Developing fire evacuation simulation through BDI-based modelling and simulation

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Abstract. Fire evacuation simulation is used to simulate the fire evacuation procedures by involving human-like agents. In this paper, the fire evacuation simulation is designed and developed by adopting the BDI agent plug-in. BDI (Belief, Desires, Intentions) is a technique used in modelling the multi-agent system. A tool and BDI methodology are introduced to help in modelling human behaviour and the decision making of an agent. In this paper, the usability of the BDI methodology and BDI agent plug-in tool is studied through a case study of a fire evacuation environment. The case study covers the three main components needed in a fire evacuation simulation: the fire (the spread of the fire and smoke), the building layout (the classroom and physical objects), and the human-like multi-agents. Using the Unity game engine, a fire evacuation simulation system is built based on the requirements, methodology, and design. The usability of the BDI agent plug-in tool can be proven by observing the results of the fire evacuation simulation and the reaction of agents when encountering the fire situation. However, there are also some limitations of this fire evacuation simulation. Therefore, there are works to be done to develop a more realistic fire evacuation simulation and more human-like multi-agents in future.

1. Introduction

Fire evacuation procedures are the procedures to be used in case of fire. A fire drill is conducted to practice the emergency procedures when there is a fire. However, there are some limitations when conducting fire drills. For example, conducting a fire drill is costly, and there is a risk that participants get injured. Besides, the number to examine the fire evacuation scenarios is also limited [1]. To overcome the insufficiency of fire drill, fire simulation is introduced. Fire evacuation simulation has imitated the situations where the occupants (the agents) evacuate from the building in case of fire [1]. The advantages of using fire simulation are that the participants (the agents) will not risk getting injured when exposed to various fire situations.

From the review by [2], several models have been introduced for evacuation simulations. They are flow-based modelling, cellular automata, and agent-based simulation. Work has been done to introduce BDI methodology and UnityBDI plug-in for BDI-based social simulation. With the methodology, developers can analyse and design complex human behaviour in simulation. Meanwhile, the developer can use the BDI plug-in to model human behaviour as a non-player character in the fire evacuation simulation. The tool is integrated with Unity3D and developed with a simple analysis component so that the end-users can observe the real-time simulation and results of the evacuation.
Although the methodology and tool can simulate a group of virtual characters on a bush fire evacuation, to what extent the tool can develop a real-world simulation is yet to explore and further develop.

2. Materials and methods

To model and develop the multi-agent system in fire evacuation simulation, the proposed methodology our early work [3][9] is adopted and is described briefly in the related background's section. The proposed methodology adopted agent-oriented modelling (AOM) and extending AOM to the human decision-making model in evacuation simulation [3]. AOM is a modelling language to model a complex socio-technical system[4]. It has been adopted in ICT4D, games[10], mobile applications [5] and etc.

In this research, the requirements of fire evacuation simulation and its system modelling is discussed in the design and development section.

2.1. Related background

Several components are needed in building up a fire evacuation simulation. [7] stated three main sub-models in modelling an agent-based evacuation simulation model. They are fire sub-models, building geometry sub-models, and occupant behaviour sub-models. In the fire evacuation model, a fire dynamics simulator (FDS), a computational fluid dynamics (CFD) model, and a geographic information system (GIS) are adopted to develop occupant behaviour in real-time interactions. These models are integrated to detect the motion of an occupant and figure the clearing time for the building. [2] considered the BDI technique (Beliefs, Desires, Intentions) in modelling the human behaviour of a multi-agent system. This technique designs the agent so that it is directed by its Desires (the goals) and according to its Beliefs (the knowledge of the world or environment) and Intentions (the actions) to achieve its Desires.

The modelling of human decisions in this research is based on [3]. When modelling human decisions, there are three abstract levels which are the computation-independent model (CIM), platform-independent model (PIM), and the platform-specific model (PSM). The model represents the requirement model, design model and implementation model of BDI architecture. The detail of the modelling is described in the following subsection.

2.2. Design and development

In designing and developing the proposed fire evacuation simulation, requirements of the system are collected based on the studied related research mentioned in the related background's section. The requirements are collected by reviewing the research papers that are summarised in the literature review. In dealing with fire evacuation, there are three main models referred to by [7]: fire sub-model, building geometry sub-model, and occupant sub-model. These three components included in the model are the basic requirements and features for developing the simulation in this paper. These sub-models can interact with each other by providing the information needed to develop the simulation. Besides the three main sub-models, the agent's attributes and the occupant behaviour or the decision-making process are also referred to by [2]. Several aspects are considered and required for the actions of an agent based on [2]:

- The world conditions analysis according to elements such as presence of smoke and fire.
- Observation of other agent's behaviour.
- Visibility conditions of an agent.
- Knowledge about the world, building, exits, and shortest path to exits.
- Physical conditions of an agent such as health.

The decision-making algorithm for an agent to plan its strategies includes:

- Exit path.
- Alternative path to the exit when conditions changed.
• Informing other agent's action.

There are three basic components required to develop the fire evacuation simulation. For instance, the building layout, the fire, and the agents. There is also a world state which represents the environment of the simulation. The world state is dependent on these three main components. The world state of the simulation consists of the observable information that is sharable among the agents of simulation. The agents will depend on the world state to perform actions. The fire model requires information from the building layout for fire distribution. The agents will take action according to the information provided from the building layout and the fire model.

From the requirements, we proceed to model the human decision through BDI methodology. The following shows the steps of the proposed methodology in modelling the BDI agent of fire evacuation simulation.

Step 1: Actor identification
• The organisation model and role model are depicted in this step. Figure 1 shows the organisation modelling of two types of agents: an agent with a helping attribute and an agent without a helping attribute. The agent without a helping attribute is dependent on an agent who has a helping attribute. Table 1 shows the role model of two different types of agents. The responsibilities and constraints of the agents are described in the model.

![Figure 1. Organisation model.](image)

**Table 1. Role model.**

| Role Name | Agents |
|-----------|--------|
| Description | The common role of agents with and without helping attribute. |
| Responsibilities | Find a path to the exit. |
| | Avoid obstacles, fire, and smoke. |
| Constraints | If an agent is injured, it cannot move and need to get help from an agent who has the helping attribute. |
| | The agent may pass away if it cannot get help from others. |

Step 2: Belief modelling
• Figure 2 describes the entities to be modelled in the fire evacuation simulation. There are ten entities and two types of agents in modelling the simulation. In the simulation, two types of agents are placed in the building layout. In the layout, there are five physical objects: fire or smoke, chair, table, wall, and door. Knowledge of the agents contains the information of the building layout and the world's beliefs. The knowledge of the agents updates their belief when agents perceive an incident. When an agent perceives an incident, it will take actions that can act on the physical object.
Step 3: Desire and intention modelling

- The desire (the goal) and intention (the actions) are modelled at this step. Figures 3 show the desired model for both actors. In this case, some actors will leave the room without helping the others, and some will help the injured before leaving the room.

Figure 4 describes the shared goals and actions of agents to leave the building during evacuation. To achieve the sub-goal "Go to the nearest exit", the agent needs to locate the nearest exit in the building. For an agent with a helping attribute to provide help to an injured agent, it needs to look for any injured agent. Figure 5 shows the interaction model between agents without helping attribute and with helping attribute. The agents can get help from the agent with helping attribute whenever they get injured. The helpful agent will react and provide help to who is in need.
Step 4: Deliberation modelling
- In this step, the knowledge model and scenario model are designed. Figure 6 shows the knowledge model that describes the agents' beliefs with and without helping attribute while the scenario model describes the agents' actions, as shown in table 2.
Table 2. Scenario model.

| Strategy 1 |
|------------|
| **Goal** |
| Leave the building |
| **Initiator** |
| Two types of agents (with and without helping attribute) |
| **Trigger** |
| Has fire |
| **Description** |
| **Belief** | **Step** | **Desire** | **Plan** | **Soft goal/goal or plan selection** |
| hasFire | 1 | Go to the nearest exit | Target the exit. | Not injured |
| isInjured | 2 | Get help | Wait for help | Not injured |
| | 3 | Provide help | Look around | Not injured |

Step 5: Platform-specific design and modelling
- Unity game engine is used to model the fire evacuation simulation. There is also a user interface designed to control the number of two types of agents, the distribution speed of fire and smoke, the speed of an agent to evacuate from the scene. Besides, agents count, a current agent with helping attribute, total death, current injured agent, total injured agent, and survived agent are displayed in the simulation's interface. Other than displays and controls, the scene can also be rotated to view different perspectives of the simulation with control keys designed. Furthermore, the user can control the fire by disabling or enabling it and dragging it to a particular location in the simulation.

3. Results
Based on the design and modelling of the fire evacuation simulation, a fire evacuation simulation is built. This section will focus on and discuss the prototype of the fire evacuation simulation. Figure 7 shows the interface of fire evacuation simulation. There are play and pause panels, setting panel, and resource panel. The setting button controls the setting panel, while the resource button controls the resource panel. A replay button also allows users to replay the simulation when the simulation is executing or ending.

Figure 7. The interface of fire evacuation simulation.

The fire evacuation simulation is implemented so that the parameters of Occupant Speed, Occupant Health, and Sparkle Hold Number control the MAX_DAMAGE of floor, wall, cabinet, and seat. The MAX_DAMAGE refers to how much fire can hold by a grid of an object. The higher the value of MAX_DAMAGE, the fire is spread slower in the object or resource. The execution of the fire evacuation simulation is shown in figure 8. The setting of the simulation contains ten agents with four helpful agents and six normal agents. There are also 16 seats and one cabinet in the classroom. At the beginning of the simulation, the agents go into the classroom and take their seats. When the fire is
being added to the scene, the agents escape and go to the exit. The result of the simulation is displayed after a cycle of simulation ends. The total number of saved injured, escaped occupants, and dead occupants are displayed after a simulation in figure 9.

![Fire evacuation simulation process.](image1)

![Results after simulation.](image2)

4. Discussion
From the prototype of fire evacuation simulation, the agents act as the participants or occupants during the fire evacuation procedure. The setting of the fire simulation is set in the classroom. The goal of the agents is to escape from the fire environment. However, there is still a long way to go to create a more human-like agent. The use of the BDI plug-in tool is proven as agents are functional. By having the result after the fire evacuation simulation, the data can be easily observed. However, the fire evacuation simulation still cannot replace the fire drill. This is because much work needs to be done to create a more human-like agent that can imitate the behaviour of a human in emergency situations.
Besides, the setting of the proposed simulation is not enough to perform the real environment. Hence, there is a need to develop in more detail for this proposed simulation.

5. Conclusion
The fire evacuation procedure is important because it can help the occupants of a building become familiar with the escape routine in case of fire. However, there are some insufficient of practising fire drills. So, a fire simulation system is introduced. With fire simulation, the participants will not get injured when getting into fire situations. Besides, it can also run several times of simulations with different parameters. The result of the simulation can be observed quickly after the simulation. Besides, with the game-like features in fire evacuation simulation, the users can interact with the environment during the simulation. Several events can be created to produce various consequences. The usage of the BDI plug-in tool in Unity is proven when agents can successfully perform actions to accomplish their goals according to their beliefs. However, there are still some limitations of the simulation. The fire simulation cannot fully replace the fire drill as it cannot fully imitate the real-world situation. There is more work need to be done to make the fire evacuation simulation more realistic.

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