Crowd Behavior Modelling in Emergency Situations

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1 Abstract

In our work, we address the problem of simulating crowds in emergency situations. Modeling crowd behavior in a realistic manner is of great significance though not a trivial task taking into account the complex irrational behavior of crowd in panic situations. We have created a generic framework which characterizes the crowd behavior by generating scenes given some input parameters through a graphical interface. The tool can be used to analyze evacuation time and to visualize how a crowd will behave in the given situation. The model used is based on both psychological as well as physical forces.

2 Introduction

In a crowded environment, it has been observed that most victims were injured or killed by the so-called non-adaptive behaviors of the crowd, rather than the actual cause (such as fire) of the disaster. Non-adaptive crowd behaviors refer to the destructive actions that a crowd may experience during a disaster, such as stampede, pushing others out of the way, knocking others down, and trampling on others, etc. These actions are responsible for a large number of injuries and, even, deaths in crowd disasters. To study the non-adaptive behavior in a crowded environment, we need to carefully study human behavior in panic situation from both the psychological and sociological perspectives.

2.1 Related Works and Developments

Existing theories on crowd behavior in emergency situations can be classified into three basic categories: Panic Theory, Decision-making Theory, Urgency theory.

2.1.1 Panic Theory

Panic theories deal primarily with the factors that may make the occurrence of panic during emergencies. The basic premise is that when people perceive danger, their usual conscious personalities are often replaced by the unconscious personalities which lead them to act irrationally.
2.1.2 Decision-making Theory

Decision-making theories assume that human behavior, even under dangerous situation, can still undergo rational decision making process, attempting to achieve good outcomes and objectives in the situation. In a situation such as a theatre fire, cooperating with others and waiting their turn can likely be beneficial to the group and, in turn, increasing the individuals likelihood of exiting. On the other hand, if some people are pushing, then an individual may feel that his/her chances of exiting safely are threatened if he/she does not react and join the competition; the best course of action for the individual may be to join the competition and push, in order to maximize the chance of exiting safely.

2.1.3 Urgency Theory

This theory suggests that the occurrence of (human) blockages of exiting space depends on the levels of urgency to exit. There are three crucial factors that could lead to such situation: the severity of the penalty and consequence for not exiting quickly, the time available to exit, and the group size. A problem arises when the distribution of the urgency levels contains a large number with a high urgency to leave for example, too many people try to exit quickly at the same time. Thus, any effort that can reduce the number of people having a high urgency to leave will cause a decrease in jams and less entrapment.
3 Model

3.1 Notations Used

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Used for</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_i$</td>
<td>panic of individual $i$</td>
</tr>
<tr>
<td>$v^a_i$</td>
<td>actual velocity of individual $i$</td>
</tr>
<tr>
<td>$v^d_i$</td>
<td>desired velocity of individual $i$</td>
</tr>
<tr>
<td>$m$</td>
<td>mass of each individual</td>
</tr>
<tr>
<td>$r_i$</td>
<td>radius of individual $i$</td>
</tr>
<tr>
<td>$f_{ij}$</td>
<td>force on individual $i$ by individual $j$</td>
</tr>
<tr>
<td>$f_{iw}$</td>
<td>force on individual $i$ by wall $w$</td>
</tr>
<tr>
<td>$r_{ij}$</td>
<td>characteristic time of individual $i$</td>
</tr>
<tr>
<td>$d_{ij}$</td>
<td>distance between the centre of mass of $i$ and $j$</td>
</tr>
<tr>
<td>$d_{iw}$</td>
<td>distance of person $i$ to wall $w$</td>
</tr>
<tr>
<td>$A$</td>
<td>constant $(2 \times 10^2)$</td>
</tr>
<tr>
<td>$B$</td>
<td>constant $(0.08m)$</td>
</tr>
<tr>
<td>$k$</td>
<td>$1.2 \times 10^5 m/s^2$</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>$2.4 \times 10^5 kg/m^1s^{-1}$</td>
</tr>
<tr>
<td>$n_{ij}$</td>
<td>normalized vector pointing from person $j$ to $i$</td>
</tr>
<tr>
<td>$t_{ij}$</td>
<td>tangential direction</td>
</tr>
<tr>
<td>$n_{iw}$</td>
<td>direction of $i$ perpendicular to wall $w$</td>
</tr>
<tr>
<td>$t_{iw}$</td>
<td>direction tangential to $w$</td>
</tr>
<tr>
<td>$\Delta v_{ji}^t$</td>
<td>tangential velocity difference i.e. $(v_j - v_i).t_{ij}$</td>
</tr>
<tr>
<td>$v_{min}$</td>
<td>minimum desired velocity of an individual</td>
</tr>
<tr>
<td>$v_{max}$</td>
<td>maximum desired velocity of an individual</td>
</tr>
<tr>
<td>$v^c_i$</td>
<td>magnitude of actual velocity of individual $i$ in the direction of his desired velocity</td>
</tr>
</tbody>
</table>

3.2 Description

On a macro level, crowd behaviors are essentially emergent phenomena (interactions among simple parts can simulate complex phenomena such as crowd dynamics) that arise due to high crowd density, severe environmentally imposed constraints, and panic (e.g., high emotional arousal) within a crowd. On a micro level, crowd behaviors can be modeled as decision-making processes of individual humans influenced by panic. We have built on the model proposed by Dirk Helbing, Illes Farkas and Tamas Vicsek[1].

A generalised force model is used to describe the crowd behavior. In the model each individual has the parameters: panic, desired velocity, actual velocity, mass, radius, position (centre of mass).
For computing the desired velocity of an individual we have made an assumption that each individual knows about the building design and thus knows the positions of the exits. We have used a **grid based model** in which we have divided the building scenario into square grids of equal size. The size of the grid is calculated according to the dimensions of the building. Now each grid is marked on its proximity to the exits and fires. We also take into account the presence of walls while grading. It means that we do not just simply find the desired velocity direction as the vector pointing to the exit but if we encounter any wall in this direction, our desired velocity direction would also get modified so as to go around that wall towards the exit.

An individual experiences three kinds of forces: contact force by wall, contact force by individuals and psychological force. An individual’s velocity gets changed due to these forces. We determine the change in position of the individual according to this velocity. Mathematically, change in velocity in time \( t \) is given by Newton’s equation of motion:

\[
m_i \frac{dv_i}{dt} = m_i \frac{v_i^d(t) - v_i^d(t)}{\tau_i} + \sum_{j \neq i} f_{ij} + \sum_w f_{iw}
\]

(1)

\[
f_{ij} = A_i e^{(r_{ij} - d_{ij})/B_i} + kg(r_{ij} - d_{ij}) n_{ij} + \kappa g(r_{ij} - d_{ij}) \Delta v_{ij} t_{ij}
\]

(2)

Here the function \( g(x) \) is defined as:

- \( g(x) = 0 \) if persons are not in contact i.e. \( d_{ij} > r_{ij} \),
- \( g(x) = x \) otherwise

\[
f_{iw} = A_i e^{(r_i - d_{iw})/B_i} + kg(r_i - d_{iw}) n_{iw} + \kappa g(r_i - d_{iw})(v_i t_{iw}) t_{iw}
\]

(3)

The first term in equation (1) represents the psychological force experienced by individual \( i \) because he is not able to move as quickly as desired in the direction he intends to move. This leads to build up of panic in the individual. The first term in equation (2) represents the psychological tendency of two individuals \( i \) and \( j \) to stay away from each other. The first term in equation (3) represents the psychological tendency of an individual \( i \) to stay away from wall \( j \). Other terms are the interaction forces. The magnitude of desired velocity is calculated as follows

\[
|v_i^d| = (1 - p_i(t))v_{\text{min}} + (p_i(t))v_{\text{max}}
\]

(4)

Hence more the panic more would be the desired velocity of an individual. Panic of an individual at time \( t \) is calculated as below

\[
p_i(t) = (1 - \frac{v_i^c}{|v_i^d|}) - 0.25(\text{firecomp}_i(t))
\]

(5)
Here \( \text{firecomp}_i(t) = 0 \), if individual is outside the threshold range of the fire else it is a measure of the proximity of the individual to fire. Effect of panic on desired velocity direction

\[
e_i^d(t) = (1 - p_i(t))\text{ind}_i + (p_i(t))\text{group}_i
\]

(6)

This equation shows that if panic of the individual is high, he will follow the group while in case of low panic he will take an independent decision. The \( \text{group}_i \) in the equation above is group velocity direction for individual \( i \). It is calculated as the average velocity direction of people in radius of 5 metres of the individual. \( \text{ind}_i \) is the desired velocity direction of the individual when he takes an independent decision. It is calculated according to the grid model described above.

The model also takes into account the stampede condition. We mark a person as killed due to stampede if sum of all the radial forces on the individual exceeds a threshold.

Thus at each step of the simulation the various parameters of the individual like panic, desired velocity, actual velocity and position are updated in accordance with the equations given above.

4 Software Specifications

Our tool has a graphical user interface using which the user can design the scene, generate crowd, and mark the disaster site. The result is in the form of a continuous simulation showing the behavior of the crowd with time.

4.0.1 Input

The user has to add walls, mark exits and disaster site and add crowd. He can add crowd in two ways: either place people one by one at his desired position or select a region and specify the number of people he wants to add in that region. The user can also choose the rate at which the fire (disaster) expands. The user has an option of either creating a new file and save it or making changes in an already existing file. When the user is done with the input he can finalise the scenario and proceed to the simulation.

4.0.2 Simulation

Our tool provides the facility of continuous and step by step simulation. For continuous simulation, user has to choose play button and for step by step, the forward icon. In the simulation each human is represented by a circle. The tool
also shows the total time elapsed and number of people trapped, escaped and killed during the simulation. People killed by either stampede or by fire are marked as black and we assume that people can move over dead people.

5 Results and Analysis

6 Future Work

A 3-Dimensional visualization of our software can be done. Our code can be optimised to execute faster than the present.

7 References

[1] Simulating dynamic features of escape panic by Dirk Helbing, Illes Farkas, Tamas Vicsek