Modeling Crowd Evacuation from Indoor Spaces

Pejman Kamkarian[1], **Henry Hexmoor**[2]
[1] Electrical and Computer Engineering Department, Southern Illinois University, Carbondale, IL 62901, USA
[2] Computer Science Department, Southern Illinois University, Carbondale, IL 62901, USA

Abstract - *A crowd in an emergency situation located inside a public space, they will evacuate from that space. Crowd evacuation is a dynamic process which relies to a variety of environmental factors, as well as crowd specifications itself. To help people out of danger, rapidly and safety, we need to have a previous plan for any public space, which is obtained by collecting information of crowd evacuation in different situations, for that space. Simulating a public space virtually, helps us to study on crowd evacuation, in terms of considering all possible kinds of behaviors that are as symptoms of evacuation during emergencies. Using such strategy, keeps any possible injuries limited to the virtual simulated environment and hence we are able to study on real events with no cost of occurring any damages. This paper demonstrates application of optimized Imperialist Competition Algorithm to exit doors of indoor spaces to find the best possible locations for them, and also to estimate the minimum required width for each door in order to be able to evacuate a crowd out of risk in a reasonable time, and with the most possible safety.*

1 Introduction

In the developed countries, people spend most of their lives in indoor spaces. Often, large groups of people are gathered at the same location for leisure or work purposes. We consider these groups as crowds. Generally, a crowd is defined as a set of agents as particles who are gathered at one physical location to share or follow some common activities [9]. If a life threatening emergency such as fire or earth quake occurs, there should be efficient and reliable ways available for people to rapidly evacuate buildings. Evacuation becomes more complicated when observing to increase number of people inside space, or increasing the time that occupants need to remain at the location. Derived from safety concerns in indoor spaces, there is a force to evacuate that people toward exit openings. This has best been modeled in terms of a game among members of a crowd [8], Game theoretic modeling and analysis as well as a extensively validated fire evacuation simulator are reported from a finish research center [8]. We will focus more closely on characteristics of a crowd in the context of an emergency that requires evacuation. Although each group has a shared set of goals among its members, individuals do not necessarily decide on sharing similar actions. This is especially true when they encounter dangerous situations such as fire. In such cases, because of fear and natural instinct for survival, individuals will take separate, individualistic actions to address their own needs for survival. They will not follow group patterns for action selection. This is similar to what one can expect when a crowd of people is running away from source of danger (e.g., a fire) towards a safe place [11].

The idea of evacuating a crowd is not limited to humans and it pertains to all other types of animals. The safest exit doors should be able to evacuate not only humans but all kinds of animals that might be present in indoor spaces. This urges us to consider appropriate designs for exit doors. Buildings must adhere to an acceptance standard to be able to evacuate people who are inside it in an emergency. In most cases, such standards must account for combinations of exit doors including stairs and ladders. Emergency evacuation conditions of a crowd and abstraction of the real crowds are modeled by [13], [1]. The required number of exit doors will vary based on the size and architecture of each environment. One of the most important considerations about locating exit doors is having evacuation rate for public space. The goal is to evacuate most number of people in least amount of time. Lacking such strategy leads us having serious problems in emergency situations, even if exit doors themselves are built and located in safe and reliable positions. To make this clear, we point to stampeding events, which are one of the most common occurrences during an emergency. A stampede can occur due to human reaction to unexpected sets of events. People will herd and push each other in competition to reach the exit doors. People who are in emergencies often behave irrationally, largely based on reactions to the information available to them at the time. For instance, studies of evacuations in fires such as in [12], and in [4], indicate that people tend to leave gathering venues through the original pathways they entered. This holds even people have better solutions in terms of availability of closer, more accessible exit doors. This can be seen as irrational behavior. In fire, the smoke and heat in fires create limited visibility, which may cause people to seek escape through an exit door that they already know exists if they are unfamiliar with other possible choices.

To study and simulation crowd, macroscopic models are computationally less expensive because they consider less detailed interactions among people and with their environment. Instead, mathematical models are used to describe crowd movements as liquid flows [5], [6], [7].

2 An Overview of Environmental and Exit Door Features

As one of the most important steps to studying, designing and locating exit doors, we have to consider salient attributes that can directly or indirectly affect exit doors designs. In the following we outline several of these key attributes. Specifications of attributes for people present inside the public space, such as their health status, or their age range will lead to a better and safer selection of exit doors in terms of design and location for each. In case of considering only human beings in our environment, we can use particle systems that were proposed in [2], to simulate human behaviors. Based on particle swarms theory, each agent is considered to be a particle, augmented with a state and a feedback function to dominate its behavior. All agents' behaviors constitute the whole system's performance. Particle systems are also used for modeling the motion of groups with significant models of physics [2], [3]. Considering the number of individuals leads having a more accurate estimation. As an important factor, it should be taken into account while deciding widths and locations for exit door. As we pointed in previous examples, absence of these attributes was the main reasons for injuries and deaths. The width of exit doors should be determined relative to the proportion of the crowd. Time is another important attribute that should be accounted while designing and locating exit doors. On the other hand, exit doors should be able to service evacuation of the crowd through them in the minimum possible time. This will reduce the number of people who may potentially lose their lives due to breathing poisoned air, or stampeding of herding behavior.

3 Imperialist Competition Algorithm (ICA)

The Imperialism competitive algorithm is a natural inspiration method, which can solve variety types of optimization processes. It classifies as an evolutionary algorithm that relies on collecting a set of candidates random solutions, called initial countries. At the beginning, each country may have a different size of population, based on its features. A few such countries that have the most power among are called empires. After forming empires, all remaining countries, are called colonies. As a strategy, each empire, tries to extend its power and royalty of its government beyond its territory by trying to absorb and control the weaker countries as its colonies. At the end of initialization process, all colonies with their populations are divided among imperialists based on their powers. The total power of each empire, defines based on the power of the imperialist country itself, as well as the total powers of respective colonies. In other terms, this model obtains the amount power of each empire by adding the imperialist country itself and the mean power of its colonies in percentage. In the beginning of competition process, all colonies start moving toward their relevant imperialism country. In other hand, the imperialistic competition begins among all existing empires by increasing their power that earns by stimulating to take control on more colonies. During the process, any empire that is not able to increase and developing its power, or preventing losing its colonies, will be replaced [10], and hence eliminates from the competition.

4 Application of Optimized ICA

Based on ICA, the solution consists of many different sections. In order to focus on crowd evacuation, as well as people inside a public space, and exit doors, many sections are optimized to meet our research project requirements. At first glance, the examined space is classified to have three different kinds of components: *exit doors*, *obstacles*, and *people* present inside. The obstacles themselves can be categorized into two different groups. The first group includes the ones that are installed inside the public place, based on a previous plan. The second group may be formed accidentally, during emergencies, such as smoke, debris, and the wall or ceil parts that can block the whole, or a part of environment. Each exit door, represent a country. By initializing, they can have a population gathered around them. The people inside the space are considered as the population. Based on each person's distance from each exit door, as well as the velocity that each one may has based on some physical body features, they are classified to belong to the nearest exit door at the beginning. For instance, the equation $\{ed_1, ed_2 ed_3, \ldots, ed_{N_{var}}\}$, denotes a group of exit doors, where each 'ed', represents a separate door. Each exit door, measures with a floating point number, which indicates the cost of it. The cost of each exit door, determines by the total number of people who are belong to that door. In the public space, the walls that have any unblocked exit door on them called a valid region. A collection of an exit door with its population is called a zone. The size of each zone might vary based on the size of that particular exit door as well as the total number of population that belongs to that door. Each person inside the space, as an entity, has a speed to reach to its designated exit door. At the beginning of the process, the initial cost for each exit door is captured by $Init\ Cost(ed_1) = Init\ Cost(ed_2) = \cdots = Init\ Cost(ed_n) = m$, where '$m$' is the initial value of each exit door as initial. The velocity of population is showed by $(p_n) = f(p_n) = f(sw_n) + f(bd_n)$, where '$p$' represents as a person inside the public space. To find the best possible exit door for each person, we use the following equation: $\{p_n \in ed_n\} \equiv \{\max(Velocity_{p_n}), \min(Distance_{ed_n})\}$. On the other hand, dependencies for each exit door are measured and determines by evaluating the maximum speed and the minimum distance from each exit door. After the initialization phase, we may have many different valid regions. Each valid region may have many exit doors. Each exit door as an empire, has a zone including population as its colonies, belong to that door. At the beginning of the process, we consider any separator walls that divide the interior area from the exterior, as a valid region. As initial locations of exit doors, based on the potential crowd inside space, each valid region may have one or more exits in same distances from one another. Each exit door has an initial width that will be determined based on the number of people that gather around it. We note this initial width as γ. For example γ_i is the width of i^{th} exit door. Assuming crowd forms randomly inside the space, the application classifies each person as a colony to be dependent to the nearest exit as its calling an empire. To increase accuracy and also accounting for possible symptoms that crowd may have while emergencies, initially, we considered having a number of people as colony to choose their exit door as empire randomly regardless of distance. This may occur in the real world, for some reason, such as smoke covers the air and hence limited the vision site of people inside public space that leads choosing an inefficient exit door as the best solution to evacuate through.

When the process starts, people move toward the nearest exits to which they belong. If a person reaches and crosses through any exit door, it is removed from the process of evacuation. Hence that exit door as an empire loses that person as a colony. This reduces empire's power consequently. Based on the capacity and status of each exit door to evacuate people at each moment, and also with respect to other exit doors, exits as empires, they will try to raise their power by absorbing other colonies of people, from any other zones, into their own zones. In the real world, when an exit door has more capacity to evacuate people than those people around it, the other people who are currently trying to evacuate toward other exits might change their exit door, to the one with the least risk and lower number of people around it. As another reason to change the zones by people inside, we can address formation of unwanted obstacles, such as smoke or debris that are symptoms of emergencies. In case of presence of obstacles between a person and his chosen exit door, he tries to find the shortest path to turn around toward the exit. If there are other exit doors located closer to such a person changing the zone belongs to that exit door might be the best option for that person to choose. In other terms, this is a way for empires to increase their power. The following figure 1 shows a person, and an obstacle, which is located between him and his zone.

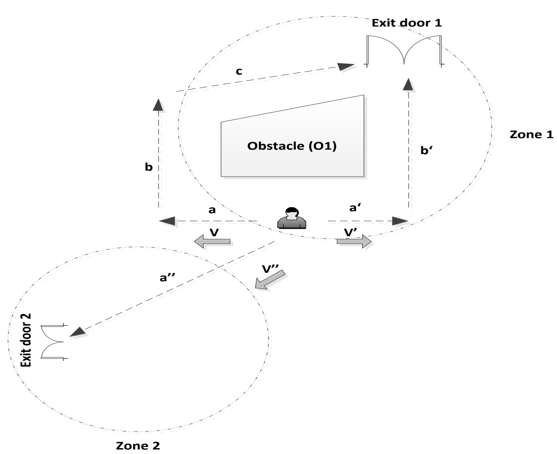

Figure 1. A person as a particle and an obstacle located between him and his optimal exit door with another exit door as an alternative to change the zone

Figure 1 shows obstacle O_1 forms during an emergency situation. The routes to reach the current optimal exit door are based on the following equations: $V = a + b + c$, $V' = a' + b'$. If there was another exit say exit door 2, located at a close distance of such person, the distance from it is calculated based on $V'' = a''$. Considering that exit is capable to accept more people to evacuate, Figure 2 is a decision flowchart which may apply to a particle as a person, in order to continue staying at the current zone, or changing it to the exit door 2.

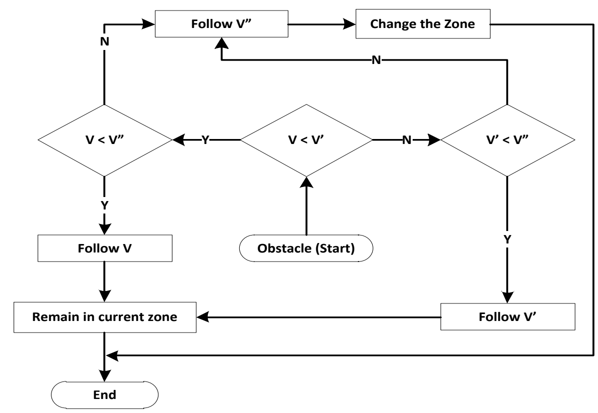

Figure 2. Decision flowchart to decide about to staying or leaving zones

We can consider other kinds of objects, between particles and exit doors at any time as obstacles. For example, any other person, or group of people who are located at any positions between any person and his optimal exit door can be classified as obstacles. In such cases, following the decision flowchart to decide about to staying or leaving zones by people as particle is essential. The process of evacuation continues until all particles as people evacuate through available exit doors. Based on the number of people who could evacuate successfully, using equation 1, the application determines the best possible width of each exit.

$$W_i = \left\lceil \frac{\sum Pop_i}{\sum S_i} \right\rceil \times \partial \ (in) \qquad (1)$$

Here W_i is the suggested width obtained from experiment cycle for exit door, i. S_i is the number of people who changed their zones during the experiment for any reasons. ∂ is a constant that can be vary based on the examined public space and the native architecture standards. Here we assumed $\partial = 10$, as the default value. Each exit door, based on its status during the experiment, may have a different W. based on this value, the amount that should be added to each exit, obtains. To increase the accuracy, we can repeat the experiment until the W became either minimum or very close to its previous value in last experiment. At the end of process, the total amount of value that should be added to each exits, determines by equation 2.

$$C_i = \sum W_i + \gamma_i \quad (2)$$

C_i is the total optimized amount in inches that should be added to exit door i. γ_i is the first initialization value that i^{th} exit door had at the beginning of the first period of experiments, and W_i is the total value that earned during experimental processes.

5 Conclusions

This paper has explored the implementation and adaption of the optimized imperialist competitive algorithm to a sample indoor layout to demonstrate a solution for locating the best exit doors. The results of our implemented system are applied to prototypical scenarios has demonstrated that the location of each exit door in an indoor space can affect significantly in terms of evacuating the crowd out of danger in emergency situations. Future work will account for complex floor plans. We will also relax our assumption about traps so we can add to realism of evacuation chaos with unexpected clutter and debris.

6 References

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