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Modelling the independence factor and its effect on the preferred force of the Social Force Model in emergency and non-emergency situations

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Representing the reality of the pedestrian route choice activity in both normal and evacuation situations has not been completely done due to some inaccuracies in representing the functionality of the independence factor that governs the preferred force. In addition, the limited options available to the pedestrians while they are in emergency situations are unrealistic. Hence, in this paper, we have introduced a brief demonstration of the factors that govern the preferred force. Then, we have modified the concept of the independence factor of pedestrians and subsequently modelled the effects of this factor on the pedestrian's decision-making while he is in motion. Lastly, we have introduced more features into the preferred force of the original Social Force Model to give the pedestrians more options and, in turn, make it appear more representative of what actually happens in reality.

Keywords: Social force model, preferred force, independence factor.

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1 Introduction

Within the last few years, researchers have developed several microscopic models to solve one of the most pressing environmental concerns relating crowd disasters. Prediction of pedestrian flows in extreme conditions such as evacuation is crucial in the investigation of crowd behavior. The evacuation process in emergency situations such as a fire in crowded buildings " [1, 2]" usually causes panic and tragic blocking situations. In this connection, a significant usefulness of microscopic models is the introduction of the real aspects of the interactions between the pedestrians and their physical environment, which, in turn, can be utilized to correct the undesirable ones. The Social Force Model which was introduced by "Helbing and Molnar [3]" has gone through many modifications " [4–7]".

One of which is the incorporation of the physical forces into the model. Moreover, the authors in " [5]" have taken advantage of such incorporation as a factor to validate their contributions to the model. However, the problem has not been treated sufficiently due to the shortage of incorporating the factors that enhance the pedestrian's ability in making decisions into the models in the case of an evacuation state. In the next section of this paper, we present a brief background of the social force model. In the third section, we present more details of the preferred force which has the main role in governing the pedestrian's velocity and direction. In the fourth section, we incorporate more factors into this force to provide the pedestrian with more intelligence and more options while he is fleeing. We carried out the simulation of the evacuation process to demonstrate the results of our work and finally, the conclusion is presented in the last section.

2 The Social Force Model

The interactions between a pedestrian and his environment, which consists of: 1) pedestrians; 2) physical environment; 3) repulsive and attractive sources (pedestrians or objects such as walls or columns); 4) intermediate targets and 5) destination, generate motivations inside the pedestrians and physical interactions such as pushing and friction. The Social Force Model is distinguished from the other microscopic models by modelling these motivations as forces. Namely, the motivation of pedestrian i to avoid an obstacle j such as a column, a wall or another pedestrian is modelled as a social repulsive force $\vec{f}_{ij}^{rep}$, the motivation to orient his direction toward a certain object j is modelled as a social attractive force$\vec{f}_{ij}^{att}$ and lastly the motivation to adapt his velocity to another velocity he prefers to move at is modelled as a driven force$\vec{f}^{pref}$. Similar to the physical forces, the social forces have magnitudes and directions " [3]"

$$\vec{f}_{ij}^{rep} = A^{rep} e^{(R_{ij} - d_{ij}(t))/B^{rep}} \vec{n}_{ij} \tag{2.1}$$

$$\vec{f}_{ij}^{att} = A^{att} e^{(R_{ij} - d_{ij}(t))/B^{att}} \vec{n}_{ij} \tag{2.2}$$

$$\vec{f}^{pref} = \gamma \left(\vec{v}_i^0 - \vec{v}_i \right) \tag{2.3}$$

where A^{rep}, B^{rep} are parameters representing the strength and the characteristic distance of the repulsive force, respectively; A^{att}, B^{att} have the same functions as the previous parameters but different values and A^{att} is negative; $\vec{n}_{ij}$ is the normalized vector which points from the object j to the pedestrian i; R_{ij}, d_{ij} are the sums of the radius of i and j and the distance between the centers of i and j respectively; $\vec{v}_i^0$ represents the velocity at which the pedestrian prefers to walk and $\vec{v}_i$ represents his actual velocity; $\gamma = m_i/\tau$ where m_i and τ represent the mass of the pedestrian i and the relaxation time respectively. In case j is a wall or the like:R_{ij}, d_{ij} are altered by R_{iw}, d_{iw} which represent the radius of i only and the shortest distance between i and the wall respectively. Modelling the interaction behavior such as pushing and the friction among pedestrians in contact, has been incorporated into the Social Force Model by " [4]" as physical forces

$$\vec{f}^{push} = k\eta\left(R_{ij} - d_{ij}\right)\vec{n}_{ij} \tag{2.4}$$

$$\vec{f}^{friction} = \kappa\eta\left(R_{ij} - d_{ij}\right)\Delta v_{ji}\vec{t}_{ij} \tag{2.5}$$

wherek, κ are constant parameters; $\eta\left(R_{ij} - d_{ij}\right)$ is equal to $\left(R_{ij} - d_{ij}\right)$ when $R_{ij} \geq d_{ij}$ and zero otherwise; $\vec{t}_{ij}$ is the tangential unit vector orthogonal to $\vec{n}_{ij}$; Δv_{ji} is the relative velocity between i and j and $\Delta v_{ji} = v_i$ in case j is a wall or the like. Using the additive property of vectors, the acceleration of the motion of pedestrian i is mathematically modelled by the following Newtonian equations:

$$\frac{d\vec{x}_i}{dt} = \vec{v}_i \tag{2.6}$$

$$m_i\frac{d\vec{v}_i}{dt} = \vec{f}_i + \epsilon_i = \vec{f}^{pref} + \sum_j \vec{f}_{ij} + \sum_{wall} \vec{f}_{i,wall} + \epsilon_i \tag{2.7}$$

$$\vec{f}_{ij} = \vec{f}_{ij}^{rep} + \vec{f}_{ij}^{att} + \vec{f}_{ij}^{push} + \vec{f}_{ij}^{friction} \tag{2.8}$$

$$\vec{f}_{i,wall} = \vec{f}_{i,wall}^{rep} + \vec{f}_{i,wall}^{att} + \vec{f}_{i,wall}^{push} + \vec{f}_{i,wall}^{friction} \tag{2.9}$$

where $\frac{d\vec{x}_i}{dt}$ is the temporary change of the location of pedestrian i; $\frac{d\vec{v}_i}{dt}$ is the acceleration of pedestrian i resulting from the sum of the total forces upon him ; ϵ_i is the fluctuation of individual i. The model has been validated by obtaining the self-organized phenomena " [8]".

3 Stages of developing the preferred force

Modelling the preferred force has gone through several developments in line with the developments of the social force model within the last years: first of all, modelling the normal situations was done by " [3]"; and subsequently, incorporation of the panic situation by " [4]"; later, a different contribution has been done in " [6]" (for brevity, by following [6], we denote the contribution of " [4]" by HMFV contribution. we also denote the modification of " [6]" by LKF contribution).

3.1 The normal (non-emergency) situation

The preferred force $\vec{f}^{pref} = \gamma\left(\vec{v}_i^0 - \vec{v}_i\right)$ is composed of two terms: the preferred velocity and the actual velocity of pedestrian i. Since the actual velocity is a result of the acceleration in equation "(2.7)", the preferred velocity is the substantial term which influences the preferred force. The preferred velocity's aspects vary according to the various situations that the pedestrian may experience. Starting with the normal situation, while individual wants to reach his destination, the preferred velocity is predicted to be the one which would provide the convenience to the individual such as the uniform movement. The determination of this preferred velocity is subject to the characteristics of the individual, the environment and the trip purpose. The individual, while he is walking, may be exposed to many delays and deviations. Thus, he will adapt his actual velocity to reach his preferred one. Given a time constraint, the preferred velocity $\vec{v}_i^0$ of pedestrian i at position $\vec{x}_i$ is modelled in " [3]" as

$$\vec{v}_i^0 = \frac{\left\|\vec{x}_i^0 - \vec{x}_i^{n-1}\right\| + ... + \left\|\vec{x}_i^j - \vec{x}_i\right\|}{T - t} . \vec{e}_i^0 \tag{3.1}$$

$$\vec{e}_i^0 = \frac{\vec{x}_i^j - \vec{x}_i}{\left\|\vec{x}_i^j - \vec{x}_i\right\|} \tag{3.2}$$

where $\vec{x}_i^j$ is the next intermediate target among $\vec{x}_i^{n-1}, ..., \vec{x}_i^j$ which form the polygon shape of his path to his destination $\vec{x}_i^0 = \vec{x}_i^n$. Note here, we considered the general walkway form which has a polygon shape composed of the mentioned intermediate points. According to "(3.1)", the preferred velocity would be influenced by any unsystematic change between the numerator and the denominator, namely, any delay or deviation.

3.2 Incorporating the panic (emergency) situation in the HMFV model

Incorporating the nervousness factor (the panic parameter) into the preferred force was the main contribution in " [4]". Due to such incorporation, a new formula for the preferred velocity has been modelled as follows

$$v_i^0(t) = (1 - p_i(t))\, v_i^0(0) + p_i(t)\, v_i^{max} \tag{3.3}$$

$$\vec{e}_i^0(t) = NORM\left((1 - p_i(t))\, \vec{e}_i + p_i(t) \left\langle \vec{e}_j \right\rangle_i\right) \tag{3.4}$$

where $p_i(t) = 1 - \bar{v}_i(t)/v_i^0(0)$ reflects the nervousness (panic parameter); $\bar{v}_i(t)$ is the average speed in the preferred direction of motion; $\left\langle \vec{e}_j \right\rangle_i$ is the average direction of the neighbors $j's$ of i. A great advantage of the latter formulas is that it takes into account the different dynamics of pedestrians in normal and panic situations.

3.3 The LKF contribution

The LKF contributions " [6]" to the preferred force have been done in order to provide the pedestrians with some kind of intelligence, namely, to offer more options to the pedestrian for selecting his route. It has been done by incorporating memory of the locations of exits into the model as an independent aspect of the pedestrians, and distinguishing those who are dependent as a separate term, as reflected in the following model

$$v_i^0(t) = \vec{e}_i^0(t)(1 + E_i(t))\, v_i^0 D_i + \langle \vec{v}_j \rangle_i (1 - D_i) \tag{3.5}$$

$$\vec{e}_i^0(t) = \left[\frac{\vec{v}_i(t)}{|\vec{v}_i(t)|}(1 - \tilde{\rho}_i(t)) + \vec{e}_{collect}\tilde{\rho}_i(t) \right](1 - M_i) + \vec{n}_{i,exit} M_i \tag{3.6}$$

where D is the independence factor, M and E are the memory parameter and the excitement factor, respectively, and both of them were modelled by modelling their rate of changes " [6]"; $\tilde{\rho}_i(t)$ indicates the nondimentional product of the crowd density around a given pedestrian and the pedestrian area; $\vec{n}_{i,exit}$ is the unit vector pointing from individual i to the exit memorized by him.

3.4 Incorporating the familiarity factor

A comprehensive comparison has been done in " [9]" which gave complete details of the advantages and the disadvantages of the aforementioned contributions. The result of the comparison lead the authors to adopt the LKF contribution to the preferred force because of its capability in representing realistic simulations while selecting the exits in an evacuation situation. However, they argued that the evacuation process in the LKF simulation suffers from the lack of some real aspects as occurred in real situations, and that because of the limited purposes of the LKF simulation. One of these aspects is the chaotic behavior of the fleeing pedestrians which causes collision amongst them, and this is a natural result because of the abundance of the available exits in most normal environments. For that reason, the authors have incorporated the familiarity factor into the equation of the direction of the preferred force, as follows

$$\vec{e}_i^0(t) = \left[\left[\frac{\vec{v}_i(t)}{|\vec{v}_i(t)|}(1 - \tilde{\rho}_i(t)) + \vec{e}_{collect}\tilde{\rho}_i(t) \right](1 - f_i) + \vec{n}_{i,f\_exit} f_i \right](1 - M_i) + \vec{n}_{i,exit} M_i \tag{3.7}$$

where f denotes the familiarity factor and $\vec{n}_{i,f\_exit}$ is the the unit vector pointing from individual i to the destination which is based on his assessment that it may lead to the exit.The familiarity factor is assigned to each individual initially and is estimated subject to the characteristics of the environment and the different characteristics of the individual's awareness. In the last subsections, the contributions associated to the preferred force have been summarized which have reduced the variation between the reality and the simulation. However, a model for the familiarity factor in " [9]" has not been presented. It was an exogenous factor given by the users. Moreover, some other aspects have not been dealt with, such as, the reaction toward a source of danger. In the next section, we will provide a model for the familiarity factor and another model for the reaction factor.

4 Modifying the route choice activity by modelling the familiarity and reaction factors

According to the psycho-social studies " [10, 11]" which show a fundamental aspect of the independence state of the pedestrian, so-called decision-making aspect, the most essential feature of this aspect is the pedestrian's capability to make his own decision even under perceived danger situations. In an evacuation situation, one of the factors that help make a decision is having a memory of the exit, and it has been already modelled in LKF contribution as an aspect of the independent state. Also, those who have the ability to assess the situation of the environment to judge which exit may help them to get out of the dangerous place using their knowledge, has been identified as the familiarity factor. However, this factor has been introduced without introducing its features or modelling its aspects " [9]". In reality, the capability to assess a situation is subject to other factors of the pedestrian's personality such as his intelligence and his experience. Nevertheless, for simplicity, we ignore the variance of the last two factors among the individuals. In our simulation, those who would assess the exits would be granted this ability randomly by having the value 0 or 1 $(f_i = 0 or 1)$. Our work now is limited to model the process of assigning the best exit for those who carry the value one from their perspective. We mean by assigning exits here is assigning the familiar exit to the pedestrian such as the door, corridor, or walkway, which are parts of the physical environment (building, hall, factory or the like). Two main factors, apart from the factors associated to the individual, have major roles for assigning the best exits: the distance and the design. As the design is based on many characteristics of the exit such as the width, the construction and so forth, the general model of such factor can be represented by

$$design\_eff_j = \sum_m w_{jm}.g_j\left(char_{jm}\right) \tag{4.1}$$

where w_{jm} is the weight of characteristic m of the exit j denoted by $char_{jm}$ and the function g_j is to represent the impact of this characteristic of exit j. However, due to the lack of serious psychological studies to find out the effects of these characteristics upon the human personality, it suffices in this paper to consider the design factor as an exogenous factor having a range of values. notice that in our simulation below, one characteristics has been modelled to achieve the objective of the simulation. On the other hand, according to " [8]", the effect of the distance between a pedestrian i and exit j is conversely proportional to the possibility of choosing it by the pedestrian, this effect is modelled by

$$dist\_eff_{ij}\left(t\right) = e^{-l.d_{ij}.E_i(t)}.\delta\left(\varphi_{ij}\left(t\right)\right) \tag{4.2}$$

$$\delta\left(\varphi_{ij}\left(t\right)\right) = \begin{cases} 1 & |\varphi_{ij}(t)| \le \frac{\pi}{2} + \frac{\pi}{2}(1 - E_i(t)) \\ 0 & otherwise \end{cases} \tag{4.3}$$

where d_{ij} is the distance between pedestrian i and exit j; l is positive constant to consider the individuals' variances in the estimation process of the distance factor; E_i is the excitement parameter and was incorporated into "(4.2)" to capture the curve of the model according to how much the individual is excited (the degree of his panic); $\delta\left(\varphi_{ij}\right)$ is a function to take into account that the perception of the individual i of the exits would be influenced by the degree of his excitement. In other words, if the excitement parameter is very low, the perception of the individual would cover all the surrounded area and that represents the behavior in non-emergency situation. On the contrary, if the excitement parameter is very high, finding out the suitable exit for egress would be limited to the visible area of the individual while he is fleeing. The excitement parameter has another role in determining which effect will work more than the other in the last step of the assessment process

$$exit\_value_{ij} = dist\_eff_{ij}\left(t\right).E_i\left(t\right) + design\_eff_j\left(1 - E_i\left(t\right)\right). \quad (4.4)$$

Eventually, individual i would direct his motion toward the exit which has the maximum value resulted from applying equation "(4.4)" to the available visible exits

$$f\_exit_i\left(t\right) = index\left\{max_j\left(exit\_value_{ij}\left(t\right)\right)\right\} \quad (4.5)$$

where f_exit_i is the index of the exit that has the max value among the other exits. The other issue we have addressed is the counterintuitive result which had emerged whilst performing many simulations for testing our expansion of the LKF simulation, namely, improper behaviors from those who are dependent while fleeing from the source of panic such as directing their motion toward unsuitable areas and being in stationary state as well. The reason of such behaviors is that those who were dependent did not have a significant velocity under their perception to follow. Actually, the aforementioned reason is a natural case that may appear any time. By incorporating another real aspect of the emergency situation which is the reaction against the source of panic we have eliminated this counterintuitive result. From the perspective of the psychologists, every individual has a natural reaction against any risky source, and it differs from one individual to another. We subjugated the pedestrians to this factor by taking into account the individual's differences. The pedestrian would direct his direction totally against the panic source as an instant response for a short period which differs from one another according to some psychological characteristics

$$r_i\left(t\right) = \left(1 - \frac{t}{a_i}\right)^{1/s_i}, 0 \leq t \leq a_i \quad (4.6)$$

where $r_i\left(t\right)$ is the degree of the reaction of pedestrian i, a_i is the range of the time that the pedestrian i is under the control of his reaction, and s_i is a parameter to capture the curve in a way to fit the individual characteristics. By this factor, the dependent pedestrians have a reasonable collective velocity which they keep following. Lastly the model of the preferred velocity of pedestrian i

$$v_i^0(t) = \vec{e}_i^0(t)(1 + E_i(t))v_i^0 D_i + \left[\langle\vec{v}_j\rangle_i(1 - r_i(t)) + (v_i^{max}.\vec{n}_{opp})r_i(t)\right](1 - D_i) \tag{4.7}$$

$$\vec{e}_i^0(t) = \left[\left[\frac{\vec{v}_i(t)}{|\vec{v}_i(t)|}(1 - \tilde{\rho}_i(t)) + \vec{e}_{collect}\tilde{\rho}_i(t)\right](1 - f_i) + \vec{n}_{i,f\_exit}f_i\right](1 - M_i) + \vec{n}_{i,exit}M_i \tag{4.8}$$

where v_i^{max} is the maximum preferred velocity of pedestrian i ; $\vec{n}_{opp}$ is a vector pointing from the source of panic toward him; $\vec{n}_{i,f\_exit}$ is a vector pointing from him towards the exit which has index f_exit_i .

5 Simulation results

In our simulation, we designed a physical environment with multi exits located at different positions and having different characteristics to help assess the role of the familiarity factor. The physical environment in figure ”5.1” is a room of 20 m width and 20 m length and has four exits. The pedestrians were generated at the lower half part of the room.

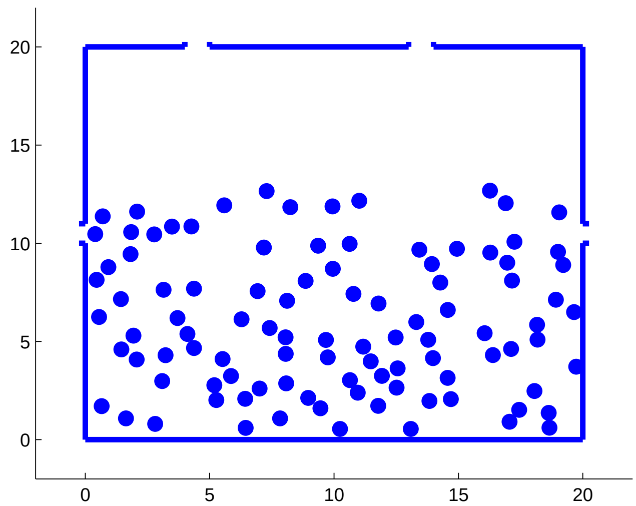

Figure 5.1: The physical environment and generating the pedestrian in the lower half part of the room.

The source of panic would appear from the lower wall. Our criteria of judgment that the simulation is realistic are the appearance of the multi-directional movement of the pedestrians and the usage of the exits which have not been known to the pedestrians regarding its characteristics. In order to demonstrate how the effect of distance and design will influence on the decision of the independent pedestrians, the simulation has been divided into two parts. Both have the same room characteristics and the number of exits except one of the upper exits in the second part has been widened to be double in size. Equation "(4.1)" has been modelled with respect to one characteristic which is the width. In this case

$$design - eff_j = \frac{s}{(s + (b - s)e^{-m.w_j})} \tag{5.1}$$

where s is the shortest width of the exits under investigation, b is the longest width and w is the width of exit j, respectively. m is a parameter to capture the curve shown in figure "5.2". the influence of the above work has been shown in figure "5.3".

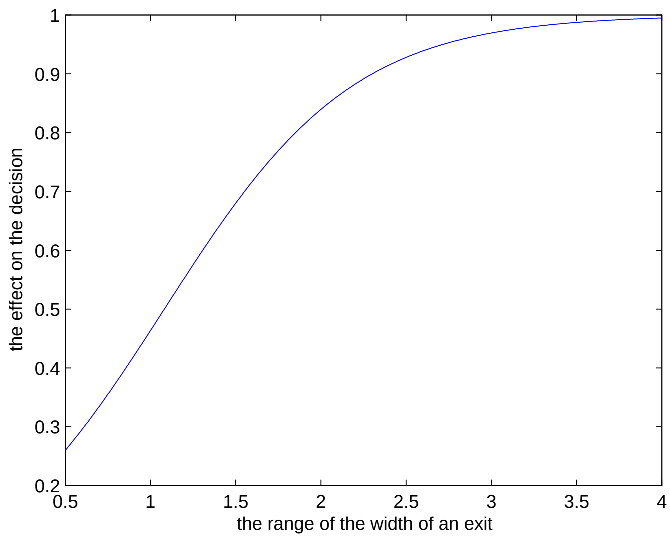

Figure 5.2: the curve of the $design\_effect$ where $s = 0.5m$,$b = 4m$ and $m = 2.5$.

On the other hand, we focused on the role of the reaction factor for eliminating the counterintuitive result mentioned in the above section. The values of the parameters a_i, si, l were determined in a way to represent a realistic evacuation behavior. All pedestrians have been granted the same value of the excitement parameter which equals to $1/2$, and lastly, the values of the parameters of the social and physical forces has been set as has been done in " [6]". By obtaining an illustrating snapshot of each part as shown in figure "5.3", the counterintuitive result which has been noted in LKF contribution has disappeared.

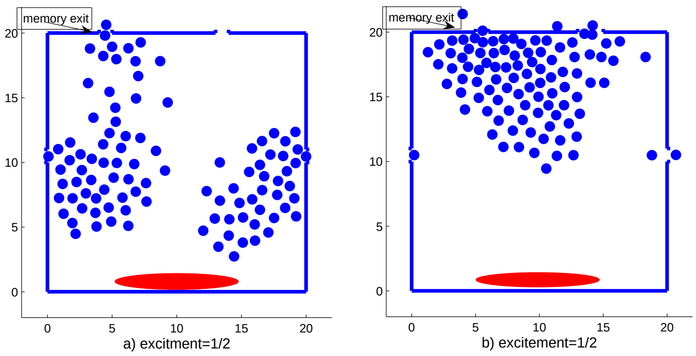

Figure 5.3: Two snapshots with different widths of the right upper exit. In a) the room has one memory exit and three normal exits which have the same width. the oval shape indicates the source of panic. The pedestrians who did not have memory chose the nearest exits (the left and the right) because of the effect of the shortest distance. In b) the room has the same environment except for the upper door which has a double width of the others. Most of the pedestrians who did not have memory chose the wide exit because of it was more attractive, that is, it was wider than the others which inspired the pedestrians for safe exit. Notice that the excitement parameter was moderate.

6 Conclusion

In this paper we have demonstrated the aspects of the independent factor and its stages of development. The familiarity factor which is a decision making process has been modelled based on two essential terms, namely, the distance and the design. In addition, to make the model more realistic and to eliminate the aforementioned counterintuitive result which emerged by the dependent pedestrians, a new factor so-called the reaction factor has been incorporated into the last process. A simulation to demonstrate the positive effect of our work has been done, namely, introducing the capability of the pedestrians to make decisions as independent people whether in emergency or non-emergency situation. Moreover, we have let the dependent pedestrians to behave naturally when exposed to a source of panic. We hoped that this work will give benefit especially to those who are involved in the applications of the microscopic studies. Further investigations are currently being carried out by incorporating more factors, and by performing high performance simulations to facilitate the process of the validation and calibration of the developed model.

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