Journal of Physics: Conference Series

PAPER • OPEN ACCESS

# 3D-simulation of emergency evacuation

# 3D-simulation of emergency evacuation

**M A Tugarinov, I D Shulga, E A Yurchenko and A D Ermakov**

[1] National research Tomsk state university, Tomsk, Russia

E-mail: torgaev@tpu.ru

**Abstract.** The article presents the results of the development of the 3D modelling system for the evacuation process of people in case of fire and test experiments. The article describes the choice of the programming environment and the behaviour of the characters. The results of the test simulations of character behaviour, including processes of assisting other characters and fire-extinguishing, are shown. The presented results are the basis for creating a complete simulation model with increased realism.

## 1. Introduction

Usually, the consequences of emergencies are difficult to predict, as they depend on many factors. The important factor in an emergency evacuation is a time it takes for people to leave the dangerous territory. One of the causes of death is the impossibility or difficulty of evacuating people promptly. This can be influenced by the structure of the building as well as by the state of the people themselves at the moment of danger. Unfortunately, in practice, even the implementation of all fire-fighting requirements and guidelines for accommodation does not guarantee the effectiveness of evacuation, as the time of evacuation is still depends largely on the behaviour of people in critical situations.

Simulation of human behaviour is an effective method of assessing the security of premises. Creating an adequate 3D model of the emergency evacuation process is quite complex. This is due to the need to take into account a large number of modelling parameters with the possibility of 3D visualization. For example, when modelling the processes of the evacuation of people in case of fire, it is necessary to take into account the properties of materials, the specifics of the design of buildings, various psychophysical states of people, etc.

Current models have many limitations, both in the use of 2D visualization techniques and in the large number of simplifications, which are needed to optimize calculations. There are works on the use of 3D visualization, but they work on the same principle as 2D models. The use of 2D models does not allow performing a fully realistic simulation of the evacuation process, since such models cannot adequately take into account the processes of interaction between people.

At the moment, there are 4 main approaches to modelling human behaviour:

- Molecular Approach [1, 2]. In this case, people are represented as circles on the plane. The dynamics of human motion and interaction are described by the laws of molecular physics. This modelling approach has several limitations, such as the lack of capacity to determine the individual parameters of people, and psychophysical factors are used only to change the speed of people.
- Route-based approach [3]. This approach to modelling is aimed at finding and visualizing the most effective escape routes.

- Group-based approach [4, 5]. In this approach, a crowd of people is divided into separate groups, the movement of each is described separately. In group modelling, it is possible to take into account the social interaction of people. Typically, such models are two-dimensional and thus limited to the perception of the reality of the evacuation process.
- Agent-based approach [6, 7]. This approach allows you to create a flexible model of human behaviour, i.e. define individual characteristics, rules of interaction and decision making.

In this regard, the development of a system for simulating the behaviour of crowds in emergencies, which takes into account a large number of psychophysical parameters of a person, is highly relevant. The developed model will allow analyzing the processes of evacuation from buildings, and can also be used for teaching and training.

## 2. Choosing a simulation program

When choosing a simulation program, it is necessary to take into account the following features that it must satisfy:

1. the presence of an AI editor, which is necessary to simulate human behaviour using blocks that describe the state of the character and his actions under certain conditions;
2. the presence of a visual programming editor, which is a block with a pre-printed code.

We have reviewed the programs presented in table 1.

**Table 1.** Characteristics of modelling programs.

| | **Unreal Engine** | **Unity** | **CryEngine** |
|---|---|---|---|
| Free | + | + | + |
| Material editor | + | + (limited range) | + |
| AI editor | + (BehaviorTree) | - | - |
| Visual programming editor | + (Blueprint) | - | + (FlowGraph) |
| User interface editor | + (UMG) | - | - |

As can be seen from table 1, Unreal Engine is the most suitable environment for model creation. The Cry Engine Environment, which is gaining popularity recently, can also be considered. It is capable of working well with artificial intelligence, although it does not have a separate editor.

The Unreal Engine software includes the visual programming editor Blueprint. With the help of this editor, all actions are carried out inside the simulated space. Let's consider the process of the editor using the example of the implementation of the character's movement (figure 1).

In ***Blueprint***, all processes are represented in the form of blocks in which a certain code is written that performs the required action. There are many types of such blocks. The algorithm in Figure 1 uses three types of blocks: an event block (red); action block (blue); auxiliary block (green). An event block starts the entire subsequent chain of blocks when a certain action (event) occurs. An event block starts the entire subsequent chain of blocks when a certain action (event) occurs.

The example uses the ***EventBeginPlay*** block i.e. when the simulation process starts, this block is triggered and activates the subsequent blocks. An action block performs a specific action on the received initial variables. The example uses the ***AiMoveTo*** block, i.e. coordinates are supplied to the ***Destination*** variable, which is then put into the ***Pawn*** variable. An auxiliary block performs many different secondary tasks for an action block. The example uses ***MakeVector***, which creates a vector from input variables. The ***GetControlledPawn*** function helps to get the input variable (character) of the action

Journal of Physics: Conference Series **1680** (2020) 012052 doi:10.1088/1742-6596/1680/1/012052

block, and the ***RandomFloatinRange*** function gets a float variable in a certain range, which we set ourselves.

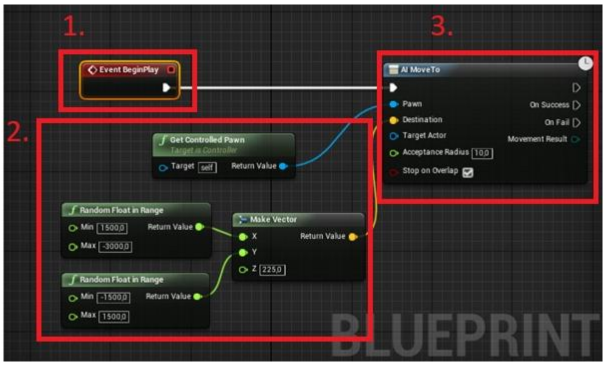



**Figure 1.** An example of the implementation of the algorithm for character movement in the Unreal Engine.

Thus, with the help of several blocks, the character can move a random route within a certain range. Other processes work similarly, but other types of blocks can be used.

For improved character definition, ***Unreal Engine*** has an ***AI Perception*** component, which can be added to the character to determine its perception of something.

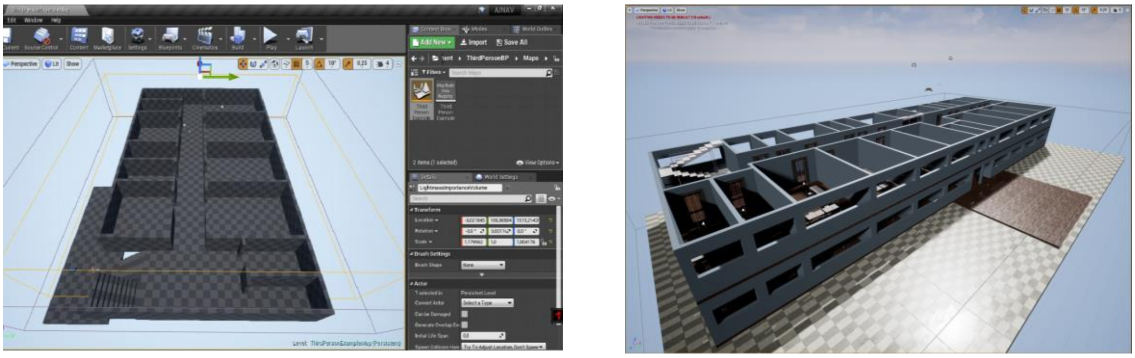
## 3. Elements of the 3D model

An algorithm for the occurrence and propagation of fire and smoke was developed for simulation. The algorithm consists of three stages: the stage of faint light (smoke), the stage of medium-light (smoke) and the stage of strong light (smoke). The algorithm has nine cells. Fire or smoke occurs in the central cell. In simulations of fire and smoke, the central cells are used to create conditions for poisoning or burning the character.

A detailed algorithm for simulating the behaviour of each character was also developed. The distinctive feature of this algorithm is the presence not only of the character's physical states but also of a mental state. The character's input parameters are Health, Stress, Speed, Mass. During the simulation, the character may be in the following states: ***Calm, Psychology (Stupor, Aggression, Sympathy), Dropped, Poisoned, Dead***. Depending on the states in which the character is currently located, he or she can move from one state to another. Substate ***Sympathy*** allows us to realize the possibility of helping one character with another.

## 4. Test environment

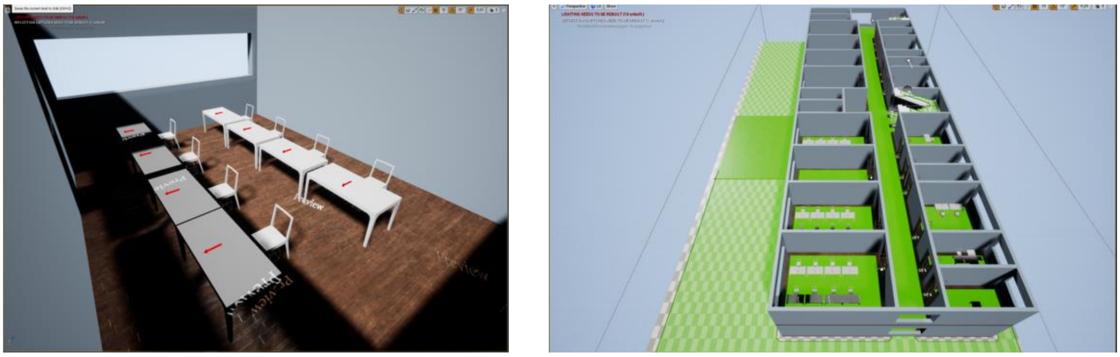
To conduct test simulations in Unreal Engine building model was created. The model does not reflect detailed accuracy and it is just an example of a simulation space (Figure 1). The lighting, camera position and character restrictions are set.



a b

**Figure 2.** Example of test environment: one floor (a); two floors (b).

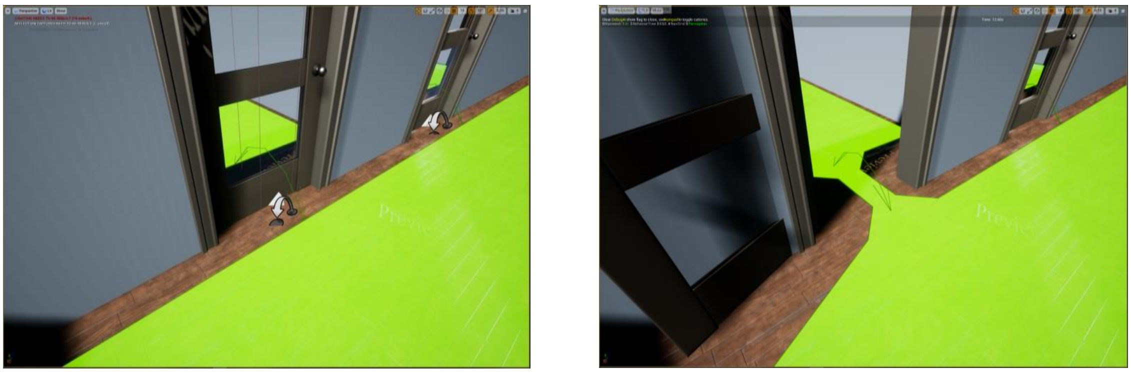
To make the simulation more complex, a two-storey model of the building was created with several exits on the first and second floors (Figure 2b). An exit through the window, opening doors and the base material of the walls, floor, doors and roof were added too (Figure 3a).



a b

**Figure 3.** An example of a room (a) of a floor (b).

There was also a statistical navigation mesh, which was replaced by a dynamic one. A navigation mesh is a geometric grid constructed along a landscape, with the possibility of a character passing at each point of geometry. The navigation mesh is the basis for artificial intelligence pathfinding.



a b

**Figure 4.** Dynamic navigation mesh using the door example.

A dynamic navigation mesh, unlike a static one, is updated after a certain time. This is convenient if there are objects that make changes to the navigation mesh, such as doors, windows, elevator or gate (Figure 4). Also, a dynamic navigation mesh can be used in buildings where walls, ceilings will collapse.

Journal of Physics: Conference Series **1680** (2020) 012052 doi:10.1088/1742-6596/1680/1/012052

## 5. Test simulations

During the simulation, the physical interaction of the characters with each other was added when body parts collided (Figure 5).

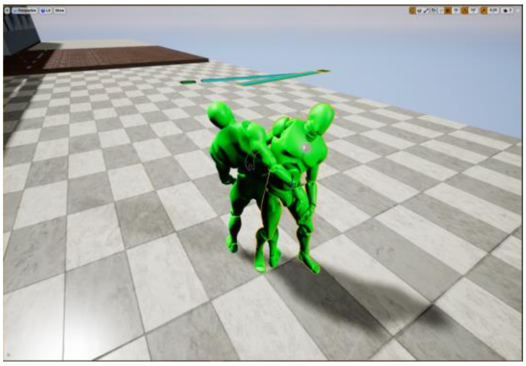
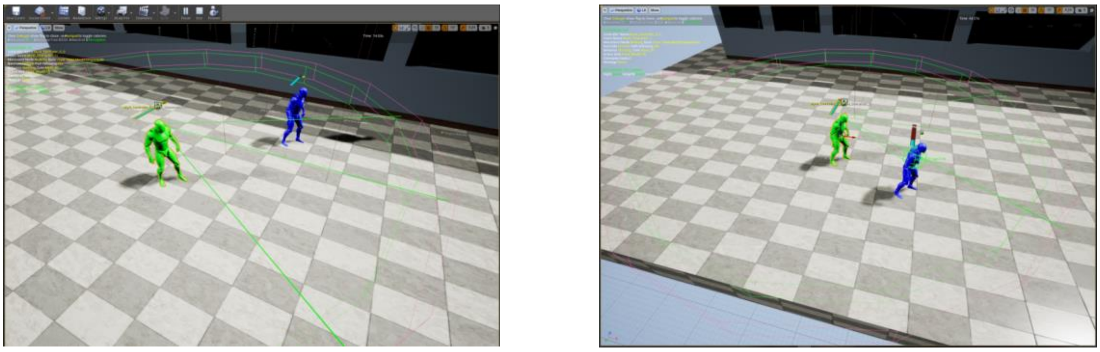


**Figure 5.** Characters colliding with each other.

For each component that the character's body is composed of, its physical parameters are included.

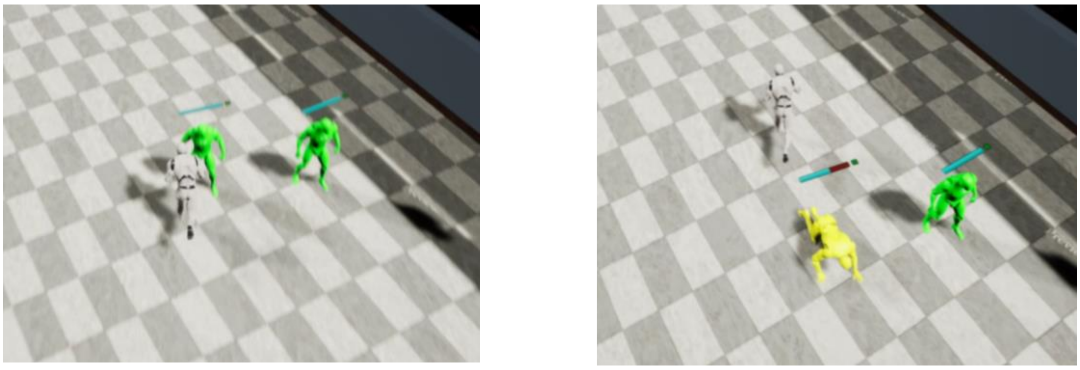
In a collision, the components react according to these physical parameters, and the body parts associated with the colliding components stretch behind them. It should be mentioned that each component tends to return to its original position.



a b

**Figure 6.** Example of character definition.

In figure 6, a character in a state ***Calm*** (green) can determine the state in which the characters standing beside him are and act according to the conditions set, in our case the stress scale is increased.



a b

**Figure 7.** Example of taking damage by a character.

A character with low health changes to ***Dropped*** (yellow). The speed in this state decreases, the character moves on a crawl (Figure 7).

**Figure 8.** Example of the state ***Dead***.

When the character's health is zero, the transition to the ***Dead*** state (white) will be triggered, accompanied by the corresponding animation (Figure 8). As noted above, the model created an interaction of helping the character to another character. A character in a ***Sympathy*** state identifies a character in need of assistance with an ***AiPerception***. The assistance process is divided into three phases: identification, convergence and assistance (figure 9).

a b c

**Figure 9.** Example of fire-fighting animation: needy (a); convergence (b); the assistance (c).

Once a person is identified as needing help, the character approaches him and the help is animated. Depending on the state of the person in need, the following assistance may be provided:

- calm in case of a state ***Stupor***;
- raise for state ***Dropped***;
- give a wet cloth, as a filter, for the state ***Poisoned***.

In turn, the person in need of help plays an animation corresponding to the assistance provided to him. As a result, a character in need of help moves to the ***Calm*** state.

Before the evacuation begins, the character moves along random coordinates that change over time. It also triggers a random selection between several behaviours, accompanied by various animations while walking. If the character in the course of his movements finds a chair, he checks whether it is busy, in case of a negative answer, the character goes to the selected chair and sits on it. Then a random selection between several behaviours is triggered, in a sitting position (Figure 10).

a b

**Figure 10.** Example of a character walking behaviour (b) and his sitting position(b).

In the model, the interaction of fire extinguishing by the character is added. Character in a state ***Sympathy*** detects fire with the aid of ***AiPerception***. Then the character goes to the fire extinguisher if he has been seen before. The character plays the animation of picking the fire extinguisher up and heads towards the fire. After the character, using a fire extinguisher extinguishes the fire for a certain time with the appropriate animation (Figure 11). If the fire extinguisher has not been seen before, the character does not take action to extinguish the fire.

a b c

**Figure 11.** Example of assistance: pick a fire extinguisher up (a); fire-fighting (b,c).

## 6. Summary

In this way, a prototype of a 3D simulation system for the process of evacuating people in the event of a fire was developed. The prototype system includes elements of simulation of fire and smoke, as well as algorithms for the character's behaviour in different psychophysical states. The behaviour algorithm includes not only an evacuation but also helping other characters, as well as taking action to extinguish the fire.

## Acknowledgments

The work was supported by the Innovation Promotion Foundation, grant UMNIK.

## References

[1] Dirk Helbing, Illés Farkas and Tamás Vicsek 2000 *Nature* **407** 487-490
[2] Yunyun Niu, Yongpeng Zhang, Jieqiong Zhang and Jianhua Xiao 2018 *International journal of computers communications & control* **13** 865-880
[3] Jialiang Kou, Shengwu Xiong, Zhixiang Fang, Xinlu Zong, and Zhong Chen 2013 *Hindawi Publishing Corporation Computational Intelligence and Neuroscience* **2013**
[4] Ping Du, Yan Li, Hong Liu and Xiangwei Zheng 2018 *9th International Conference on Information Technology in Medicine and Education* pp 1018-1026
[5] Anne Templeton, John Drury, and Andrew Philippides 2015 *General Psychology* **19** 215-229
[6] J. Shi, A. Ren and C. Chen 2009 *Automation in Construction* **18** 338–347
[7] Wei Xin-quan and Wang Jian 2015 *Systems Engineering — Theory & Practice* **35** 2473-2483