

## LifeBelt: Silent Directional Guidance for Crowd Evacuation

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**Abstract**— The effectiveness of an evacuation process in an emergency situation is heavily dependent on the understanding of the dynamics of crowds. Evidence has been delivered supporting the hypothesis that crowd behavior is self referential in the sense that movement patterns of individuals constitutes crowd movement, which in turn impacts the behavior of individuals. In this paper we build on this evidence and propose a belt like wearable device for vibro tactile directional guidance, LifeBelt, to notify individuals in panic about exits. To assess the potential improvement in evacuation efficiency when using the LifeBelt instead of when not, we empirically analyze the behavior of individuals in panic on the microscopic level, and parameterize large scale simulations (of up to 2000 individuals) with this evidence on the macroscopic level. Simulations show that LifeBelt based guidance can damp panic growth and increase the number of successful evacuations per unit time.

### I. CROWD EVACUATION

A large number of people (and/or things) considered together is often referred to as a crowd [1]. The notion of togetherness is related with physical space shared by the members of a crowd. An area confining a crowd can be a building, a sports arena, an underground sub-station or even a street. In case of an emergency or critical situation, the sense of confinement creates a state of mental discomfort for the members of a crowd. In addition, physical pressure built due to difficulty in occupying a place or free movement, creates a state of physical impatience. In combination, both these states may lead some of the members in the crowd to panic, thus creating potentially an even more dangerous situation within a emergency situation. To avoid such a situation, it is desirable to direct the crowd towards safe exit(s) as fast and as calmly as possible. This process is generally termed evacuation process, which can be defined as the escape from an area due to a real or potential threat [2].

The success of an evacuation process is dependent on precise behavioral studies related with individuals and groups. But understanding crowd dynamics in emergency situations is a difficult task due to variety of internal and external factors. Internal factors point towards psychological, physical and social attributes of individuals constituting a crowd, and effects due to dynamics of activities in local neighborhood of an individual. External factors include placement and level of threat(s), already damaged region(s) and the geometry of the confinement area, to name a few. All these factors (internal and external) contribute to collective effects which need to be considered when designing an evacuation system. Most important collective effects are jamming, density waves, lane formation, oscillations at

bottlenecks, patterns at intersections and phenomenon of panic (see [2] for more detail). In addition to collective effects, the interaction among individuals results in formation of group primitives, namely collision avoidance, following, dispersion, aggregation, homing, flocking and togetherness (see [3] for more detail). Though knowledge about the neighborhood is a building block upon which group primitives are built, still neighborhood dynamics are different from group primitives. Finally, there is a definite linkage between types of crowds, group primitives and collective crowd effects, which in our view, has not caught much attention from research community, primarily due to its complexity [4]. In this paper we approach these interrelationships via crowd modeling and simulation.

Crowd behavior models used in simulation can be classified into two broadly categories: macroscopic and microscopic. Macroscopic models focus on dynamics of crowd at coarser scale, where individuals are not distinguished from each other. Instead collective attributes are measured and examined. Crowd densities and average velocities at different regions are typical examples of these measures. Microscopic models focus on attributes of individuals and their interactions in their local neighborhood. Individual choices to avoid collisions, local congestion and individual's emotions are typical example of these attributes. There is little doubt in importance of dynamics emerging at local level as a result of interaction of individuals in proximity. Humans, in general as well as specifically engaged in an evacuation situation, are always more affected by incidences happening in local environment, even if they are informed about the global situation.

As opposed to the traditional approach for collecting empirical evidence (videotaping real or trial evacuations can be examined to extract behavior of crowd at the macroscopic level), we therefore propose to collect "local behavior" using a wearable evacuation device, which at the same time serves as a navigation device to support the evacuation process. A belt like device is proposed, capable of recording interactions, actions and emotions at microscopic level, while at the same time guiding him towards the nearest exit. Towards this end, we propose a congestion avoidance mechanism in conjunction with directed motion. The mechanism is based on sensing the neighborhood for a variety of ranges (distances) and relative orientations (angles). The mechanism calculates the optimal site that an individual should move to based on relative congestion in regions around him. We have particularly focused on maintaining positive perception of person (wearing the device) about his progress. The key is to keep him moving to decrease the panic. In situations with restricted sight,

(smoke, darkness, etc.) this is a realistic strategy. The device in question is considered to have following capabilities: (i) capability to sense the neighborhood, (ii) capability to extract the relative spatial relations (distance and orientation) of all neighbors, and (iii) the capability to interface (interact) with the person wearing it in a natural and strictly personal way.

The rest of the paper is organized as follows. In Section II, we have examined the simulation techniques for crowd evacuation. The outlook of silent assisting device is presented in Section III. Section IV is concerned with the details of evacuation model we are proposing. Section V is devoted to details of simulation and results. With Section VI, we conclude the paper.

## II. EVACUATION SIMULATION TECHNIQUES

Among the most practical crowd evacuation simulation techniques addressed in the literature –besides others– are cellular automata (CA), and fluid dynamics (FD). CA models are rule-based dynamical models which are essentially microscopic in scale. A CA model is based on regular grid of cells in which each cell is occupied by a single individual. The space and local rules in combination, describe the next cells an individual needs to occupy at each time stamp. Space rules are based on states of cells around a cell whereas local rules are based on individuals' characteristics in neighborhood. Usually the success of model depends on the adequacy of the determination for each next step. This means that individuals are tied with strict rules and cannot possess any freedom. They can only move to a nearby cell based on transition probabilities based on three factors: (i) direction of motion (e.g. shortest path towards an exit), (ii) interactions with other individuals, and (iii) interactions with the structure of confinement area (e.g. obstacles, walls etc.). FD models are typically macroscopic, deterministic and force-based. These models use laws of fluid dynamics to govern the flow of crowd. A thorough comparison of these modeling approaches is provided by authors in [5]. Since in our case (as we have already stated in introductory section), microscopic interactions are more valuable than macroscopic ones, hence FD models are clearly not a choice considered. Moreover, the purpose of our research is not to study the effects of complex physical forces between individuals. Here we intend to build a case which favors the use of assisting devices, able to record interactions and make definite decisions based on commutative state of proximity. Therefore, a simple CA model suffices our purpose.

## III. LIFE BELT

The development of our LifeBelt [6] vibro-tactile wearable notification system was motivated by the threat of overseeing or overhearing in situations when human senses are exposed to an overload of visual and auditory stimulation, such as in disaster situations. Whenever eyes, ears and maybe also hands are in charge, human attention is hard to raise beyond the effective engagement concerned with this charge. A subtle, yet effective channel of communication in such situations is the stimulation of tactile

perception. Empirical evidence has been delivered, that tactile stimulation can raise attention in an un-obstructive, yet demanding manner. LifeBelt exploits the variation of vibro-tactile stimuli (such as intensity, duration, frequency) to indicate both orientation as well as directional guidance through factor-elements embedded into a hip worn belt. The fully functional LifeBelt system is shown in Fig. 1(a).



Figure 1. (a). LifeBelt with embedded vibra elements.

Eight vibrator elements, are lined up in the fabric of a hip belt, and connected to the belt controller shown in Fig. 1(b). The controller is built upon an Atmega32-based microcontroller board, and activates the vibrator switches according to commands received wirelessly from a global control unit, in this case a global evacuation control unit.

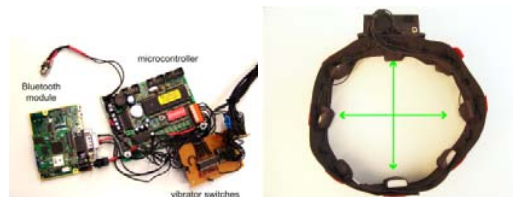


Figure 1. (b). Microcontroller, Vibra-Element Array

The LifeBelt basically serves two purposes. (i) it indicates the direction (as recommended by the evacuation control unit) towards the optimal exit for each and every individual by triggering vibrations on those vibrators in the belt that head to the recommended exit. (ii) Additionally, it assists individuals in taking local next step decisions by sensing the neighborhood for a variety of ranges (distances) and relative orientations (angles) towards the recommended exit, and indicates potential hazards, threats or sources of danger, again by predefined vibration patterns. In summary, LifeBelt (see Fig. 1(c)) comprises the (i) capability to sense the neighborhood, (ii) capability to extract the relative spatial relations (distance and orientation) of all neighbors, (iii) the capability to interface with a back-end system (evacuation control unit), and (iv) the capability to interact with the person wearing it in a natural and un-obstructive way.



Figure 1. (c). The LifeBelt for Vibrotactile Guidance

#### IV. A LIFEBELT BASED EVACUATION MODEL

To assess crowd evacuation based on our LifeBelt technology, we have considered a subway station scenario. Given a single exit which each individual within the crowd has to reach for escape, we are interested in two efficiency indicators for the evacuation: (i) the time needed to evacuate the whole population and (ii) the aggregate value of panic (a well established evacuation efficiency parameter). We consider a complete breakdown of infrastructure resulting in complete darkness, but due to the LifeBelt technology, still each individual knows the direction of to the exit at each time stamp.

Quite a few research efforts have considered evacuation in situations without visibility. Authors in [7] have studied the evacuation process from a smoky room validating experimental results with a simulation. The following results are worth mentioning: (i) in an environment where there is no visibility, the population being evacuated experience a different behavior when compared with an environment where there is visibility, and (ii) there is no improvement in jamming situation in case of a dense crowd, even by adding more exits, since most people are diverted towards the exit which is discovered first, attracted by non local acoustic interaction. In [8], authors have studied statistical characteristics of evacuation without visibility for random walk model. As a navigation strategy, like in [7], a simple mechanism of navigating along a wall is considered. By continuously being in touch with the wall, individuals trust to find the exit. We consider the LifeBelt (and hence the person wearing the LifeBelt) to give directional awareness about the exit, but without having to move and to touch the reference system (wall). From the implementation point of view, each cell in CA model grid is provided with a variable which stores direction of motion at that cell directed towards single exit. The motivation of this mechanism is borrowed from a subset of CA models called floor field models. For example, in [9], authors have proposed a stochastic CA model based on floor field which acts as an assistant to human cognition.

##### A. Next Step Modelling

Floor field models describe individual behavior based on steps towards neighboring cells. To calculate the next cell to move to, authors in [10] have introduced a CA model based on square lattice. In this model, four possible values of orientation are considered, namely, 'up', 'down', 'left' and 'right'. Out of these four possibilities a source cell chooses a destination cell based on its direction of motion (DOM). Possible values of DOM are moving up, moving down, moving left and moving right. For example, Fig 2 shows eight possible configurations of an object moving up (the similar configurations can be drawn for object moving down, left or right). In Fig. 2, circles at the center of the cells represent presence of an individual; gray cells represent valid possibilities and central cell is where the individual making a decision is residing. In fact, instead of eight, there are 16 possible configurations for a single DOM. The other 8 (not shown in figure) are constituted by a replica of 8 with the cell 'below' the current cell (opposite to DOM) empty. In this way a cell (object on the cell) decides the next cell to move

to. In simple CA models, in case of square lattice, the preference is given to cell ahead, followed by cells at sides and then cell at back. In case of competition (e.g. Fig 2 (d)), the choice can be random or based on cultural preferences. In more complex CA models, the choice of next cell is based on required functions (e.g. collision and congestion avoidance) which require extended neighborhood information.

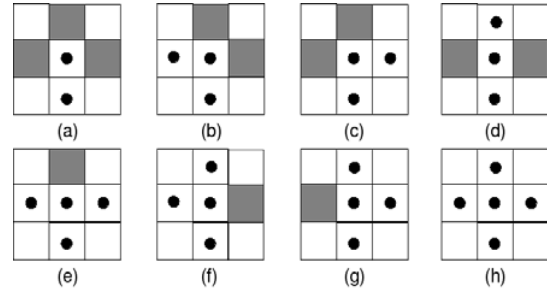


Figure 2. Possible configurations of an object moving up in a square lattice with cell below the cell at center blocked. Figure adopted from [10].

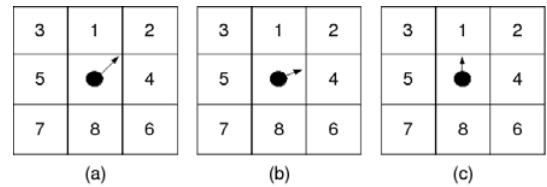


Figure 3. Examples of possible configurations in Moore's neighborhood.

As the basis of our model, we have extended the concept of neighborhood to gain a compatibility with the concept of neighborhood as implemented in the LifeBelt. To this end, instead of using von Neuman's model of neighborhood, we have used Moore's model of neighborhood [see [11] for more detail]. Figure 3 represents graphical view of extended neighborhood. In addition to using a complete neighborhood instead of a square lattice, we have also generalized the concept of DOM (which can be any angle between 0 and 359). A complete neighborhood adds following relations (orientations) to the set of front (up), back (down), right and left: front-right, front-left, back-right and back-left. Since having a DOM precisely normal (or even at exact diagonal) to a cell would be a rare event, the approach of our model is more realistic when compared with majority of CA models. We present a generalized mechanism of calculating the angular difference between DOM of current cell and that of eight possible angular drifts namely 0, 45, 90, 135, 180, -45, -90, and -135 degrees. However, to avoid repetition of a cell appearing in more than one angular relation, we make sure that an individual always occupies the center of a cell. Fig. 3 shows a few examples of possible configurations which are:

DOM = 45°, relations: front = 2, back = 7, right = 6, left = 3, front-right = 4, front-left = 1, back-right = 8, and back-left = 5. (b) DOM between 0° and 22.5°, relations: front = 4, back = 5, right = 8, left = 1, front-right = 6, front-left = 2, back-right = 7 and back-left = 3. (c) DOM = 0°, relations:

front = 1, back = 8, right = 4, left = 5, front-right = 2, front-left = 3, back-right = 6, and back-left = 7.

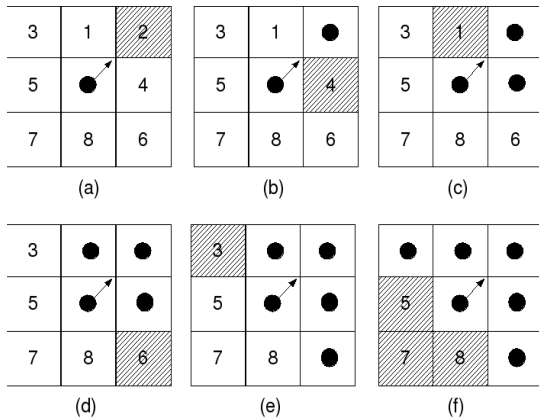


Figure 4. Possible configurations of an object moving at angle  $45^\circ$ . Black circles represent the cells occupied by an object. Cells hatched show the adopted choice.

Clearly we have more options available as next cell when compared with mechanism in [10]. For example in Fig. 3 (c), if only cell 8 is occupied, the next cell can be any of the remaining seven cells. We have devised following simple mechanism of choosing between the candidate cells taking motivation from [12]. The cell in front (at angle  $0^\circ$  relative to the current cell), if empty, would always have a preference on others followed by cells at angle  $\pm 45^\circ$  and then at angle  $\pm 90^\circ$ .

The preference given to right on left is motivated by the claim in [13] that in case of competition between right and left, the majority of people have a tendency to move towards right. The rest of the mechanism is simple and evident from Fig. 4.

In Fig. 4, we have shown a random choice between last three cells (5, 7 and 8) if none of the first five cells are available. It results in letting the individual move in a counterproductive (away from destination) way. But, it is not the strategy strictly followed all the time. Functional requirements (e.g. collision, congestion, and panic avoidance) heavily influence the strategy devised for choosing next cell to move to. The purpose of Fig. 4 is to introduce the strategy at basic level.

### B. Empirical Evidence for Next Steps

A well designed experiment was conducted to validate the strategy described in the previous subsection, involving a group of 30 individuals in a classroom setting. From the center of the room, individuals were instructed to rush towards one of the two possible exits. To avoid pre-planning, the target exit was chosen ad hoc. To mimic obstacles in the way (and keeping them safe from bumping into physical objects like tables and chairs), each individual was assigned one of the two disclosed roles; blocker and mover. The role of the blocker was to permanently occupy a position of his/her liking after he/she crosses a limit where permanent positioning is not allowed. The strategy was designed to ensure an initial move towards the exit hence avoiding jamming right from the beginning. The role of the mover was to evacuate as early as possible. We conducted three experiments with 10%, 25% and 50% blockers. Fig 5 shows screen shots of a video for experiment with 50% blockers.



Figure 5. Experimental Evaluation: Solid and Dashed arrows show next and previous orientation of individuals respectively. Blockers (permanent) are indicated by a cross, the rest is moving.

In Fig. 5 (a), we have highlighted two individuals with numbers (1 and 2). In initial phase of evacuation (up to 5 seconds), individual 1 and individual 2 moved towards exit in smooth way since places in forward (front, front-right, and front-left) direction were predominately vacant (situation in Fig. 4 (a, b, c)). As soon as blockers started effective blocking, both individuals were stuck. In Fig 5 (a), they are waiting in hope of clearance of jamming ahead. In Fig. 5 (b), individual 2 starts to look at other options after waiting for a while. He knows that his 'front' is blocked and he cannot move towards right side due to fence. Therefore he looks for an option using 'front-left' direction. Since 'front-left' is also not available, he finally moves towards 'left' (Fig. 5 (c), situation in Fig. 4 (e)), squeezing between stream of crowd already following an open corridor towards exit (shown with curved trajectory in fig. 5 (a)). Meanwhile individual 1 starts to panic after waiting for a long time. Interestingly, he starts moving in 'back-right' direction instead of 'back-left', not becoming part of crowd stream (Fig. 5 (d)). His choice of moving towards right is governed by region of his influence. Since his intend (moving forward towards exit) lets him focus on neighborhood (both close and near) relatively in 'forward' direction, he is not able to perceive any pattern 'near' him in backward direction. He finally finds a place to move 'close' to him, not perceiving a 'near' pattern in backward direction (Fig. 5 (e)). His choice of right instead of left must have cultural significance (situation in Fig. 4 (f) where cell 8 is preferred over cell 5). He follows same path as that of individual 2 afterwards. In contrast, individual 3 (introduced in Fig. 5 (d)) has a broader perception of what lies ahead. That is why he follows an optimal path throughout his journey.

The following conclusions are drawn from the experiment:

- (i) The mechanism of choosing the next place (cell) to move to as shown in Fig. 4 is validated.
- (ii) There is tendency that initially a person waits at his place if he is not able to move in forward direction. As soon as he realizes that waiting would not improve the situation, he tries to move sideways and then in backward direction to find another way.
- (iii) The tendency of preferring 'right' over 'left' is observed.
- (iv) A preemptive decision is dependent on levels of details in relatively forward direction. Knowing the surrounding at a larger scale helps avoiding jamming (or becoming part of a jammed crowd).

### C. Modeling Congestion Avoidance

As we have already mentioned that the strategy of choosing a cell to move to depends on congestion in the surrounding. Therefore an obvious choice (as depicted in Fig. 3 and Fig. 4) can be overruled keeping in view more congestion in that particular orientation. But to do so, information about extended neighborhood is required. Authors in [10] have introduced a concept of extended neighborhood in which a 3x3 grid is used around an object (cell) to assign relative probability of proceeding towards 'right', 'left', 'up' and 'down'. Fig. 6 (a) shows such a

configuration for an up moving object. As the number of occupied cells in a region increases, the probability of choosing one of the cells in orientation towards that region decreases.

In our case we are concerned with a complete neighborhood (not a square lattice). The numbers of hops constituting a neighborhood are decided by the capability of the device that reports a qualitative distance i.e. close (one-hop neighbors) and near (two-hop neighbors), hence a complete grid of 2x2. We show concept of relative 'front', 'back', 'right' and 'left' for the same configurations as that of Fig. 3 in Fig. 6 (b). It is evident that the choice between one of the two regions (left and right) is made by scanning cells at  $\pm 45$ ,  $\pm 90$ ,  $\pm 135$ ,  $\pm 62.5$ , and  $\pm 112.5$  degrees relative to the current DOM. In all three cases, cells colored black are cells lying in 'front', cells colored gray are cells representing 'right' and hatched cells are forming the 'left' of the cell residing at center. In congestion avoidance mechanism, we are not counting on congestion based in orientation opposite to DOM as evident from the Fig. 6 (b). Still in some cases a move to one of the cells in backward direction is made to avoid an increase in panic.

### D. Modeling Panic Avoidance

Panic occurs in situations when numerous people desperately crave for comparatively scarce resources which lead to unsocial and irrational behavior of individuals. Although many researchers deny existence of such a behavior, there is a definite likelihood of some kind of abnormal behavior (we call it panic here), particularly when people progressively know that they cannot escape [14]. In environments without visibility, the probability of occurrence of such a phenomena increases, if individuals start bumping into each other thus developing a perception that they are pushed to stick to an area and not progressing towards exit.

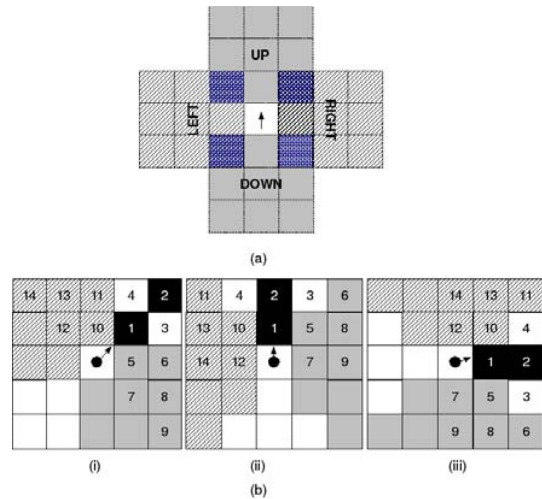


Figure 6. (a) 3\*3 regions in left, right, up and down surrounding an object, (b) possible configurations of relative right (gray region) and left (hatched region). Figure (a) adopted from [10].

One way of avoiding this situation is to perform congestion control. The other way is to maintain perception of an individual that he is progressing. One advantage of evacuation in dark is that as long as someone is moving, he perceives that the progress is being made. In mechanism discussed in the next section, we make sure that an individual does not occupy a single site too long. A step is taken as soon as there is a potential site around an individual in collaboration with congestion avoidance mechanism and next cell calculation.

### V. LARGE SCALE EVACUATION SIMULATION

We used netLogo [15] as simulation tool. The simulation environment is based on concept of patches which may contain turtles (agents) on top. A global space of 65x65 is considered for each experiment resulting in total of 4225 patches. A patch can accommodate a single agent and an agent is always occupying center of the patch. We performed simulation for 500, 1000 and 2000 agents which is a realistic choice considering total number of patches. All agents are moved towards an exit patch that serves as destination. We have performed two sets of simulations: one for exit at the center of the scene and the other for exit at the middle of one of the four walls. While proceeding towards destination, an agent can be in one of the three states; (1) 'happy' if its last move was successful, (2) 'wait' if last few moves were not successful but the patience level is not exceeded, and (3) 'panic' if in state of wait for so long that patience level has exceeded (typically a wait for 3 consecutive iterations). As soon as an agent has performed a successfully move, its state is changed to 'happy' irrespective of the state it had previously. The algorithm is implemented in an incremental way (case 1 to case 5), starting from basic strategy to more complex. The main purpose of the algorithm is to decide about the optimal choice of the next cell avoiding congestion and panic. The results are evaluated based on evacuation time and aggregate values of panic for different combinations of population density and cases.

Fig. 7 (a-e) explains main features of algorithm listed below.

Case 1: step 1 = If cell ahead is empty, instantaneously move to the cell. Otherwise apply step 2. Step 2 = Choose a random empty cell from remaining cells (indicated by partial square), but if and only if  $w$  (wait) is greater than  $p$  (patience). Else wait.

Case 2: similar to case 1 except that a cell relatively closer to the destination (front-right or front-left) is chosen in step 2 and 3. Random choice step degrades to step 4 applied to lesser number of cell.

Case 3: is further extension of case 2 in which cell at right or left is also considered if steps 2 and 3 fail. The choice of cell at  $\pm 90^\circ$  is a counter-productive choice, particularly when DOM is exactly diagonal to cell (as shown in Fig. 7). But in most of the cases (see Fig. 6-b (ii, iii)) this is a neutral choice. Individuals experiencing a jam always adopt a sideways movement in normal circumstances. Case 3 is a benchmark which can be considered as the normal human behavior without panic. This is the behavior that would most probably be adopted by an individual in dark, if

he is not wearing belt (probing forward and sideways with hands before making a move). On the contrary, case 4 and 5 can only be materialized in presence of belt.

Case 4: if steps 1 to 5 fail, a congestion avoidance mechanism is applied to choose between two candidate cells (indicated by thick dashed lines with double arrow head). Congestion avoidance mechanism is only applied if cell ahead of cell ahead is occupied by NOT a happy person (indicated by dashed elliptical line), and both comparative cells are empty. If one of them is empty, individual just moves to that cell. If both of them are occupied, individual moves to previous cell (in backward direction), if waiting has exceeded the patience level, otherwise he waits.

Case 5: is a special case of case 4 in which CAM is applied for each pair of comparative cells.

The congestion avoidance mechanism (CAM) is applied when there is a competition between cells.

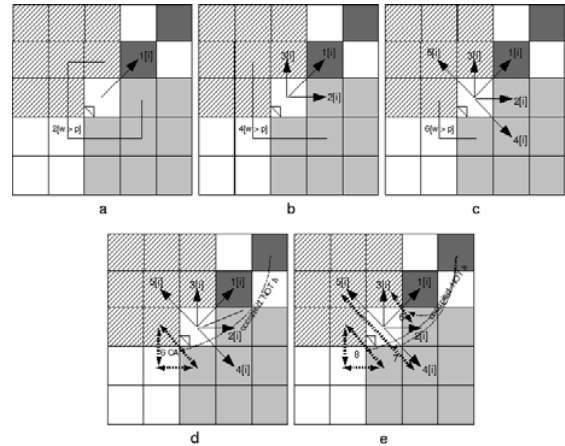


Figure 7. Algorithm. Arrow head of uni-directional lines point towards DOM. Each move is numbered describing its sequence in algorithm. (a) Case 1, (b) Case 2, (c) Case 3, (d) Case 4, (e) Case 5.

For example in Fig. 7 (e), if both back-right and back-left cells of source cell are vacant, a choice between two is based on comparison of number of occupied cells in right and left directions. Whoever has less number of cells occupied wins the race.

In Fig. 8, we have elaborated the algorithm with the help of an example. The example shows that in the case an individual cannot take the next step, e.g. due to the occupation of the cell by another individual, the following decisions are made. In case 1 and 2, the choice between right, left, back-right and back-left is random (indicated by transparent background). In case 3 and 4, the choice 'right' is a strict choice (indicated by black background) - as a result of the preference of right over left. In case 4 no CAM is applied, since it is only intended to resolve conflicts among back-right and back-left cells. In case 5, since CAM is applied on each competitive choice, the cell at 'left' is chosen because there is less congestion towards left as compared to right.

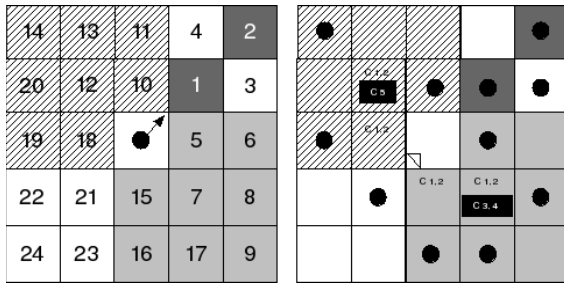


Figure 8. Left: Possible configurations of relative right (gray region) and left (hatched region) for direction of motion 45 degrees. Right: Algorithm Applied.

All experiments were run for 50 times with random placements of 500, 1000 and 2000 individuals, in order to assess the following measures:

1. the number of iterations required for evacuation is equal to the number of ticks required to evacuate 100% of the individuals, averaged against 50 runs.
2. the aggregated panic state is the aggregate count of appearance of individuals in the state of panic, averaged for 50 readings, divided by the number of individuals.
3. the longest panic chain is the longest sequence of an individual residing in the state of panic consecutively, averaged for 50 readings and divided by the number of individuals.

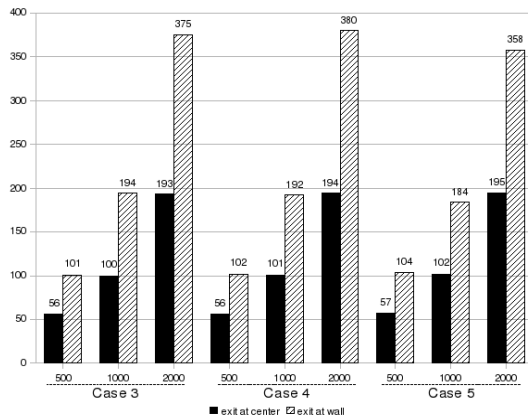


Figure 9. No. of Iterations required for evacuation

In Fig. 9 the number of iterations required to evacuate (in terms of time stamps) are shown for case 3-5. For the exit being at the center of the floor, from case 3 to 5, the number of iterations required for evacuation is more or less the same. For the exit located at the side wall, there is a drop in evacuation time (up to 6%), particularly in more congested situations. In Fig. 10, the aggregated panic is shown. For the exit being in the center, there is certainly a drop from case 3 to 4 which is not evident from case 4 to 5. But for the exit at the side wall, a drop of 12% is observed (500). Fig. 11, shows the longest panic chain. There is a general trend of decrease from case 3 to 5.

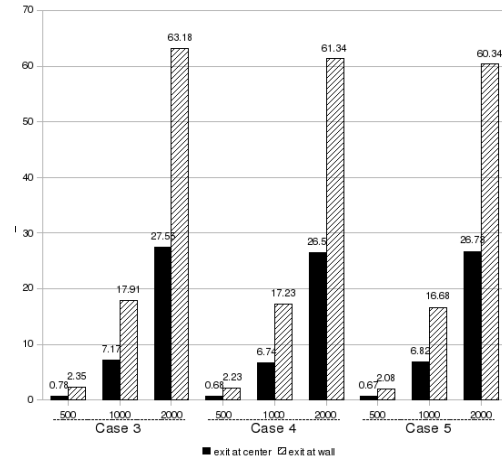


Figure 10. Aggregated panic

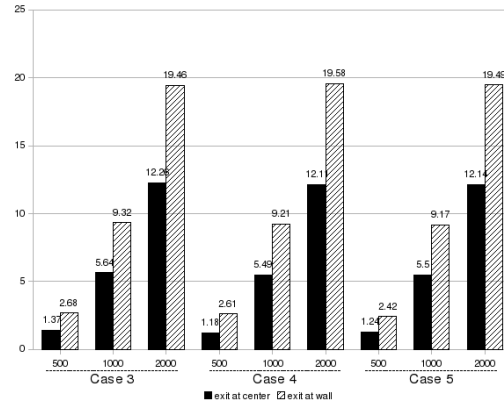


TABLE I  
COMPLETE DATA OF SCENARIO CENTER EXIT.

Case	Panic at t=25	%age saved t=25	Panic chain Len	$\Delta t$	Total panic	Total PCL
3	40	40	0.012	56	361	1.24
4	18	42	0	56	315	1.09
5	43	38	0.04	57	338	1.20

TABLE II  
COMPLETE DATA OF SCENARIO CENTER EXIT.

Case	Panic at t=25	%age saved t=25	Panic chain Len	$\Delta t$	Total panic	Total PCL
3	40	40	0.012	56	361	1.24
4	18	42	0	56	315	1.09
5	43	38	0.04	57	338	1.20

Figure 11. Longest panic chain

A comparison, finally, reflecting the impact of the exit location (center in Fig 12, side wall in Fig 13, see also Table

II and Table II) onto panic growth indicates a dramatic increase for the side exit case. As the panic chain drops (in all cases) with center exits, the panic growth can ultimately controlled with the right exit planning.

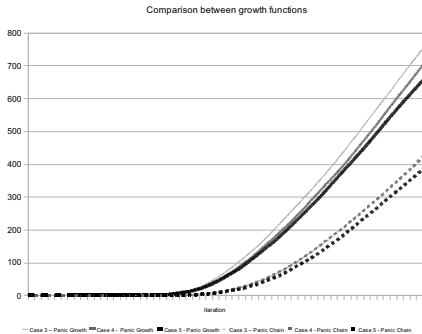


Figure 12. 500 individuals, center exit

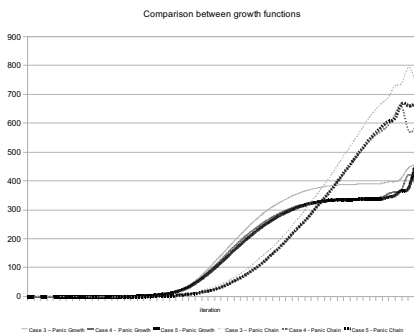


Figure 13. 500 individuals, side exit

## VI. CONCLUSIONS

Supportive means to improve the effectiveness of emergency evacuations is of outstanding importance as far as the safety of buildings or the management of events is concerned. Aside pure organizational (e.g. evacuation plans) and structural measures (e.g. exit planning) of evacuation efficiency, also measures related to the individual itself appear as potentially effective means to raise efficiency.

This paper proposes to use wearable computers as a direct measure of improving individual safety in evacuation situations. A wearable device, LifeBelt, has been developed for guiding individuals from emergency situations to escape. LifeBelt as a cooperative wearable device collects position and orientation information about individuals from embedded sensors, shares this information with a background emergency coordination systems, receives an individualized optimized path plan (e.g. the way towards the exit with the chance of earliest escape), and guides the individual via vibro-tactile stimulation, indicating direction and distance to the recommended exit. At the micro level, as a *personal life saver technology*, LifeBelt gives escape

guidance even in situation when eyes, ears and hands are in charge (as it is the case in most emergency situations). At the macro level, as a *crowd saver technology*, LifeBelt provably reduces the emergence of panic (and consequently the length of panic chains), and thus reduces the time to successful evacuation. Evidence is delivered for this finding based on the analysis of individual motion patterns represented as next step CA models, and the parameterization of large scale simulations with those models (evidence based simulation).

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## VII. REFERENCES

- [1] N. Pelechano, J. M. Allbeck, N. I. Badler - "Virtual Crowds: Methods, Simulation, and Control", Synthesis Lectures on Computer Graphics and Animation, 2008, Vol. 3, No. 1.
- [2] A. Schadschneider, W. Klingsch, H. Klöpfel, T. Kretz, C. Rogsch, and A. Seyfried, "Evacuation Dynamics: Empirical Results, Modeling and Applications", in Encyclopedia of Complexity and System Science, R. Meyers, ed. Springer, Berlin Heidelberg New York, 2009. 0802.1620.
- [3] M.J. Matarle. "Designing Emergent Behaviors: From Local Interactions to Collective Intelligence." In From Animals to Animats 2: Proceedings of the Second International Conference on Simulation of Adaptive Behavior. MIT Press, 1993.
- [4] MSA. Report on Exercise Invicta. Technical report, Marine Safety Agency, 1997. Available from MSA, 105 Commercial Road, Southampton.
- [5] X. Zheng, T. Zhonga and M. Liua, "Modeling crowd evacuation of a building based on seven methodological approaches", Building and Environment, Volume 44, Issue 3, March 2009, Pages 437-445.
- [6] A. Ferscha, et al. "Vibro-Tactile Space-Awareness", Video paper, adjunct proceedings of the 10th International Conference on Ubiquitous Computing (UbiComp 2008), Seoul, South Korea, September 2008.
- [7] M. Isobe, D. Helbing and T. Nagatani, "Experiment, theory, and simulation of the evacuation of a room without visibility", Phys. Rev. E 69 (2004), p. 066132.
- [8] T. Nagatani and R. Nagai, Statistical characteristics of evacuation without visibility in random walk model, Physica A 341 (2004), pp. 638-648.
- [9] C. Burstedde, K. Klauck, A. Schadschneider and J. Zittartz, Simulation of pedestrian dynamics using a two-dimensional cellular automaton, Physica A 295 (2001), pp. 507-525.
- [10] S. Maniccam, "Adaptive decentralized congestion avoidance in two-dimensional traffic" in Physica A: Statistical Mechanics and its Applications Volume 363, Issue 2, 1 May 2006, Pages 512-526.
- [11] T. Kretz and M. Schreckenberg, "Moore and more and symmetry", in Waldau et. al. [50], pp. 297-308.
- [12] K. Nishidate and M. Baba, "Cellular automaton model for random walkers", Phys. Rev. Lett. 77 (9), 1675-1678 (1996).
- [13] N. Pelechano, J. Allbeck and N. Badler, "Controlling individual agents in high-density crowd simulation" in ACM SIGGRAPH/Eurographics Symposium on Computer Animation (SCA) (2007).
- [14] T. S. Sharma, H. Yaping and M. Mahendran, "Lifts for emergency evacuation in apartment buildings", in: 9th International Symposium on Fire Safety Science, 21-26 September 2008, Karlsruhe, Germany.
- [15] <http://ccl.northwestern.edu/netlogo/>, accessed March 2009.