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RESEARCH ARTICLE

A crowd route choice evacuation model in large indoor building spaces

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Abstract
Route choice is a fundamental requirement in the evacuation process. The aim of this paper is to identify a method to simulate crowds in large indoor spaces with consideration of the acoustic system. This paper first extends an existing cellular automaton model and proposes a cellular automaton crowd route choice model (CACR model) to simulate evacuees in large indoor spaces. It then defines a measure for evaluating the utility of evacuation time using the CACR model under different circumstances, such as a fire situation or different voice warning systems, which other commercial models cannot simulate. The analysis of the characteristics of a sound field in large indoor spaces is based on field measurements. An observation experiment in a gymnasium is employed to test the proposed model in a stadium evacuation scenario. The results demonstrate that the CACR model can accurately simulate the evacuation process in large indoor spaces under various circumstances.

1. Introduction

The evacuation process is very complicated considering the variety of individual features. Previous research work has been developed on two aspects, evacuation time (Gwynne et al., 1999; Ashe and Shields, 1999) and human behaviour (Sekizawa et al., 1999; Sime, 2001). The evacuation time consists of pre-movement and movement time. It is a common practice to set the pre-movement time in the calculations according to past experience as an effort to avoid too much deviation (Gwynne et al., 1999). Attention has also been paid to research on formulas for and models of movement time (Ashe and Shields, 1999). On the other hand, investigation of human psychology and behaviour plays an important role in the research on

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evacuation efficiency. Three interactions will have important influence on decisions individuals make during evacuation: interactions between people, between people and architecture, and between people and the environment (Yang et al., 2005). Human cognitive behaviour will influence the evacuation process in emergency situations (Pires, 2005).

Further research has found that different building styles may cause polytropic evacuation processes. This finding has made research on evacuation times and human behaviour more diversified and closer to actual experience (Tong and Canter, 1985; Fang et al., 2011; Zheng et al., 2010). For instance, large building spaces such as airports, railway stations, libraries, gymnasiums, and exhibition halls (Shi et al., 2009a) have large capacities and long and complex pedestrian routes. Due to the spatial conditions of these large open buildings, smoke may influence the evacuation direction and cause delays in the evacuation time, especially in the case of a fire. For this reason, the research field has been extended, and multiple-factor models have been developed based on basic research on evacuation time and human behaviour mentioned above (Kobes et al., 2010; Pu and Zlatanova, 2005; Pereira et al., 2013). Zheng reviewed the basic models for evacuation simulations (Fang et al., 2011), including cellular automaton (CA) models, lattice gas models, social force models, fluid-dynamic models, agent-based models, game theory models, and models based on animal experiments, as the basis for evacuation simulations. The connection between the environment and evacuation has been considered in these models.

Jeon and Hong (2009) and Kobes (2010) studied human movement when visibility is decreased in evacuation experiments. Further research has found that sound plays an important role in the evacuation process. Bryan (2002) found that acoustic signals indicate danger, especially in a fire situation. Bruck discussed the influence of 13 factors on responsiveness during sleep and proposed consideration of the situation, sound pressure level and frequency in the installation of fire alarms (Bruck, 2001). Ramachandran (1991) proposed that a high-frequency alarm tone notably reduces pre-evacuation time. Previous research has considered environmental information, uncertainties in evacuation time (Jeon and Hong, 2009; Kobes, 2010), and the choice of route and human behaviour under voice guidance (Bryan, 2002; Bruck, 2001; Ramachandran, 1991). However, further studies are necessary to address uncertainties by introducing additional influential factors into the evacuation model.

The aim of this paper is to develop a method to simulate a crowd's evacuation process in large indoor spaces and to propose the integration of a voice warning system (VWS) into emergency systems. The paper first develops a numerical simulation model, the cellular automaton crowd route choice model (CACR model) based on the CA model, to describe a crowd's evacuation process. It then explores each variable used in the model, including some indefinite variables that are determined by evacuation experiments and sound-field tests. Experimental data from an observation experiment are used to validate the CACR model.

2. Numerical simulation model

In this section, the CA model is chosen as the original model in which each cell evolves according to the way it interacts with its neighbours. Some rules have been reset, and the model has been extended. The CACR model has been developed as follows. First, according to the operating rules of the CA model, the influence of static and dynamic information attraction on the crowd's route choice is added. Second, the numerical simulation model is developed. Finally, the model and each variable are explained. Some key variables are discussed along with the experiments in Section 3.

2.1. Basic model

Many models have been developed to provide designers with ways of forecasting evacuation times for buildings (Fang et al., 2011). Based on dynamics theory, the evacuation process is described as a process in which the actions of agent objects are influenced by various factors as time progresses. A numerical model and certain rules simulate the different behaviours and features of an individual in the evacuation process. The building plan can be divided into uniform grids. Each grid is occupied by a wall, another obstacle, a human, or is free (Shi et al., 2009b). The CACR model, which is an agent-based evacuation simulation program, was developed based on one of the microscopic models, the CA model, which includes the spatial environment. The CACR model utilizes the CA model to synchronously update static and dynamic information at all times (e.g., visibility, voice commands).

Models for simulation can be classified into two categories: macroscopic and microscopic. Macroscopic models focus on people and the building as a whole system, whereas microscopic models study the behaviour and decisions of individual people and their interaction with other people in crowds. Macroscopic models include regression models (Milazzo et al., 1998), route choice models (Lovas, 1994), queuing models (Hoogendoorn and Bovy, 2003), and gas-kinetics models (Henderson, 1971). Microscopic models include social forces (particle systems) (Helbing et al., 2000), rule-based models (Wolfgram, 1983), and cellular automata models (Nuria and Ali, 2008).

Because microscopic models can consider the behaviour and decisions of individual people within the models, they are commonly used to simulate crowd evacuations. The crowd's route choice model in this paper requires one basis model from these microscopic models. The main difference between the microscopic models is whether they treat the space as continuous (social forces and rule-based) or discrete (CA). Social forces and rule-based models are used for multiple-spatial buildings, whereas a CA model is used for simple spatial buildings. Thus, to simulate evacuation in large indoor spaces, the CA model has been chosen.

2.2. CACR model

Based on the fundamental rules of the CA model, it is assumed that each person has a $0.4 \times 0.4\,m^2$ space, which is the typical spatial distribution in public crowded spaces (Burstedde et al., 2001). The location of a person is expressed in terms of rows and columns (i,j). Each cell contains one person who can move only one cell adjacently in one time step. A building plan can be represented as an