on this criteria because it is highly practical. Moreover, members of a family, friends, and colleagues often go together to the same goal. They rarely separate when moving. Because of this feature, the stability of the group is higher. Therefore, the crowd is less affected, the evacuation is more convenient.

We choose the study in the document [39] to compare with the proposed model, the MAS-GiG model and the navigation algorithm [39] which have the same things as planning the agent navigation in crowded environments, avoid obstacles, use a pre-calculated route, and provide universal connectivity. However, the MAS-GiG model has some differences compared to the algorithm in [39] and these are also its advantages such as: first, MAS-GiG is a multi-level model. It manages and navigates the crowd by each level, each of which manages and navigates the crowd within its scope and performs the navigation under the direction of the superiors; second, the navigation plan based on the available physical environment. The physical environment is represented by a path map 2D. The path map is created from intersection points and paths connecting two intersecting points. The intersection point is called a node and the path connecting two nodes is called an edge. The navigation plan is managed and coordinated by the highest level in the model; thirdly, combine shortest path finding Dijkstra algorithm and safest route in choosing the route to evacuate.
Fourth, MAS-GiG does not calculate collisions during evacuation because it has a pre-planned plan to guide crowd evacuation.

III. MULTI-LEVEL MULTI-AGENT MODEL MAS-GiG

In this section, we introduce agent model, multi-agent system, architecture of MAS-GiG model and its application to navigate emergency crowds at a flight lounge.

A. Agent model

Each agent in MAS-GiG has autonomous, responsive, and interactive behavior. It is characterized by a set of attributes $P$, knowledge $K$, a set of roles $R$, and a set of actions $A$.

1. Agent properties

Properties agents are the variables that can be manipulated by the agent. An agent’s properties describe its characteristics, including his identifier, shape, and size. An attribute can be a variable to perform calculations such as: perception score, decision time. Or more complex like a list, a collection like: a list of agents in the same group. Every agent controls autonomously and locally a set of scopes for perception, communication and action. In this study, an agent is represented by an individual and a group is represented by a group of individuals that have a social relationship with each other. A group is a collective of individuals.

2. Agent knowledge

Agent’s knowledge, also known as cognitive score (cognitiveGrade), consists of the understanding of the environment (knownExitNo), personal experience (experience), decision-making time (decisionTime). In each level, based on the agent's knowledge to define the role. The agent with the highest knowledge in the group is chosen as the group leader. The role of group leader is managing the group.

3. Agent role

Each agent has a role to perform its respective actions. There are types of roles such as: LeaderRole, MemberRole, IndieRole. LeaderRole is the role of a group leader. MemberRole is the role of a group member. IndieRole is the role of an individual that is not in any group. LeaderRole performs a number of corresponding actions such as: interacting with group representatives in the upper level, interacting with group representatives in the same level, interacting with group members in the same group, and interacting with individuals to which they do not belong to any group. A MemberRole performs a number of corresponding actions such as: interacting with the group leader in the same group, interacting with group members in the same group, and interacting with individuals to which they do not belong to any group. An IndieRole performs a number of corresponding actions such as: interacting with a group leader in the same level, interacting with a group member in the same level, and interacting with other individuals in the same level.

4. Agent action

The agent's action depends on its decision. For each specific situation, an agent makes a decision for himself or he interacts with others and then makes a decision. An agent acts according to his decision. In the model, actions are all performed by sending/receiving messages.

B. The multi-agent system

The multi-agent system is organized according to the AEIO approach [34]. It includes agents (A), environment (E), interactions (I), and organizations (O).

1. Environment (E)

A simulated environment is a two-dimensional space. Environment objects are categorized and located in the environment for simulating. The objects are categorized based on their functions, such as obstacles, paths, exits, etc.

2. Interactions (I)

The interaction is represented by sending and receiving messages. It includes sending/receiving messages between agents of the same level and between agents of different levels. The structure of a message is based on the interaction protocol in MASH [27]. The mechanism to actually interact is based on two classes of Messages and Frames. They represent the Network and Datalink layers in the OSI seven-layer model of computer networks, respectively [31,32]. The structure of the message: Message (senderID,receiverID, content). Protocol for sending/receiving messages in MASH (see figure 2).
There are two types of interactions that are horizontal interaction and vertical interaction. Horizontal interactions are interactions performed by sending/receiving messages between agents at the same level. Vertical interactions are interactions performed by sending/receiving messages between agents at different levels. We specify five interactions to be used in the model:

1. Indie ↔ Indie: the individuals communicate with each other.
2. Members ↔ Members: the group members in the same group communicate with each other.
3. GroupLeader ↔ Member: a group leader communicates with a member in the same a group.
5. GroupLeader ↔ GroupLeader: a group leader communicates with a group leader.

3. Organizations (O)

Organization (O) is represented by the organizational structure and the relations. The organizational structure mentioned here is the group organizational structure [17].

C. Multi-level architecture of the MAS-GiG model

In the MAS-GiG model, each agent represents an intelligent and autonomous agent. It has knowledge that can decide for itself to take personal action to achieve personal goals. It can interact with other agents to perform actions and achieve common goals.

- Level 0: this is the real level, the agents at level 0 are base agents, it represents an individual in the application. At this level, the agents have the same role. The interaction is carried out between individuals. There is no organization.

- Level 1: is the first group level in the model. A group at level 1 is formed from base agents at level 0. The formation of the group based on the social relationships such as: family, couple, friends, colleagues [17]. Each group has a structure. The group structure consists of a group representative and group members. The role of a group representative is LeaderRole, the role of a group member is MemberRole, and the role for individuals who are not part of the group is IndieRole.

   The interactions include: the group members interact with each other in the same group, the group leader interacts with group members in the same group, the group leader interacts with each other at the same level, the group leader interacts with the group leader at different levels. The group leader interacts with the individuals who are not part of the group.

   - Level 2: this is the second group level. At this level, the agents are mostly representatives of groups at level 1. The agents belong to the same group when the distance between them is less than or equal to a constant r. The group structure at level 2 also includes a group representative and group members. The group representative is chosen based on the knowledge score. At this level, the role of agents, the interactions between the agents are similar to level 1. The number of agents at level 2 is much reduced compared to level 1.
The formation of levels in MAS-GiG

- Level n-1: this is the (n-1)th group level. The members at level (n-1)th are mostly representatives of groups at level n-2. At this level, the formation of the group, the group structure, group's representative selection, the interaction, and kinds of roles are similar to the level 2.

- Level n: level n is the highest level and is also the general operating level for the entire system. At this level, there is only a representative. The interaction is performed with the representatives of the lower levels.

Figure 3 illustrates the general architecture of the MAS-GiS model. Figure 4 illustrates the formation, structure, and interaction of levels in the MAS-GiG model.

D. The MAS-GiG model in crowd navigation

1. The steps are performed for simulating the application.

The steps are performed for simulating the application (figure 5). Initially, requirements are analyzed about the physical structure and estimated the number of levels of model for application. The physical structure includes the distribution of doors, paths, walls, obstacles, exits, etc. Based on this distribution, we define the levels of the model for the application and make the scenarios.

Next, we develop the evacuation simulation model. There are two agent-related factors such as: fire perception and physical disability. There are some building-related factors such as: exit width, exit location, fire location, path width. The occupancy density is representing a relation between the agent and the building. Finally, the output data include the number of total evacuation times and remaining occupants are statistically analyzed.

- Fire perception: we assume that 100% of the occupants perceive a fire emergency and they respond after 10 seconds [45].

- Physical disability: we assume that 100% of the occupants are not physically disabled.

- Exit width: the exit door pertains to the building's characteristic. In this application, we assume that the width of the exit door is 80 cm.

- Exit locations, fire locations: these factors depend on the physical structure of the application and they are described in the scenarios.

- Occupant density: this factor depends on the number of passengers in each scenario.

The last, the third is statistical analysis about total evacuation time, the number of remaining evacuees. These data can be compared with the results of other methods to evaluate the proposed model.

2. Some levels of MAS-GiG model are described for crowd navigation at a flight lounge

According to [33] guidelines for emergency evacuation at airports in case of fire, we propose the levels of the model for the application. There are five levels: indie level (Indie) is the base level, each member at this level represents a passenger in the lounge. The group level (Group) is the group of passengers. The area level (Area) is also a group level that a group at this level includes the representatives of the groups at group level. The lounge level (Lounge) is also a group level that a group at this level includes the representatives of the groups at area level. The AirportOperator level
(AirportOperator) is an emergency management department. In this application, there is only one lounge so the AirportOperator manages the lounge directly (figure 6).

The mechanism of formation of levels is carried out from the bottom up: a group consists of many Indies who have a social relationship with each other [17]. At the group level, there are many groups, each group has a group representative that is called a group leader. An Area consists of many Groups, these Groups are in a range of the Area. At the Area level, there are many Areas, each Area has a representative that is called a Guide. A Lounge consists of many Areas, these Areas are in the same lounge. At the Lounge level in the application, there is only a Lounge and the representative is called a GuideLeader.

The relationships between agent classes in the application are presented in figure 7.

**IV. EXPERIMENTING MAS-GIG MODEL IN CROWD NAVIGATION AT A FLIGHT LOUNGE**

Apply the proposed model in the application of crowd navigation when the fire occurred in a lounge with a structure similar to the lounge 5, floor 1, Danang International Airport.

**A. Introduction about MASH (Hardware/Software MAS Simulation)**

MASH [46] is a simulator developed by Professor Michel Occello et al. to experiment the works related to multi-agent based simulation in three ways: software simulation, hardware simulation and hybrid simulation (combining software and hardware simulation). The simple architecture of MASH is shown in figure 8.

MASH provides a mechanism to emulate both a virtual agent and an embedded agent. Each agent has the corresponding properties and behaviors to perform its own role. The virtual agent and embedded agent can be integrated in the same simulation, which is abstracted through the Individual Agent Manager.

In addition, to manage the communication and interaction between agents through the Society Manager. Agents interacting with the environment are managed by the Environment Manager. All information is communicated through the event mechanism, which is managed through the Event Manager.

**B. Experiment design**

The Random (i.e. scenario 0) scenario is designed to compare with some scenarios of the proposed model. The random scenario is tested with three fire locations corresponding to the three proposed scenarios F1, F2, F3. The relevant parameters are used in general for all scenarios. When all occupants are assumed to have 100% fire awareness and the occupants are not disabilities. The width of all exit doors are 80 cm. The fire origin was established at three locations as in the three MAS-GiG model test scenarios. There are about 200 to 300 evacuees in the lounge. Three scenarios are independently compared with the Random scenario. For each scenario, 10 trials are run, the average total evacuation time and average total remaining evacuees are calculated.
We assume that the fire location is at the entrance (Figure 9), the passengers are not allowed to choose the exit as the entrance, they can only choose the remaining two exits to move out. For the random scenario, an agent chooses randomly the exit, if he moves to the exit where it has a fire then he has to move back to the original place, then he chooses randomly one of the two remaining exits to move. In figure 9, the blue arrows are the directions to be moved, the red arrows are the directions that are not moved.

C. Some scenarios

We experiment on three scenarios, based on the actual flight lounge structure [44]. The lounge 5 is one of 4 lounges on the 1st floor of Da Nang International Airport. The following is a brief description of the lounge structure. Passengers enter the lounge from the stairs on the 2nd floor. They boarded the plane at the boarding gate. In addition, there is an exit to move to the ground floor, which is located in the hallway next to lounge 6. In the lounge there is an area for passengers to sit called the waiting area. An area for souvenirs is called Shop, an area is called Restaurant and an area is for Toilet. Based on the actual waiting room structure, we create a 2D map for experimental simulation. In each area are numbered correspondingly such as: (1): Safe area, (2): Boarding gate, (3): Entrance to lounge from 2nd floor, (4): Exit to go down to the ground floor, (5): Waiting area, (6): Shop, (7): Restaurant, (8): Toilet, between the rows of seats in the waiting area are paths. In the three experimental scenarios, the entrance (3), boarding gate (2) and exit (4) are used as three exits E3, E2, E1. Three fire positions are set at three positions respectively and they are noted F3, F2, F1 (figure 10).

Scenario 1: The fire occurs at the position F1 which does not coincide with one of the three exits. Each agent can choose one in three exits E1, E2, E3 to move to a safe place.

Scenario 2: Fire occurs at the exit E2. Each agent can choose one of the two exits E1 or E3 for moving. In this case, the agents are not allowed to move through the exit E2.

Scenario 3: Fire occurs at the exit E3. Each agent can choose one of the two exits E1 and E2 for moving. In this case, the agents are not allowed to move through the exit E3.

- For position F1, fire occurs at a location not close to any emergency exits, so F1 represents the fire locations where it is not located at the exits.
- For position F2, fire occurs next to the boarding gate. Only a small number of passengers know exit E2. So F2 represents fire locations where a small number of passengers know the exit at these locations.
- For position F3, fire occurs next to the entrance to the lounge. All passengers know exit E3. So F3 represents fire locations where all passengers know the exit at these locations.

In the simulation, the individual passengers are represented by blue dots, the group passengers are represented by the yellow dots, the group leaders are represented by the red dots, the area leaders are represented by the black dots and the lounge leader is represented by a gray dot.

D. Experimental results

To evaluate the proposed model, we present two types of results. First, the results are visually represented by the multi-level evacuation instructions. The groups in the areas of the lounge that are close to the fire are evacuated first. Then the groups in the areas of the lounge that are close to the exit are evacuated next (see figures 11a, 11b, 11c). Second, the average total evacuation time and average total remaining evacuees (table 1).

<table>
<thead>
<tr>
<th>The factors to compare</th>
<th>Random Scenario 0</th>
<th>MAS-GiG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F1</td>
<td>F2</td>
</tr>
<tr>
<td>Total evacuation time</td>
<td>127.4</td>
<td>139</td>
</tr>
<tr>
<td>Remaining evacuees</td>
<td>16.2</td>
<td>19.8</td>
</tr>
</tbody>
</table>
Each scenario is run 10 times and averaged to compare with the Random scenario. The experiment results for MAS-GiG model: the result of scenario 1 is presented in figure 11a, the result of scenario 2 is presented in figure 11b, the result of scenario 3 is presented in figure 11c.

The experimental results show that the total evacuation time for the scenarios of the MAS-GiG model is always less than the total evacuation time of the Random scenario. Specifically, the average evacuation total time of Random scenario with fire location F1 is 127.4s while scenario 1 of MAS-GiG model is 113.8s. Similarly, the average evacuation time of the Random scenario with fire location F2 is 139s while that of the MAS-GiG scenario 2 is 127s, and the average evacuation time of the Random scenario with the fire location F3 is 130.4 s while scenario 3 of the MAS-GiG model is 119 s. The average total remaining evacuees of Random scenario with fire location F1 is 16.2 people while scenario 1 of MAS-GiG model is 8.2 people. The average total remaining evacuees of Random scenario with fire location F2 is 19.8 people while scenario 1 of MAS-GiG model is 10.28 people. The average total remaining evacuees of Random scenario with fire location F3 is 20.6 people while scenario 1 of MAS-GiG model is 12.4 people.

V. DISCUSSION AND CONCLUSION

As we have presented in the previous sections, each group has at least 2 members, so after each new level formation step, the number of agents is reduced by more than half compared to the number of agents at the previous adjacent level and the number of interactions is also reduced by more than half. Therefore, it is easier to observe the system, and the computational complexity is reduced. This is an advantageous feature of the MAS-GiG model compared to other studies in the same field.

The proposed model has achieved a number of results: first, the navigation of passenger movement is level-by-level and collision-free. The groups in the areas of the lounge that are close to the fire are evacuated first. Then the groups in the areas of the lounge that are close to the exit are evacuated next. Second, the total evacuation time and the total number of evacuees remaining are lower than the result of the Random method. These results answer the question why we built a multilevel model? If there is only one operating level that coordinates the entire system then the guidance information cannot be transmitted to all evacuees, each evacuee finds the exit himself. In this situation, the evacuation is similar to the Random evacuation method. Therefore, the total evacuation time and total remaining evacuees are large. This leads to a high death rate.

In the next studies, we will continue to study individual behavior, collective behavior. Apply proposed model in navigating emergency crowd evacuation in many applications with different physical structures such as nightclubs, shopping malls. For the airport application, we will extend the model to multiple levels and apply on multiple lounges. There are more than one fire spot in an area that has different lounges.

REFERENCES


[17] Dinh Thi Hong Huyen, Hoang Thi Thanh Ha, Michel Ocello, “Detect the formation of groups in a crowd based on social relations” The 10th conference on information technology and its application. CITA 2021.


[44] https://danangairportterminal.vn/vi/maps/#


ĐIỀU HƯỚNG SỞ TÂN ĐÁM ĐÔNG KHẨN CẤP BẰNG MÔ HÌNH MAS-GIG

Dinh Thị Hồng Huyền, Hoàng Thị Thanh Hà, Michel Occello