Empirical Study on Modeling of People Behavior in Emergency

Ilya Viksnin[0000−0002−3071−6937], Julia Lyakhovenko[0000−0001−7396−2831], Nikita Tursukov[0000−0003−3848−1981], Sergey Chuprov[0000−0001−7081−8797], and Ekaterina Sozinova[0000−0003−0338−783X]

ITMO University, Saint-Petersburg, Russia
wixnin@mail.ru, lyakhovenko.kam@gmail.com, stepingnik@gmail.com, chuprov@itmo.ru, ensozinova@itmo.ru

Abstract. In this paper, we propose an advanced model and experimental study results considering an unorganized group behavior in case of an emergency. An approach to simulation of human behavior is based on the Dirk Helbing and Peter Molnar Social Force Model. This model depends on the informational impact on the individual behavior of group agents. The proposed model is adapted for crowd behavior simulation in emergencies. The model implies the behavior of an agent when it tries to determine the optimal direction to a safe place at any point in time. When the agent chooses the direction of movement, it takes into account both the number of people around, the average traffic of the crowd, and the presence of a nearby source of danger. Based on the model, a crowd behavior simulator was implemented in the AnyLogic simulation software, which reproduced the behavior of people during the tragedy at the Lame horse nightclub (December 5, 2009) in Perm, Russia. To verify our approach we conducted three groups of simulations and compared our model with the existing method of group behavior in a multi-level branched room, and with the method of moving agents along the shortest path. The results, obtained by the proposed model, most closely match the real data on the tragedy.

Keywords: Multi-agent system · simulation · crowd behavior

1 Introduction

At present, the design of premises intended for a large number of people implies that in emergencies crowd make the proper decisions to leave it. Because of this, the time spent on evacuation is wasted irrationally, which subsequently increases the number of victims. There are many tragic examples, such as the fire on 27th January 2013 at the Kiss night club, which began around 2:30 a.m. (2:00 a.m. according to other sources) in Santa Maria, Rio Grande do Sul, Brazil. The fire was caused by the careless use of pyrotechnics in the club. That fire killed

242 people, and 630 were injured [1]. Due to the availability of only one narrow emergency exit, a crush began, which increased the number of victims.

This event raised the importance of applying unorganized group (crowd) behavior modeling methods in the events of an emergency situations (ES) to optimize the preliminary training process and minimize victims in case of panic.

In the present work, for modeling such situations, as well as for formulating the methods, a multi-agent approach is used [2]. Based on this approach, the crowd is characterized as a group of agents with the ability to communicate and interact with each other.

2 Related Work

From the existing global approaches to modeling the behavior of an unorganized group, several types can be distinguished. The simplest approach is to transfer the area along which the agents move to a discrete form, as well as to set the rules for the agent to move to a particular area. Additionally, the behavior model can be based on Newtonian mechanics or gas dynamics [3]. In these cases, the behavior of agents in certain situations is determined by the physical properties of the elements of the group. One of the more complex approaches is the use of multi-agent systems that describe both the behavior of the agent and its interaction with other participants during the simulation.

Currently, hybrid approaches [4–6] to model crowd behavior are increasingly being used. This allows to create more flexible models with realistic behavior, as well as reactions of groups of agents in the system.

3 Materials and Methods

The basis of the mathematical model of human behavior in ES, used in the simulator, is the Social Force Model of Dirk Helbing and Peter Molnar [7–9]. The proposed model includes space and distance to different exit areas. It also covers external and internal influences on humans as part of a weakly organized mass: physiological, social and informational.

Information influence in this work is understood to be the impact of the environmental awareness of other group members by individual visible agents during the evacuation process. This implies the inability of the agent to choose the optimal direction of movement to achieve the goal (salvation) based on the choice of the average trajectory of other agents of the crowd.

To verify our mathematical model, it was implemented in the software simulator and tested. As a framework for simulation, AnyLogic 8.4 was used. The built-in Pedestrian library allows to building models with a large amount of information about pedestrian movements. With the help of the graphical interface and Java language functionality, it is possible to simulate the movement of agents in the premises and to program information interaction logic between them.

4 Our Approach to Crowd Behavior Modeling

In this section, we describe our mathematical model of the crowd behavior in ES and approach to verify it.

The proposed model considers the catastrophe as an event with a set of time intervals $T = \{t_0, t_1, \ldots, t_n\}$, i.e. it can be assumed that the system exists at different points in time. The crowd itself is a set of agents $P = \{p_0, \ldots, p_n\}$, which is divided into two subsets - the number of ordinary people and the number of informed (stewards). Each agent, at any given time, solves the problem of finding the optimal direction of movement from its location to a safer one. The main factors determining the direction of agents movement $d(p_i)$ are the assessment of movement direction of other visible agents $S_i = s(p_i)$ and the "weight" w of their direction for the agent. In this case, the "weight" of other agents directions to a particular agent depends on the agent's knowledge about the situation (whether a certain agent was seen before an emergency or not, whether it is informed or not) $w = \{w_{inf}, w_{us}\}$, where w_{inf} – "staff" agent's weight of the motion direction and w_{us} – "usual" agent's weight of motion direction, which also can be divided into sets $w_{inf} = \{w_{sinf}, w_{nsifn}\}$, $w_{us} = \{w_{sus}, w_{nsus}\}$, where w_{sinf},w_{sus} – weight of the direction, which agents seen before the evacuation and w_{nsifn},w_{nsus} – weight of the direction, which agents not seen before the ES, and $w_{sinf} \geq w_{nsifn} \geq w_{sus} \geq w_{nsus}$. In addition, each agent is defined by its location in space (coordinates): $coord_{p_{inf}}$, $coord_{p_{us}}$. It follows that the direction of agent motion can be represented as a function depending on the average motion direction of other agents (1):

$$d^t_{p_i} = f\left(w d^{t-1}_{p_i}\right) = f\left(w_{inf} d^{t-1}_{p_{inf}}\right) + f\left(w_{us} d^{t-1}_{p_{us}}\right), \tag{1}$$

where $p_{us}, p_{inf} \in s$. This depends on their number, mass, and direction of movement at the present and previous time points (2):

$$d^t_{p_i} = \left\{coord^{t-1}_{p_i}, E\left(d^{t-1}_{p_i}\right)\right\} = \left\{coord^{t-1}_{p_i}, \frac{E^*\left(d^{t-1}_{p_i}\right) \times |s_i| + coord^{t-2}_{p_i}}{|s_i| + 1}\right\}, \tag{2}$$

where $E^*\left(d^{t-1}_{p_i}\right)$ is an averaged movement of all agents at time $t-1$, including the coordinates of the agent p_i at t time moment, calculated by (3):

$$\begin{aligned} E^*\left(d^{t-1}_{p_i}\right) &= \frac{w_{inf} \sum coord^{t-1}_{p_{inf}} + w_{us} \sum coord^{t-1}_{p_{us}}}{|s_i|} = \\ &= \frac{\begin{array}{c} w_{sinf} \sum coord^{t-1}_{p_{sinf}} + w_{nsinf} \sum coord^{t-1}_{p_{nsinf}} \\ + w_{sus} \sum coord^{t-1}_{p_{sus}} + w_{nsus} \sum coord^{t-1}_{p_{nsus}} \end{array}}{|s_i|}. \end{aligned} \tag{3}$$

Expressing $E^*\left(d^{t-1}_{p_i}\right) \times |s_i|$ through the agents movement direction and their locations through the weight coefficient, we obtain the final values of the agent p_i movement direction (4):

$$d_{p_i}^t = \left\{ coord_{p_i}^{t-1}, \frac{\begin{array}{c} w_{sinf} \sum coord_{p_{sinf}}^{t-1} + w_{nsinf} \sum coord_{p_{nsinf}}^{t-1} \\ + w_{sus} \sum coord_{p_{sus}}^{t-1} + w_{nsus} \sum coord_{p_{nsus}}^{t-1} + coord_{p_i}^{t-2} \end{array}}{|s_i| + 1} \right\}. \quad (4)$$

Figures 1 (a)-(c) demonstrate the choice of the agent's movement direction. Three cases are considered at time points $t-1$ and t. Figure 1 (a) shows a slight change in movement direction by the agent when it detects the change in crowd movement. Figures 1 (b)-(c) show the behavior of an agents when they noticed informed agents.

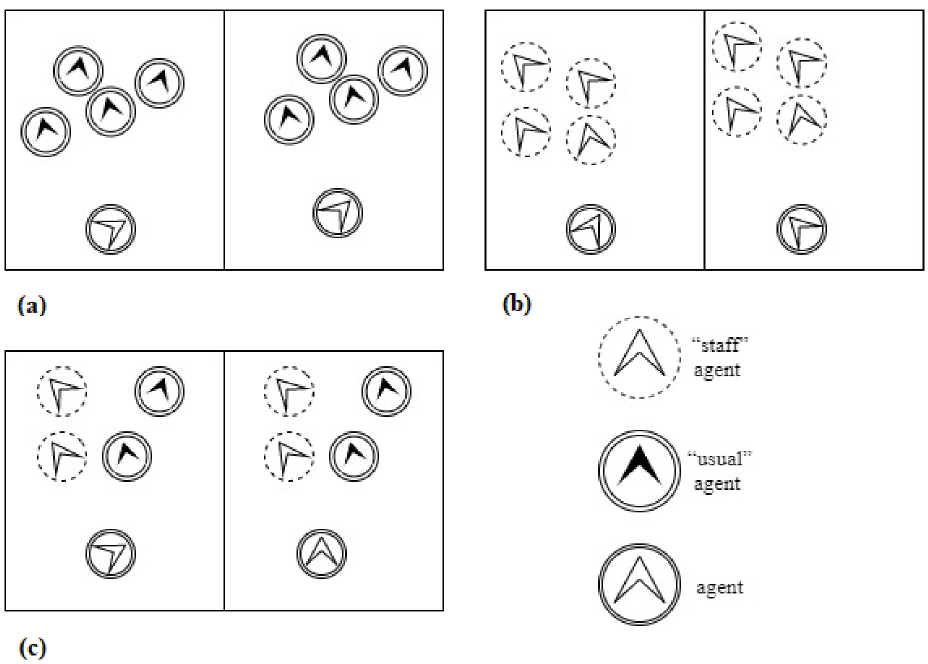

Fig. 1: Agent's choice of movement direction: (a) - when crowd is detected; (b) - when "staff" is detected; (c) - when crowd and "staff" is detected.

Available public data on the tragedy in the night club "Lame Horse" were used to simulate crowd behavior in such a scenario. The number of agents in the simulation corresponds to the actual data on the visitors in the club at the time of the fire. The blue dots in Figure 2 represent informed agents (waiters and staff members), while the green dots represent ordinary people (visitors). In addition, the simulation conditions include fire, and smoke, which spreads at a certain speed through the area. The velocity of fire propagation and the toxicity

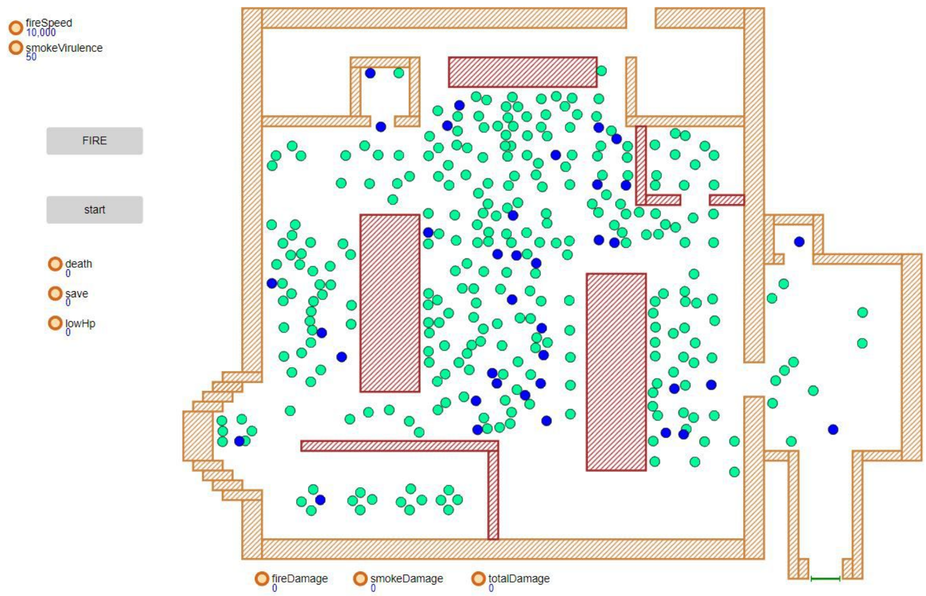

Fig. 2: Building plan and agents allocation in the club on the night of the tragedy.

of the smoke are based on available data in [10], on the material ignited during the tragedy (polypropylene). Data used in the simulator:

- number of agents: 322;
- number of waiters (informed agents): 20;
- two outputs;
- evacuation start time: ≈10 seconds after the fire starts;
- time to fill the room with smoke: ≈60 seconds.

The simulation starts with the distribution of agents throughout the club area. After the evacuation starts, the agents start moving towards the nearest exit. In doing so, the agent continuously performs verifications such as fire detection, the detection of an informed agent, or the calculation of the median movement of the crowd. These factors influence the further movement of the agent. The color indicates the amount of health of the agent so that once the agent is red, it loses consciousness and stops moving. These agents, as well as those who have lost their health, are counted with a simulator. Agents who managed to get to the exit are also counted by the simulator.

While the simulator is running, data on the number of agents' health is recorded, as well as their assigned status, where: $\leq 10\%$ health agent is dead; $> 10\%$ and $\leq 40\%$ health agent alive with low health points; $> 40\%$ of health – agent is alive. In addition, information is recorded about what exactly caused the agents to lose their health: fire or smoke. The evacuation process is shown in Figure 3.

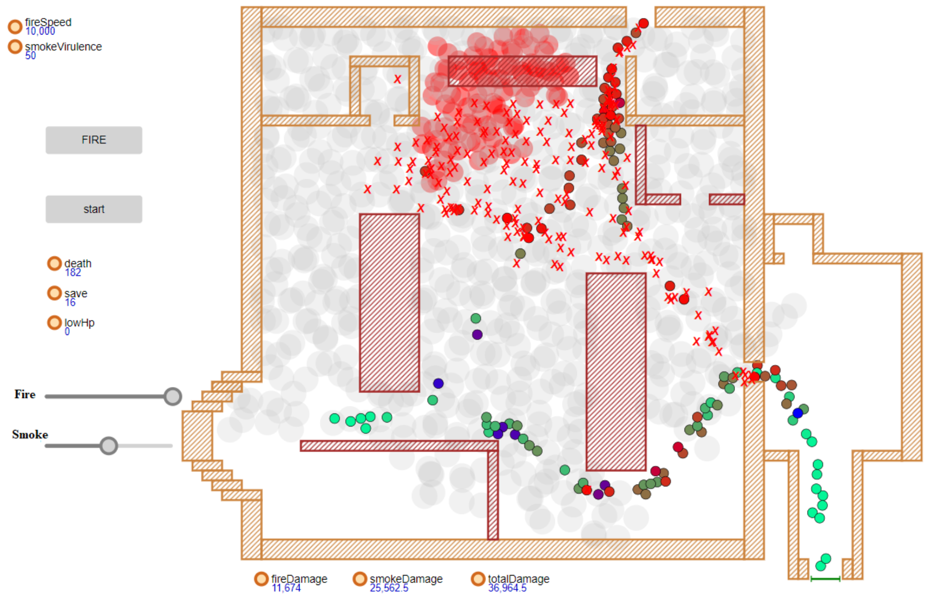

Fig. 3: The process of evacuating people during a fire.

5 Empirical Study

Two models, based on existing solutions for modeling crowd behavior were also implemented in the simulator to verify our approach. The first model, without taking into account the behavior of the crowd, is implemented by the built-in tools of AnyLogic, in which the agents move to the nearest exit. The second model is based on panic group behavior in a multi-level branched area. In this model, the agent's movement is based on the existing room structure and the presence of other agents on its path.

As a result, three groups of experiments were conducted. Each group includes 322 agents, 20 informed agents, two exits (main and emergency). Time to evacuate is 10 seconds from the beginning of the fire. Most people are located on the dance floor. When the fire begins to spread, the smoke begins to fill the club.

6 Results

Table 1 compares the results obtained using the developed model with the actual data on victims, survivors, and dead people. 1st model is a model without a behavioral pattern, 2nd model is a model with a pattern of behavior in a branched room.

From the comparison of the results it can be seen that the data obtained on the simulation using the proposed model differs from real data by an average

Table 1: Comparison of the the simulation results.

Groups of people	Real data	Simulation results		
		1st model	2nd model	Proposed model
Dead	156	202	186	151
Injured	78	14	14	45
Healthy	166	120	135	171

of 16%, which is significantly less compared to other models. This shows the accuracy of the developed model relative to the well-known models. This fact allows saying that the proposed model is more accurate in comparison with other simulated models.

7 Discussion

The results obtained with the help of the simulator are very close to the real data about the victims of the tragedy. Therefore, the obtained model of behavior of an unorganized group allows to carry out the analysis of the emergencies that have occurred and to test the existing and projected premises to ensure their safety.

8 Conclusion

In the present work, we propose a model of crowd behavior in emergencies and its validation. The model based on the information impact on the group, which allows bringing the data closer to real conditions. Existing approaches to model human behavior and their differences of the proposed model are described. The model was implemented in the AnyLogic software simulator. To verify our model, the real scenario of the emergency was simulated and the results were compared with two existing approaches to model crowd behavior. Obtained results allow saying that our model could produce more relevant results, that are closer to real data compared with the simulated approaches. The presented model can be useful in the analysis of existing and planned premises to ensure safety in the event of panic in emergencies.

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