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An FPGA implemented cellular automaton crowd evacuation model inspired by the electrostatic-induced potential fields

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ABSTRACT

This paper studies the on-chip realisation of a dynamic model proposed to simulate crowd behaviour, originated from electrostatic-induced potential fields. It is based on cellular automata (CA), thus taking advantage of their inherent ability to represent sufficiently phenomena of arbitrary complexity and, additionally, to be simulated precisely by digital computers. The model combines electrostatic-induced potential fields to incorporate flexibility in the movement of pedestrians. It primarily calculates distances in an obstacle filled space based on the Euclidean metric. Furthermore, it adopts a computationally fast and efficient method to overcome trouble-inducing obstacles by shifting the moving mechanism to a potential field method based on Manhattan-distance. The hardware implementation of the model is based on FPGA logic. Initialisation of the dedicated processor takes place in collaboration with a detecting and tracking algorithm supported by cameras. The instant response of the processor provides the location of pedestrians around exits. Hardware implementation exploits the prominent feature of parallelism that CA structures inherently possess in contrast to the serial computers, thus accelerating the response of the model. Furthermore, FPGA implementation of the model is advantageous in terms of low-cost, high-speed, compactness and portability features. Finally, the processor could be used as a part of an embedded, real-time, decision support system, aiming at the efficient guidance of crowd in cases of mass egress.

1. Introduction

In recent years, the research community has put significant efforts on the issues of crowd evacuation, presenting and updating sophisticated models that try to approach mass egress effectively. The cost in such circumstances, often severe enough and measured even in human lives, underlines the importance of consistent pursuit of theoretical as well as applicable solutions in the area of crowd evacuation. Circumstantial studies in literature prove that people under panic tend to lose their individuality, display herding behaviour and fail to use means of emergent evacuation effectively [1]. In a crowded environment, it has been observed that most injuries or losses are brought about by abrupt behaviours of the crowd, rather than the actual cause of the disaster [2]. Such behaviours, also called "non-adaptive" [3], refer to the destructive actions that a crowd may experience during a disaster, such as stampede, pushing others out of the way, knocking others down, and trampling on others.

The traditional approach of motion prediction applied to large crowds of pedestrians was based on modelling of the crowd as a continuous homogeneous mass that behaves like a fluid flowing along corridors. Fluid analogies contradict with some observed crowd behaviours, such as herding behaviour, multi-directional flow and uneven crowd density distribution. A fluid particle cannot experience fear or panic, cannot have a preferred direction of motion, cannot make decisions and cannot stumble or fall [4]. Even particle analogies to crowd seem to share same disadvantages [5]. Recent approaches, enhanced by modern computer power, suggest that the crowd consists of discrete individuals able to react with their surroundings.

Particularly, Lightfoot and Milne [6] present a model of crowd behaviour based on CA where the direction of movement is determined by a potential field technique similar to that used in robot path planning applications. The potential field is generated by a recursive flooding method, which gives an approximation to the shortest Euclidean distance between an exit to any point in the environment. Sarmady et al. have recently presented an interesting work in the area of pedestrian modelling, developing a basic multi-layer multi-agent model of human movement process, which can be parameterised in various ways to produce more realistic simulations [7]. A CA model is used to simulate small scale movements. The latter is a variation of least effort movement model using CA, which has also been modified and enriched in order to successfully support the effect of the groups [8]. An up-bottom approach is adopted in order pedestrian movement to be simulated. Assuming

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that pedestrians try to maintain a circular path, the CA algorithm tries to maintain this circular macroscopic path while performing collision avoidance and best cell selection in microscopic level. Moreover, Jiang Li-jun et al. [9] present a multi-parameterised model that simulates efficiently crowd evacuation for large stadiums. They use a 2.5-dimension CA, by attaching altitude attribute of the stadium terrain to each cell, which is used to describe the height of the cellular grid in 3D, while each cell dominates just 2D space. The simulation is agent-based, meaning that there are types of agents. There are objective factors that impact agent's motion, like space availability, altitude, exit target distance and direction and space type. There are also subjective factors such as physical status and psychological situation that affect agents' reaction.

The model developed is a CA-based system, where crowd movement simulation is approached in a bottom-up way, defining the local rule of pedestrian's interaction with her/his close neighbourhood and allowing the macroscopical behaviour to emerge. CA background enables the model to make use of powerful and sophisticated computation techniques for the development of useful modelling tools [10–12]. Consequently, it is a matrix-based system that discretises a floor area into CA cells. They may represent a free floor area, an obstacle, an area occupied by people, or a region with other attributes. Each cell is equivalent to the minimum area, which a person would occupy; in the proposed model the cell size was set to be 0.4 m $\times$ 0.4 m [13]. Rules define transition of people from cell to cell towards the final goal. Simultaneously, it is inherently an emergent system, the fundamental concept of which is that the interactions among simple parts can simulate complex phenomena such as crowd dynamics [14]. CA can sufficiently represent phenomena of arbitrary complexity and at the same time can be precisely simulated by digital computers, because of their intrinsic discreteness [15]. Furthermore, distinct phenomena of crowd evacuation captured by the panic model of Helbing et al. [16], exist to the presented model as well; clogging in front of exits, crowd transition to incoordination due to clogging, people queuing or developing herding behaviour, i.e. following the behaviour of other people (Fig. 1). In some extent, the computational model simplifies the behavioural representation of individuals, by employing one decision rule (based on assumption of the least effort) to represent the complex nature of individual behaviours. Furthermore, all individuals are considered to be the same in terms of size, mobility, sex, age and decision-making process. Palmer and Bailey [17] argued that the pedestrian velocities (in an undisturbed situation) can be considered as a normal distribution; furthermore, the average velocities of male and female pedestrians in the age group 30–50 years were considered to fit into the linear regressions $(1.5637–0.806x)\text{ms}^{-1}$ and $(1.4334–0.806x)\text{ms}^{-1}$ respectively, with a linear scale x between -1 (for age = 30) and 1 (for age = 50). An estimate of the average velocity would be 1.5 ms^{-1}, accordingly. Each cell of the CA grid stores simple values representing the state of its location. This simplicity is the inherent advantage of CA.

The theoretical background of the model issues from an electrostatic-induced potential field, which is generated by charges at selected positions and provides the essential knowledge of the whole route. The generation of the virtual potential field is explained from a physics point of view. Negative charges are placed at exit points and generate attractive forces upon pedestrians and positive charges are placed where obstacles and walls exist and generate repelling forces upon them. For every position in the space there is a direction that provides a route to the exit. Occupants attempt to lower their potential, i.e. to reduce the distance from the target, with every step or grid cell they travel to. The model calculates the exact Euclidean distance between the destination and the pedestrian, thus allowing more precise movements and smoother changes of direction. Motion mechanism arises from the gradient of the distance toward a destination [18].

As referred to Khatib [19], in robotics the artificial potential at a certain position from the destination can lead to a potential, where local minima can occur and a robot has to be equipped with the ability to realise it is in a minimum and how to get out of it. The model encounters successfully the existence of obstacles that cause such irregularities in potential fields, thus extending flexibility in the movement of pedestrians. It adopts an efficient method to overcome trouble-inducing obstacles by shifting the moving mechanism to a potential field method based on Manhattan-distance.

Finally, the model is orientated as a real-time processing module of an embedded system that could prevent clogging in exits under emergency conditions. More specifically, the initialisation process could be originated along with a detecting and tracking algorithm supported by cameras and the automatic response of the processor provides the location of pedestrians around escape points. Consequently, the realisation of the model becomes a rational additional step. Moreover, in terms of circuit design and layout, ease of mask generation, silicon-area utilisation and maximisation of achievable clock speed CA are perhaps the compu-

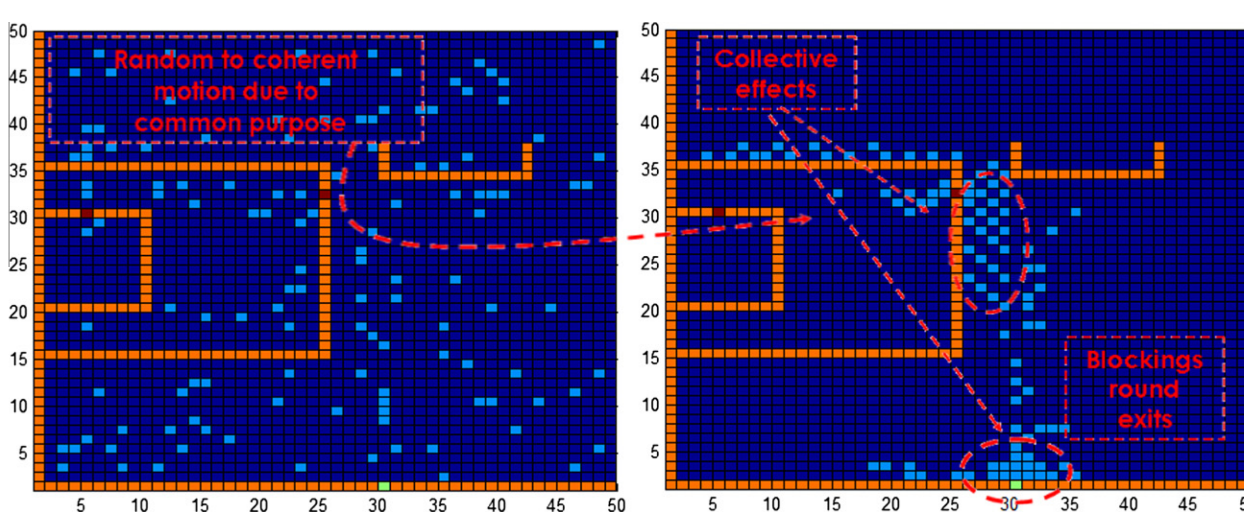

Fig. 1. Distinct features of evacuation process.