Development of elements of a 3D emergency evacuation simulation system

M A Tugarinov¹, I D Shulga¹, E A Yurchenko¹ and S N Torgaev¹,²

¹ National research Tomsk State University, Tomsk, Russia
² National research Tomsk Polytechnic University, Tomsk, Russia
E-mail: torgaev@tpu.ru

Abstract. The article presents the results of the development and practical implementation of the algorithm for the fire and smoke spreading for a 3D evacuation simulation system in case of indoor fire. Also, there is the algorithm of the character's behaviour, which takes into account a large number of its physical and mental states. The algorithm of the character's behaviour includes states in which one figure can help others and participate in the fire-fighting. The algorithms presented in the article will form the basis of the 3D modelling system with increased realism.

1. Introduction

Today realistic modelling is one of the most effective methods of analyzing evacuation processes in emergencies. The most realistic modelling requires detailed 3D models with a rich set of simulated parameter. In developing such models, special attention should be paid to modelling fire and smoke as well as to the modelling character's behaviour. Existing 2D and 3D models have a large number of simplifications, especially in terms of the psycho-physical state of people.

Consequently, the development of a system for simulating the behaviour of crowds in an emergency, which takes into account a large number of psychophysical parameters of a person, is highly relevant. Modelling realistic human behaviour in view of all psychophysical parameters is the most problematic thing during the process of creating evacuation models. This work focuses on the development of elements of a detailed 3D model of fire evacuation processes. The developed model includes a large set of people's psychophysical parameters, processes of spreading fire and smoke. It also takes into account the interaction between people.

2. Fire and smoke modelling

The fire propagation simulation algorithm consists of three stages:
- The stage of low fire – fire does not spread, it destroys materials near itself and intensifies;
- The stage of medium fire – fire begins to spread and actively emits smoke;
- The stage of intense fire – significant increase in fire size, increase in density of smoke.

Figures 1 and 2 present results of the visualization of fire and smoke spreading.
Figure 1. The visualization of fire spreading: a - the stage of low fire; b – the stage of medium fire; c - the stage of intense fire.

Figure 2. The visualization of smoke spreading.

Figure 3 presents the basic fire and smoke propagation algorithm. In the developed system smoke generates itself. Each smoke beam has nine cells (figure 2), the smoke beam itself is centered and must abide by the conditions for producing the beam: if the cell intersects with the wall, floor or central cell of the other beam, it is impossible to create the next bundle of smoke with its nine cells in the coordinates of this cell. In fire simulation, the central cells are used to create conditions for poisoning or burning the character. When a character crosses a central cell in the object of fire, part of it passes to the character’s body and the character suffers damage for a long time.
Figure 3. The basic fire and smoke spreading algorithm.

This algorithm assumes further modification. In particular, it is planned to take into account the burning and smoke-forming rates of different materials in the simulation of the ignition and fire propagation process. The circulation of smoke indoors will be implemented through ventilation shafts based on the building plan.

During modifying the model, the task of spreading fire can be divided into two ones:

1. Calculation of the spread area: the ignition site will request the possibility of spreading to one side, taking into account the information collected, a probability distribution map will be drawn up, which will account for the circulating airflow in the building and the burning rate of the material (figure 4, a). It is also possible to consider gradient maps corresponding to the fire spreading of a certain material which will be laid in the texture of the model itself (figure 4, b).

2. Creating a fire over the area. In this case, the stages of the fire will be used. In the second stage of the fire, another section of the flame will be created in the first stage according to the calculation of the area from the first task. Also, according to the burning rate of the material the time between the fire stages will be determined and according to the smoke acidity rate smoke with the corresponding health damage to the characters will be created.
3. Modeling characters and their interactions

During the simulation, individual parameters are set for each character. At this point, each character has the following set of parameters:

- **Health** – the parameter that determines the percentage of a character’s ability to work. This parameter determines the state in which the character is located.
- **Stress** – the parameter that shows the state of the character’s nervous system.
- **Speed** – parameter that determines the speed of the character depending on his condition. A panicking character will run faster than a calm or injured one.
- **Mass** – the parameter used to calculate the interaction between the bots during stampede or collision with each other.

It is possible to create a certain character type if you have a certain range of values of each parameter. To describe the character’s behavior and its interaction with other characters, a graph was developed, it is presented in figure 5.

Figure 5. The graph of the model of character’s behavior and states

The basic idea is that all decisions related to the psychology of emergency behaviour are combined into one state and described according to the selected psychotype.
As could be seen, the graph has five main states and three substates of the Psychology state corresponding to certain psychotypes. From the psychological state, the conditions of transition for the substates are the same (smoke poisoning, severe damage, critical damage).

It is also worth drawing attention to the fact that the transition to a psychological state is carried out only from a state of calm, that is the character cannot assess the situation in a state of poisoning or damage. Each character has a Stress scale (Figure 6), which determines how ready the character is to go into the psychological state of Panic.

![Figure 6. Stress scale in states Calm (a) and Dropped (b)](image)

If a character in the Calm state sees Fire, a certain amount of per cent is added to the Stress scale. Similarly, when a character sees the character in the state of Dropped, Poisoned, and Dead. It is also possible to increase the Stress scale when the character in Dropped or Poisoned state (Figure 5). In the beginning, each character has its own set of physical parameters and variables (by default). Our model of behaviour presents five states and transitions that are performed through animation:

1. State Calm. This state is consistent with the moderate speed of movement and adequate character behaviour. When the character sees fire, the character transitions to one of the states Poisoned, Dropped, or Dead. A transition to Poisoned is made if the contact with smoke lasts longer than a certain time (smokeintime). If the health variable is zero, the character state changes to the Dead state (xp==0). The transition to the Dropped state is affected by significant damage (strongpush).

2. State Psychology. Transition to a state occurs if the character has reached a certain stress level (stress==b). In this state the character behaves as though he behaves in a stressful situation, according to his psychotype. State Psychology has three substates:
   - Substate Stupor. In this substate the character is unable to make his own decisions. Transition to Calm is made in case of the fact that the character in Sympathy state calms the panicked one.
   - Substate Aggression. In this substate the character becomes aggressive, has a high speed of movement and has the ability Push to push other characters away.
   - Substate Sympathy. In this state a character is ready for Emergency Situations. He has skills to help characters in Dropped, Poisoned and Stupor states, but is unable to help characters in Aggression states.

3. State Dropped. It’s a condition in which a person falls or is injured. The speed is slower than usual. After a certain time, the stress increases. The transition to the Calm state occurs if the character in the Sympathy state raises it (help (dropped)). If the health variable is zero, the character state changes to the Dead state (xp==0).

4. State Poisoned. This is the condition of the smoke-poisoned character. The speed of movement is slower than usual and the health level decreases over time and the stress level increases. The
transition to the *Calm* state occurs if the character in the *Sympathy* state raises him (*help (dropped)*). If the health variable is zero, the character state changes to the *Dead* state (*xp==0*).

5. State *Dead*. It’s a condition in which the character is unable to function. The transition from any other states to a *Dead* state is the same and occurs if the health variable is zero (*xp==0*).

4. Summary

In this way, an algorithm was developed to simulate the spread of fire and smoke in case of a fire. The developed algorithm assumes that material parameters are taken into account in modelling.

The detailed algorithm (graph) of the character’s behaviour in case of emergency has also been developed. This algorithm takes into account the character’s various states, including psychological parameters. The functions of helping one character to another implements in the algorithm when the first one is in a certain state.

Presented in this paper algorithms will significantly increase the realism of simulations of evacuation processes in an emergency.

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