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Modelling subgroup behaviour in crowd dynamics DEM simulation

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ABSTRACT

This paper investigates the behaviour of subgroups in crowd dynamics by means of filming and observation. An existing crowd modelling program, CrowdDMX, based on a discrete element model (DEM) has been modified on the basis of observations made in this paper and literature. Each person is represented as three overlapping circles and motion is modelled in a Newtonian manner. It incorporates psychological forces as well as physical forces in a 2D time-stepping environment. The DEM model was modified to include realistic subgroup behaviour, representing people in the crowd desiring to stay together (families, friends, etc.). Subgroup psychological forces were incorporated. The previous model only simulated individuals moving independently, which was unrealistic in some situations as shown by the observation and filming part of the study. The revised program models subgroups realistically including the tendency to avoid subgroup division in cases of contra-flow.

1. Introduction

1.1. Requirement for crowd dynamic simulation

Crowd dynamic simulation includes the modelling of crowd movements and their interaction with the people around them and the physical environment. The issue of crowd dynamics is important for the safe design of venues where crowd management is a major issue. Such venues include large stadiums, theatres, railway stations, subways and other places where effective positioning of entry and exit points is required. Crowd simulation models help in effective prediction of potential crowd hazards in critical situations and thus help in reducing fatalities.

In recent years there have been many crowd related tragedies [1,2]. For example in India in 2005, 258 people lost their lives during a crush at a Hindu religious festival; and in 1986, 96 people were killed at a crowd crush at a football match at Hillsborough Stadium in Sheffield, UK. A different example is a laptop sale at a race course in Richmond, Virginia, USA in August 2005, when used Apple notebooks were on sale for a vastly reduced price. An estimated 5500 people attended, and a 'violent stampede' ensued as individuals rushed to get through the entrance [3]. Such disasters could be avoided or losses reduced by using crowd simulation models. The growing terrorist threat also increases the risk of a crowd tragedy. Thus it is important to enhance the accuracy and prediction capability of such simulation models.

1.2. Crowd psychology

The most effective studies into crowd behaviour incorporate both psychology and engineering. An appropriate approach is that of environmental psychology, where the relationship between people, physical and social settings are considered [4].

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Perhaps the most influential work in this field is that of Fruin [5], which examines the relationship between such factors as space per person, speed of movement, flow, and social acceptability. By applying to pedestrian movement the 'level-of-service' concept used in highway engineering, Fruin's approach specifies the degree to which individuals within a crowd are able to move at different speeds and in different directions to those around them.

More recently, Cooper et al. [6] suggest that there are three governing psychological factors which influence crowd movement. The first is that each person is trying to reach a specific geographical goal. The second is that people will walk at a maximum speed dependent on certain environmental conditions. The third is that a discomfort zone exists; this means that if all things were equal then someone would rather be at one point over another. This can also be thought of as personal space. These three factors all interact with each other to determine the path a person in a crowd will take when considering how to reach their desired position. Once these and other factors governing the crowd behaviour – including leadership, emotional intensity and collective unity of purpose [7] – have been established, the crowd's behaviour can be anticipated. Both individual and collective human behaviour can be predicted, as it is largely rational and goal orientated; and as time evolves a hierarchy of goals is formed and these influence the decisions that the person will make. It is for this reason that crowds can be modelled using rational computer programming [1].

The typical approach towards studying crowds conceives them as a collection of individuals who are undergoing some common experience [8] but does not always consider smaller subgroups of people within the crowd. However, the issue of groups within a crowd has not been totally overlooked by social scientists, who recognize that a 'physical' crowd may be made up of more than one 'psychological' crowd or group [9–11]. However, this observation has played a relatively small part in the modelling of crowd dynamics. If people interact with a crowd as part of a group rather than as individuals, then it may be appropriate to extend crowd analysis beyond the inter-individual level. Aveni [12] conducted a study into the relevance of considering subgroups within a larger crowd by periodically interviewing members of the public attending an American football game. The findings of this study indicated that only a quarter of the people in this crowd were actually by themselves, thus showing that the majority were not isolated, anonymous individuals. More recent research across a range of types of crowd events has supported this finding. Thus it has been show that (a) many people in crowd events are known to each other rather than being anonymous [13]; (b) large crowds such as those at sports events are sometimes made up of opposing factions, who act and move collectively yet against other groups in the crowd as a whole [14]; and (c) the extent to which people in a crowd operate and behave as individuals versus in subgroups or collectively varies over time and place [15].

These observations clearly have implications for the modelling of crowd behaviour. Therefore in order to accurately simulate crowd movement through computer programming, two inter-related levels of analysis are required; one for individuals and one for groups.

1.3. Crowd dynamics simulation models

Zheng et al. review [16] current methods of modelling evacuation including cellula automata, fluid models, social forces and agent based (which includes discrete element). The models include aspects of group and individual behaviour. Jianyong et al. [17] combine a Computational Fluid Dynamics model of fire with an agent-based evacuation model and a case study was applied to an indoor stadium used in the Beijing Olympics. They indicate that group characteristics are one of the issues that affect evacuation. Fang et al. [18] observed crowd behaviour at a railway station in China. They conclude that the crowd speed is primarily a function of front-back inter person spacing and individual motivation. Spieser and Davison [19] apply control theory to show how authoritative figures interspersed in a queuing crowd can stabilise the crowd given good communication between the controlling agents. Deere et al. [20] gives general information of a model maritimeEXODUS to assess the impact of human factors in ship design. It incorporates a number of sub-models such as hazard and movement, the most complex one is on behaviour which incorporates reaction to communication and affiliative behaviour. It uses a concept of "genes" to model social relationships, group behaviour and hierarchical structures. The group members are identified through the sharing of social "genes". Gwynne et al. [21] compares buildingEXODUS predictions with data from large building evacuation trials. Both qualitative and quantitative agreement was obtained. It highlights that many crowd models lack detailed validation data. Likewise Galea [22] has argued that, for greater realism in modelling, more observational and interview data on group behaviour within crowds is necessary. Moore et al. [23] investigate the effect of alcohol on behaviour, aided by a particle-model of crowds. Their simulations are consistent with the idea that alcohol disrupts affiliative behaviour shown by less structure in crowd flow, but also concludes more field data is required. Details of two major UK crowd dynamics simulation packages are available on the web [24,25].

One engineering approach to crowd dynamics is to model people in a "particle-like" manner, paying less attention to the psychological and social interaction between individuals [4]. In real life movement of individuals within a crowd is often dictated by the movements of the group as a whole. This collective motion of many people displays similarities to Newtonian particles such as phase transitions, cluster formation and occurrence of domain walls [26]. Due to this, several attempts have been made to model crowds as fluids on a macroscopic scale [27,28]. Fluid flow is determined by physical forces whereas crowds do not necessarily satisfy Newton's third law (i.e. the law of action and reaction) as they are also influenced by psychological factors. Therefore these methods are insufficient in situations concerning multiple groups and contra-flow. A preferred method therefore is to use a microscopic approach which models each individual, such as the Discrete Element Method (DEM).