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Crowd Management - Social Force Model

Ratish Kumar[1]
[1]P.G. Student, Mewar University,
Chittorgarh, Rajasthan, India

Abstract **- All Trips at some point need to be completed by walking. There are various models, which are used to simulate pedestrian observed flow with the real world. A literature study is performed in which we found that Social force model can be preferably used among other models like Cellular Automata model, Magnetic force model, Centrifugal force model. Social force model is one of the models which predicts a lot of observed phenomenon like lane formation, faster is slower, etc. The main aim of this work is to investigate whether the Social force model can deal with big data or not. The aim was to calibrate and validate the social force model with real-world data. If the Social Force model gets calibrated and validated with real-world data, then one can say that Social force model can be used to capture the variability and real-world pedestrian behavior.**

The pedestrian data is collected by drones. After the extraction of data, it was seen that it contains a lot of noise as speed was fluctuating too much, and while the observed video does not show such behavior. The noise errors in drone data may have occurred due to inaccuracies in the instrument, measurement error and bad weather. Therefore, data smoothening has been done with the help of filters which reject the value above a specific range of frequency. Data smoothening was essential to clean the data for further analysis. Five parameters are chosen i.e. A, B, Relaxation time, Lambda and Desired speed for the purposes calibration. These parameters were calibrated with the help of genetic algorithm by which minimizes the difference between values of observed distance and simulated distance. Initially, only one pedestrian is simulated while others move according to their observed trajectories. Later, the ten pedestrians were simulated simultaneously. Ideally, all the pedestrian should have been simulated together to minimize the error. However, as the genetic algorithm was taking lots of time to minimize the error, more than ten pedestrians was not considered for simulation simultaneously. Errors are noted in case of one pedestrian, two pedestrians and 5 pedestrian simulation together. Further, speed, flow and density variation were explored in the entire stretch over time. Further, the fundamental relation between these three parameters was also explored.

Key Words: Social force model, Data noise, Observed Distance, Strength of force, Strength of force, simulated distance.

1. INTRODUCTION

The most primitive and basic mode of transportation is walking. This mode enables individuals in reaching separate buildings/locations that are sometimes inaccessible by other modes of transportation, and this is discovered to be an essential component of any trip by any mode. Much effort has been created to understand the flow of vehicles in the Indian context, but little research has been done in the past on understanding the pedestrian flows. But now pedestrian flows have become popular among the researchers as it will help in providing the facilities for pedestrians in a better way. The appropriate standard and control of pedestrian facilities can be achieved with the help of precise data collection, followed by proper analysis of the data. With the technological advancement of computer and processing of video, the pedestrian studies can be done in a better way and which will ultimately help in providing robust designs for pedestrian facilities.

Pedestrian motion is the main challenge among researchers to understand as pedestrian movements show a more complex behavior, mainly because they are essentially two-dimensional and not limited to specific lanes. In order to design any facility for pedestrians, it is vital to comprehend pedestrian movement. Understanding the motion of pedestrians also promotes the calculation of the level of service (LOS) of the pedestrian facilities to be provided (i.e. safety, efficiency, and comfort and evacuation time of various pedestrians). These assist in better design and forecasting usability of those facilities. It cannot be contradicted that understanding pedestrian motion is of paramount importance in a nation like India, having one of the lowest vehicle densities in the world and having an enormous population, which has led to crowded pedestrian lanes in the urban areas of the country. Also, understanding pedestrian behavior can play a vital role in safely organizing religious gatherings, which are an intrinsic part of Indian culture and hence avoid stampedes during such events.

It becomes a big problem at bigger densities, particularly in a nation like India, if the pedestrians do not act consistently and orderly. In addition, collective dynamics will be created from individual human non-linear interactions in pedestrian dynamics. For instance, a crowd in ordinary circumstances forms self-organized patterns such as lane formation, oscillatory flows at bottlenecks, and stripe formation in intersection flows. Under extreme circumstances, however, coordination will fail, leading to new phenomena such as freezing-by-heating, faster- is-slower, and crowd turbulence. Crowd turbulence is responsible for sudden eruptions of pressure release comparable to earthquakes, which cause sudden displacements and the falling and trampling of people. The most important and reliable source which helps us to predict the pedestrian behavior pattern is a good quality of data. Moreover, trajectory data is the most important information from which we can extract all information like pedestrian speed, acceleration and movement patterns. Therefore, in order to understand the nature of complex and collective dynamics of pedestrians during normal and evacuation situations, mathematical models and simulation tools can play a vital role.

Increased awareness of environmental problems and the need for physical fitness encourage the demand for the provision of more and better pedestrian facilities. The implementation of a policy without pedestrian studies might lead to a very costly trial and error due to the implementation cost (i.e. user cost, construction, marking etc.). On the other hand, using good analysis tools, the trial and error of policy could be done at the analysis level. Once the analysis proves good performance of

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a policy, the implementation of the policy would be efficient and effective. The problem is how to evaluate the impact of the policy quantitatively toward the behavior of pedestrians before its implementation. Most of the pedestrian-related studies were conducted under controlled conditions, which did not represent real pedestrian characteristics under different conditions. Hence, there is a need for an in-depth understanding of pedestrian dynamics and behavior from the real world data without any prior assumption and controlled situation.

Table 1. Major Crowd Disasters in Europe, India and all over the World

Date	Place	Venue	Death	Reason
2005	Wai, India	Religious Procession	150	Overcrowding
2005	Chennai, India	Disaster Area	42	Rush for flood relief supplies
2006	Mina, Saudi Arabia	Bridge	363	Overcrowding
2010	Duisberg, Germany	Tunnel	21	Panic breaks out in a tunnel leading to festival site
2010	Haridwar, India	Kumbh Mela	9	Car lost control creating chaos in crowd
2012	Patna, India	Chhat Pooja	17	Rumor of live electric wire falling in water on Ganges Ghat

1.1 Objective of Purposed work

- The main objective of the pedestrian studies is to assess the effects of a recommended policy on the pedestrian facilities before its implementation.
- To extract the reliable pedestrians' trajectories data from a video recording of a crowded street after removing noise using appropriate noise reduction techniques.
- To validate and calibrate the Social force model with the real-world pedestrians' trajectories data obtained from a crowded street.

1.2 Scope of Purposed work

The major problem arises where a lot of people interact like in mass events, at stadiums, music concert, at stations. In mass scale events, if the available space per pedestrian is less, risk of congestion will be more, and then it will be difficult to control the pedestrian traffic as most of the pedestrian will try to reach their destination as early as possible. Therefore, this study was undertaken to simulate the pedestrian traffic with the help of microscopic model to analyses the pedestrian traffic behavior, as different pedestrians affect the traffic in a different way.

- The focus of this study is to optimize the pedestrian trajectory with the help of the social force model.

2. LITERATURE REVIEW

2.1 SOCIAL FORCE MODEL

According to Helbing & Molnar (1995), pedestrian is used to the situations which he/she generally encounter during movement and they have the ability to perceive the situations, and according to different situations, he/she will react. That's why they have defined the pedestrian behavior into the equation of motion. The interaction between the environment and pedestrian are described with forces. Pedestrians are driven by three forces namely, desired force (fi), interaction force ($f\ ij$) between pedestrians i and j, and interaction force ($f\ i\omega$) between pedestrian i and the walls. According to Newton's second law of motion, the corresponding mathematical expression of each pedestrian i is

$$F_{Total} = m_i (v_i^0(t) e_i - v_i(t))/\tau_i + \sum_{j=1, j\neq i}^{N_j} f_{ij} + \sum_{\omega}^{N_\omega} f_{i\omega}$$

Where mi is mass of pedestrian i, certain desired speed v^0 i

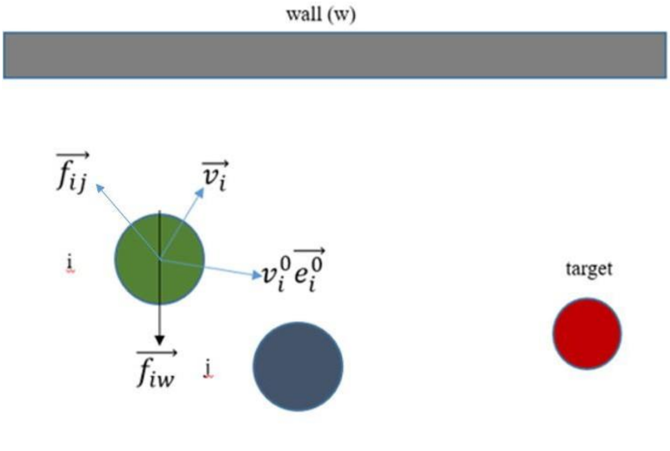

Fig.2.1 Diagram of Social force model

2.1.1 Desired force

The desired force, $f0$ reflects the pedestrian's willingness to achieve the desired velocity so that he/she can move towards his/her destination. This force can be expressed by the following form:

$$f_i^0 = (v_i^0(t) e_i - v_i(t))/\tau_i$$

Where v^0 is the desired speed with a certain direction ei, and τi is a constant of adaptation time to adjust pedestrian's actual walking velocity.

2.1.2 Repulsive force

As pedestrian (i) is moving towards his destination, his motion is affected due to the presence of other pedestrians. As pedestrian is getting closer to the stranger, who may react in an aggressive way, he/she feels uncomfortable. Therefore, it results in repulsive effects due to other pedestrian's j

$$f_{ij} = A_i \exp\left(-\frac{\varepsilon_{ij}}{B_i}\right) \overrightarrow{n_{ij}}$$

2.1.3 Attractive force

During the movement of pedestrian towards his destination, they are attracted by other persons like friends, street artists. Due to this attraction effects, pedestrian groups are formed. These attractive effects can be modelled with the help of monotonically increasing potential $W\ i\alpha$ ($\|r\ i\alpha\|$, t). Helbing and Molnar also introduced the effect of direction in the attractive and repulsive forces, as pedestrian generally reacts to

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the activities which can be perceived in the desired direction of motion.

2.2 ESCAPE PANIC VERSION OF HELBING (2000)

The initial model is basic for the study of pedestrian behavior, and various modifications are done to mimic the real-life situations, as, in the initial version, it was developed for the pedestrians which are under low-density conditions. But as the density increases like for a case of religious gatherings, social gatherings, concert and stadium, researchers start focusing on escape panic version. When pedestrians come closer to each other then they shouldn't squeeze through each other for overcoming that case normal contact force, and tangential sliding friction force are added into the interaction equation of pedestrian, and that is called physical force.

$$f_{ij}=A_i\exp(-\varepsilon_{ij}B_i)\vec{n}_{ij} + kg(r_{ij}-d_{ij})\vec{n}_{ij} + \kappa g(r_{ij}-d_{ij})\Delta v_{ji}^t \vec{t}_{ij}$$

where, $\varepsilon_{ij} = d_{ij} - (r_i + r_j)$

The interaction force between pedestrians i and j, is the repulsive interaction force against each other, where Ai and $Bi$are constants, dij denotes the distance between the centers of mass of pedestrians, nij is the normalized vector that points from pedestrian j to i and ri& rj are the radii of pedestrian i & j, respectively. The psychological tendency between pedestrians i and j to stay away from each other is expressed by the repulsive interaction force, fswhich obtains its maximum value when two pedestrians have minimal distance.

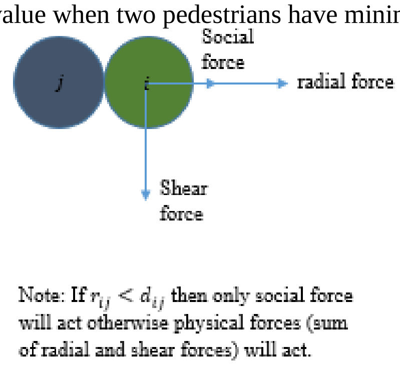

Fig. 2.2 Diagram showing physical force

2.3 IMPROVEMENTS IN SOCIAL FORCE MODEL

By using the above mentioned two versions of SFM, the improvements are done by the various researchers [Johansson, Helbing & Shukla, 2007]

2.3.1 Pedestrian shape

There are various kinds of shapes like circle, ellipse and three circles which can be used to represent pedestrian. In reality, a pedestrian is best suited with representation by ellipse as they have different widths on the two-dimensional plane. Initially, pedestrians are represented by circles in the Helbing escape panic version of the model. In three circle representation, various forces are added like sliding friction force, physical damping force. But as we have seen in terms of computational terms circle representation is best suited for a large scale crowd simulation.

2.3.2 Pedestrian Group

To develop a valid prediction model for designing pedestrian facilities or crowd safety during mass event, it is requisite to understand the effect of grouping behavior, which helps us incorporate similar actual behavior in model.

The new model equation of SFM by incorporating group behavior is:

$$dVidt = Fi0+\Sigma Fij++Fiwall+i\neq jFigroup$$

2.4 FORCES IN BONDING GROUPS

The main focus is to add the effects of bonding among groups into the mathematical equation, which will ultimately help in enhancing the accuracy of the current simulation. The work was carried in the past on the crowd dynamics, but they emphasized on different features rather than cohesion & bonding between groups.

2.4.1 Objective

The effects of bonding forces and repulsive forces inside bonded groups are considered, and it is modified in the social force model by

$$m_i\frac{dv_i}{dt} = m_i\frac{v_i^0 e_i^0 - v_i(t)}{\tau_i} + \sum_{\substack{j\neq i \\ j\in B(i)}} f_{ij} + \sum_w f_{iw} + \sum_{j\in B(i)} (k_{ij}^{bond} + f_{ij}^{bond})$$

2.4.2 Observation

This model considers the bonding rate rather than the desire of pedestrians to see their partners, which is important in modelling group behavior. Moreover, this model is mainly for a group of two people.

2.5 CELLULAR AUTOMATON MODEL

2.5.1 Objective

The main purpose of a cellular automaton is to transform the effects of long ranged interactions into local interactions with memory. It means as a pedestrian will move towards his/her destination, he/she will leave some trace, and with the help of that, the path of upcoming pedestrians can be modified.

2.5.2 Model

Cellular Automaton has been used for vehicular traffic extensively, but it is not used for pedestrian dynamics. The basic idea while developing this model is as pedestrian moves towards its goal he/she will need a leave trace of his/her movement. Based on that transition probability is defined and according to the transition probability movement of the pedestrian is allowed.

2.5.3 Observation

Lane formation, separation of two particle species, oscillations were observed with the help of above stated model. With the variation in the values of parameters like static field and potential field, the above phenomenon can emerge. Various evacuation simulations like evacuation through a large room, evacuation through a large room in which it is filled with smoke were done with the concept of static field and dynamic field respectively. As latter gives us virtual trace left by pedestrians, which ultimately gives the direction to other pedestrians to follow the trace left by pedestrians.

2.6 MAGNETIC FORCE MODEL (MFM)

2.6.1 Objective

The objective of this study is the development of a computer simulation model for pedestrian movement, which ultimately helps designers to understand the relation between human behavior and space.

2.6.2 Model

Magnetic force model treats the pedestrians as charged objects within the resulting magnetic field. In a system, pedestrians are assigned as a positive pole while their destination is assigned as a negative pole, which means the attractive nature of opposite magnetic charges will help the pedestrian to move towards their destination. Obstacles like walls, columns are assigned as a positive pole, which means that pedestrian exerts repulsive force upon them as well as on each other that ultimately leads to avoid collisions.

2.6.3 Input Data

The model requires the detailed amount of input data before simulation so that realistic results can be produced and input data consists of data of plan and pedestrian data. The required data is data of walls, openings in the plan, corners, desired destination, initial position, initial velocity, the orientation of pedestrian, time that the pedestrian starts walking and their method of the walk.

2.6.4 Magnetic force among pedestrians

It is well known that if any object is treated as magnetic objects, then the force law which is applicable to Coulomb's Law and the force is given by

$$F = \left(\frac{q_1 q_2}{4\pi\varepsilon r^3}\right) * \hat{r}$$

2.6.5 Simulation

This model was used to simulate a fire escape on one floor of an office building, to track pedestrian motion in part of an underground railway station, and to track pedestrian flows in a hotel lobby. By giving the input for simulating an escape from fire, it can be found where stagnations and congestion are occurring and how they affect the entire movement of pedestrians and how long it takes for all pedestrians to escape from the building. Moreover, how pedestrians are moving in queue spaces can also be simulated by using MFM.

2.6.6 Observation

This model can be used to simulate movement in case of the fire escape, as it is able to calculate how long pedestrians will take to escape from the building, but this model doesn't give any information on how the intensity of magnetic load can be chosen. There should be more information on how the intensity of magnetic load can be chosen.

2.7 CENTRIFUGAL FORCE MODEL

2.7.1 Objective

The primary goal is if velocity adjustment is not achieved in the term which represents repulsive force, then in a panic scenario, aggressive pedestrians squeeze through the front, creating clogging and arching at exits.

2.7.2 Model

Centrifugal Force Model consists of three terms, the main terms which govern the motion of pedestrian i were examined.

1. Centrifugal Forces between pedestrians
2. Effect of borders and obstacles
3. Relaxation Time

Centrifugal Forces between pedestrians

Relative speed impacts are considered, as pedestrians speed is affected by neibhouring pedestrian speed. Moreover, it is assumed that the faster-preceding pedestrians will have no repulsive impacts on those behind them. Also, as the stranger gets nearer to the pedestrian, discomfort zone will increase. Pedestrian generally react with those people who are within their angle of view and field of vision is 180°. That coefficient is also introduced in the centrifugal force equation and denoted by Kij.

2.8 MODIFICATIONS IN CENTRIFUGAL FORCE MODEL

2.8.1 Objective & Model Parameters

Simplify the CFM by excluding CDT without deteriorating performance. In the CFM model proposed above, there are some behavior which is unrealistic if we don't comply with the CFM model with CDT technique. If pedestrian comes near to one another, then repulsive force needs to grow but in CFM as repulsive force depends on both relative velocity and inversely to the distance between them therefore repulsive force doesn't grow that much which prohibit overlapping. Therefore, to make the model more effective, it is improved by some researchers, and it is assumed that there should be some proportionally between the repulsive forces acting on a pedestrian i and its desired velocity. Thus a pedestrian tending to move with high velocity "feels" intense repulsive actions. By means of the parameter, the strength of the force can be adjusted while the diameter of pedestrian's Di depends linearly on the velocity. This incorporates the dynamic space requirement of pedestrians, modeling the fact that faster pedestrians require more space than slower pedestrians.

2.8.2 **OBSERVATION**

The simulation is done in which 60 pedestrians were flowing under the bottleneck situation. The width of the bottleneck is changed from 0.8m to 1.2m. Then the results were compared with the empirical data of pedestrian flow through the bottleneck.

3. METHODOLOGY

The present chapter describes the details of the methodology adopted during data collection, which is followed by data extraction. Then the noise is removed from the data by using a low- pass filter and then the various parameters were discussed which were selected for calibration and validation of the microscopic model for the pedestrian.

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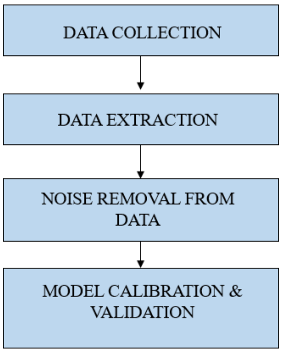

Figure 3.1 Methodology adopted in the current study

3.1 DATA COLLECTION

Data collection is done with the help of drones with the proper selection of road on which a large number of pedestrians were moving towards an ongoing soccer event.

3.1.1 Study Location

The data is collected from Croatia through Drones. The length of the road stretch is around 55 m on which pedestrian data is collected. Due to the occasion of the soccer match, the road allowed the movement of pedestrians only, therefore, cars were parked along the side of the road. The width of the road is between 6-7 meter. Pedestrians were crossing the road to attend the soccer match, which is in the nearby stadium. From the below figure it is seen that almost all pedestrians are stopped near the round junction of two roads.

3.1.2 Data Collection Procedure

The video data is collected with the help of drones, which is also called unmanned aerial vehicle. As compared with the previous methods like cameras, UAVs is capable of taking large view scope, uniform scale, and moreover, they have the ability to move quickly and easily. The positions of pedestrians can be recorded more accurately with the help of UAVs then cameras. UAVs is capable of capturing a lot of complex information like pedestrian trajectory data, vehicle trajectory data and lane change data. Therefore, UAVs plays an important role in several fields of transportation engineering as it captured very useful data which is the base of research.

Fig.3.2 Data collection through drones

3.2 DATA EXTRACTION

The first video is given as input in the "Data from Sky" software. Then the pedestrians were selected randomly for pre-processing, detection and then followed by tracking. These three main steps are described in the subsequent paragraph.

3.3 NOISE REMOVAL FROM DATA

The real-world trajectory data measurement errors can be interpreted as random noise on the positional location of the pedestrian, and when speeds and acceleration values are calculated, these errors will further increase by doing differentiation. The useful information from raw data can be extracted through reasonable and robust noise removal methods. Different smoothing techniques such as moving average filters, locally weighted regression, and bi-level optimization structure can be applied for removing noise from the data. The noise from collected data has been removed using a low-pass filter.

3.4 MODEL CALIBRATION & VALIDATION

Model is applied to the real-world data, which is attained with the help of data collection, followed by data extraction and noise removal. The Social force model is chosen to calibrate the real-world data as it can define various phenomenon like lane formation, clogging and arching effects at exits.

3.4.1 Parameter of Model

A total of 5 parameters (out of 8 parameters) of the social force model have been chosen for calibration with the help of sensitivity analysis. These are Strength of the interaction (A), Interaction range (B), Relaxation Time (τi), Desired speed (vd) and Lambda (λ). We have represented pedestrian as a circular shape with a radius of 0.2 m.

1. Strength of interaction (A) and Interaction range (B)

These parameters define strength (A) and the typical range (B) of the social force between two pedestrians. Their value changes with the change in environment.

2. Relaxation Time ($\boldsymbol{\tau i}$)

Tau represents the relaxation time or inertia that can be related to response time, as it couples the difference between the desired speed and desired direction with the current speed and direction for acceleration. If relaxation time is more, then the pedestrian will POI move very slow, but if it is low, then the pedestrian will move very fast.

3. Desired speed ($\boldsymbol{vd}$)

Pedestrian's desired speed is influenced by many factors:

a) Surrounding density: As the surrounding density increases, the pedestrian's desired speed will decline.

b) Pedestrian characteristics: It is affected by lots of pedestrian characteristics, such as gender, age, luggage and action ability, affects the pedestrian's desired speed. These differences will be described by a distribution of the desired speed.

c) Specific environment: Pedestrian's desired speed is different in the normal and emergency evacuation. In the case of an emergency evacuation, pedestrian's desired speed is the combination of his own speed and the average speed of the surrounding pedestrians.

4. Lambda (λ)

Lambda governs the amount of anisotropy of the forces from the fact that events and phenomena in the back of a pedestrian do not influence him (psychologically and socially) as much as if they were in his sight.

3.4.2 Model Parameter Optimization by a Genetic algorithm

A random pedestrian is chosen, which will move according to a simulation of the social force model while others will move exactly according to the trajectories extracted from the videos. This procedure is performed on all pedestrians.

1. First, one has to choose the starting point, and the state (position, velocity and acceleration) will be calculated for each pedestrian.
2. Assign the desired speed to each pedestrian. Between the selected time frames, all the moving pedestrian will be chosen to correspond to that time frame.
3. One needs to define the desired direction for pedestrian so that they can easily move from origin to destination. In our case length of the road, the stretch is around 50 m.

So we divided the length of the road into segments and at the end of divided segments desired direction is given.

4. Now, we selected the 10 surrounding pedestrians, which will change all over the length from which interaction force between pedestrians is calculated.
5. Then, we also selected the wall; there will be a force on subjected pedestrian from the nearest point of a wall which is repulsive in nature.
6. Then the sum of all the forces which are coming out on the subjected pedestrian and based on the force, future velocity is calculated. Above procedure is repeated at the time frame of 80 milli-second.
7. Afterwards, parameters which were selected for calibration these for obtained through the genetic algorithm in which difference in actual and simulation position is minimized.

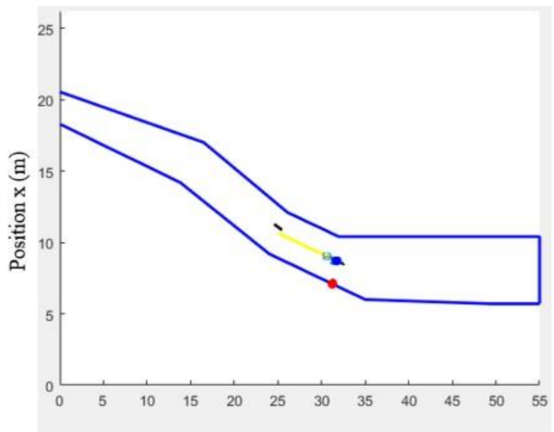

Fig. 3.3 Stretch of the road with blue one as a simulated pedestrian, yellow is desired direction.

The above figure represents the subjected pedestrian (blue one), which is going to be simulated with the help of above model applied. As above model also states that the subjected pedestrian movement should be affected by pedestrian-wall interaction, pedestrian desired direction, so pedestrian-wall interaction effect is represented by a red circle, and the yellow line represents the desired direction which motivates the pedestrian to move from origin to destination. Moreover, as the simulation takes a significant amount of time in the calculation of various parameters, therefore, above methodology is first applied to one pedestrian, then it is extended to three and five pedestrians subsequently. The results from the single pedestrian were applied to three and subsequently on five pedestrians to check the difference between positions obtained from the simulated and the actual data. Moreover, the parameters from the single pedestrian were also applied to obtain the simulated data for three and five pedestrians respectively and also this data was compared to the simulated data for three and five pedestrians obtained separately to check the difference in the positions obtained from the two data sets.

4. ANALYSIS AND RESULTS

Data obtained from the methodology as described in the previous chapter, is used for analysis purpose. Noise is removed from the data by using low pass filter which accepts the frequency of certain range and rejects the frequency which is above the cut-off frequency. Data before and after noise is shown below. The pedestrian x and y-direction are indicated in the figure below in which pedestrian movement pathway is also shown with the blue box. Pedestrians are represented with the circle of radius around 0.2 m.

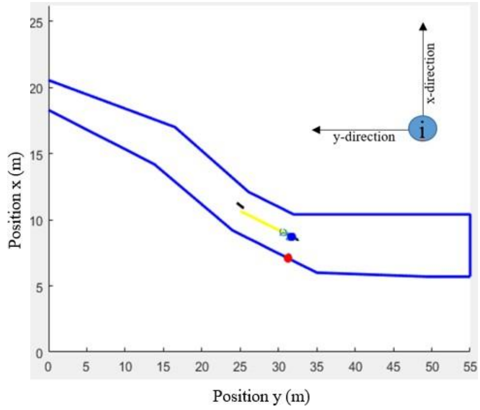

Fig. 4.1 Diagram showing pedestrian movement corresponding to x & y directions

4.1 POSITION DATA OF DIFFERENT PEDESTRIANS

4.1.1 Trajectory of Pedestrian id-1

From Figure 4.2-4.5, It can be found that pedestrian 1 is moving towards its destination from the origin without getting any obstructions. It is found that the pedestrian 1 was continuously walking without any stoppages, as he/she started walking when the barrier was removed (soccer match was about to start). As his/her relative position was near to the destination, so he/she reached the destination early relative to other pedestrians because their relative position was far from pedestrian 1, so they felt several forces which causes their delay in journey.

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It was found out that the speed of pedestrian 1 was initially low, as the barrier was removed manually. So when the barrier effect was reduced to zero, then only the pedestrian gained his/her desired speed and reached the destination freely. It is also observed that initially, pedestrian speed is low because the road width was less due to the barrier and as the barrier was removed gradually it gained its momentum and then proceeded with free speed towards the destination. This is the initial pedestrian. With the plot of this trajectory, a comparison is made with the other trajectories of the pedestrian how they are changing as the pedestrian starts moving far away from the destination.

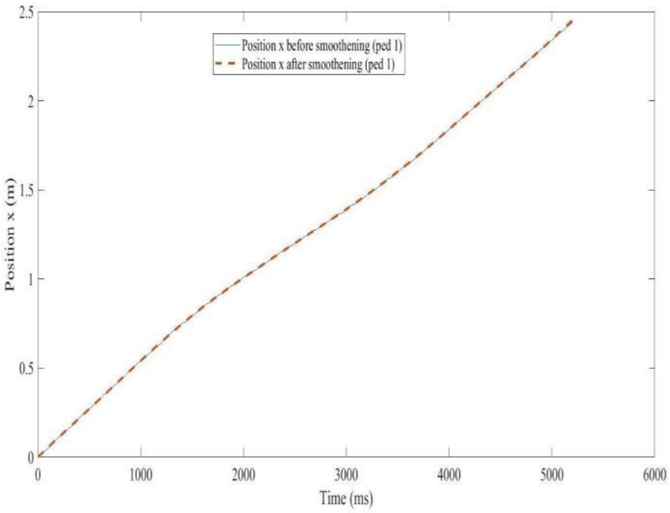

Fig. 4.2 Position of pedestrian 1 throughout the time-frame in the x-direction

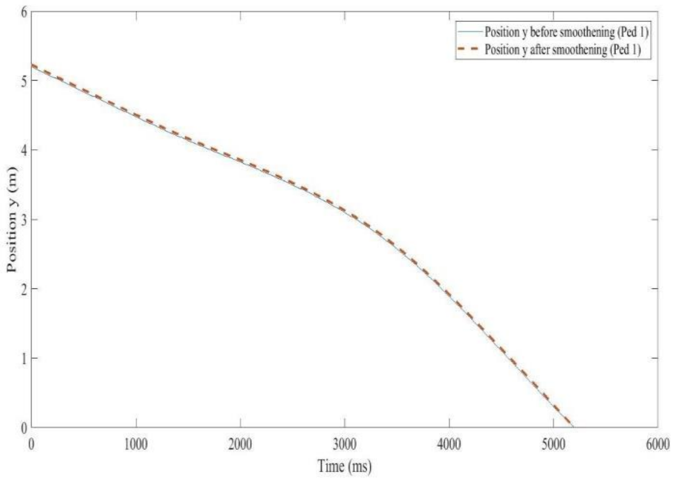

Fig. 4.3 Position of pedestrian 1 throughout the time-frame in the y-direction

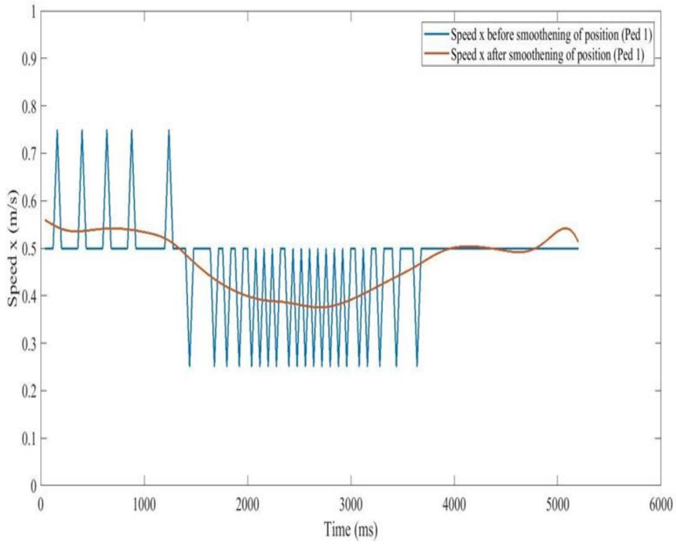

Fig. 4.4 Speed of pedestrian 1 throughout the time-frame in the x-direction

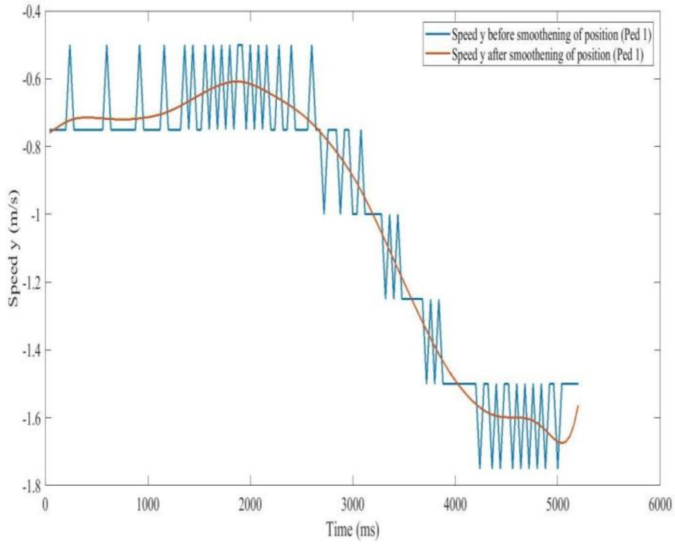

Fig. 4.5 Speed of pedestrian 1 throughout the time-frame in the y-direction

4.1.2 Trajectory of Pedestrian id- 220

From Figure 4.6-4.9, it was seen that pedestrian initially was at rest then he/she starts moving as soon as the front pedestrians start moving. As compared to the front pedestrians, he/she is not able to move continuously. As it was seen from Figure 4.3 that pedestrian 1 was moving without encountering any problem as he/she was only 5.2 m away from the destination. Speed of pedestrian 220 is also less as compared to pedestrian 1. The speed variation diagram is also plotted in which the variation of average speed along the length of travel will be shown.

Moreover, there are a lot of trajectories of pedestrians which were plotted. Trajectory data is an important source of every information like speed, flow, density, which are macroscopic characteristics

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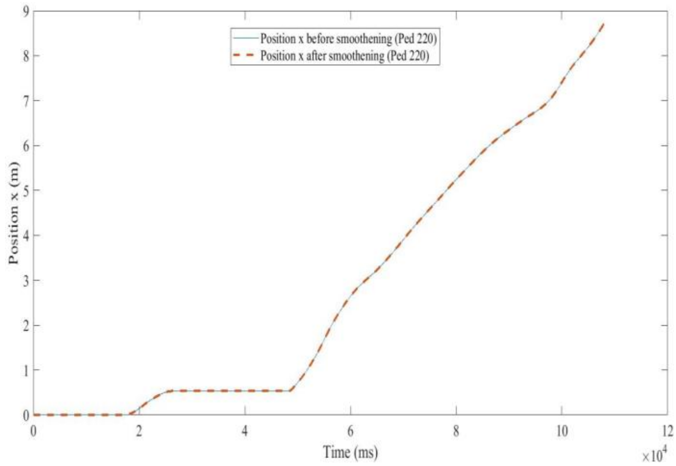

Fig. 4.6 Position of pedestrian 220 throughout the time-frame in the x-direction

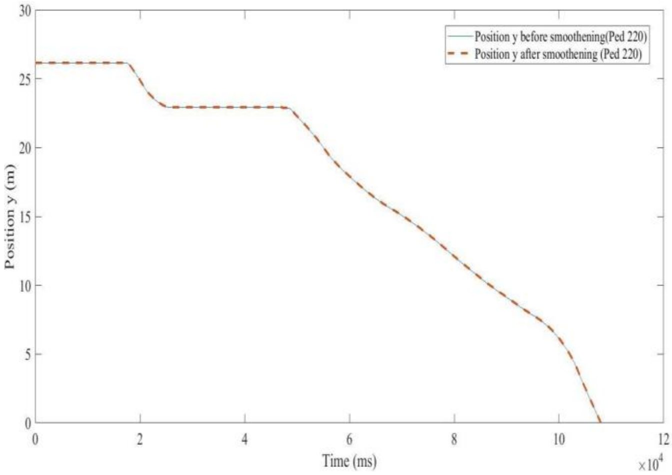

Fig. 4.7 Position of pedestrian 220 throughout the time-frame in the y-direction

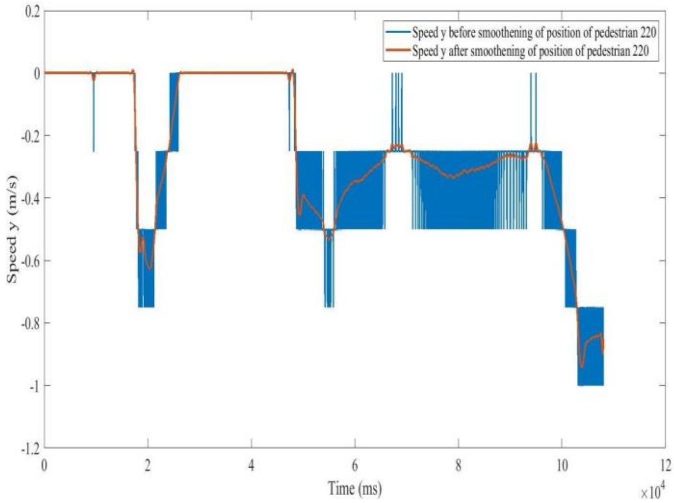

Fig. 4.8 Speed of pedestrian 220 throughout the time-frame in the x-direction

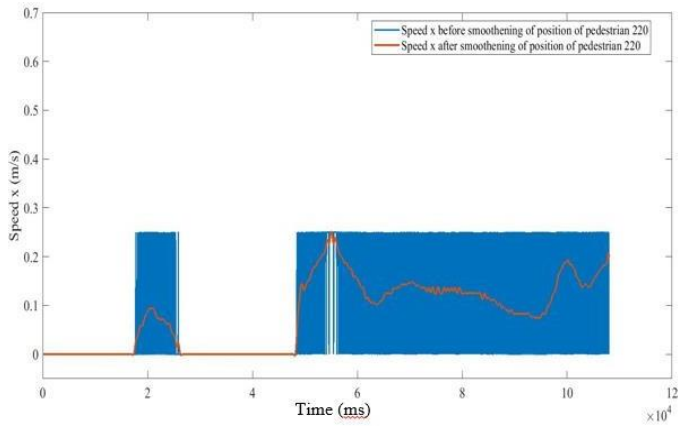

Fig. 4.9 Speed of pedestrian 220 throughout the time-frame in the y-direction

4.2 SPEED DISTRIBUTION AND FUNDAMENTAL DIAGRAM

These speed values are used to plot Figure 4.11, which presents the speed variation along the length of road. The region 1 denotes the starting section of road, which is not that crowded, due to which the average speed of that region is 0.78 m/s. But as we move from region 1 to region 2 which is around 10-12 m far away from region 1, the average speed goes down to 0.62 m/s. It is seen that the crowd were more at the back end, rather than in the front, therefore as one move far away from destination the average speed of pedestrian's decreases. Therefore, the increase in the crowd at the end of interaction decreases the average speed**.**

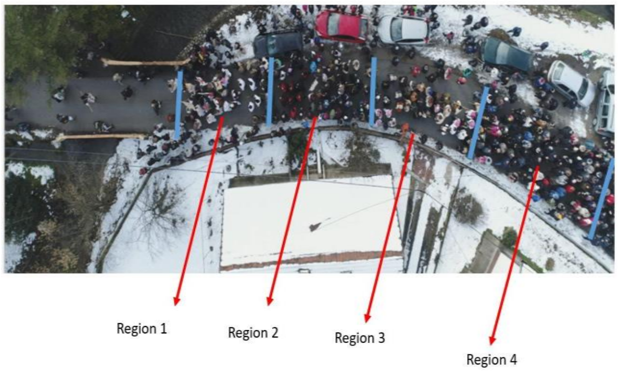

Fig. 4.10 Different Section of road for frequency distribution

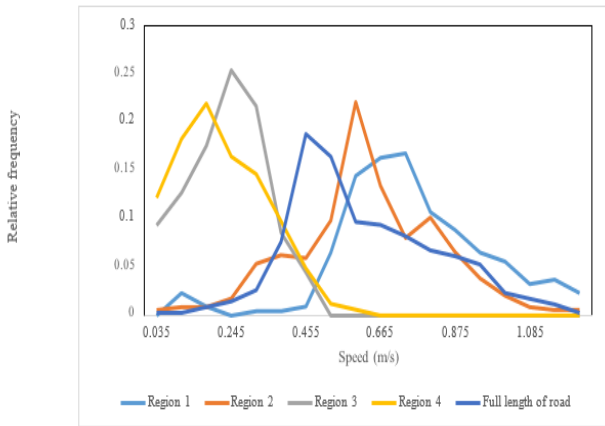

Fig. 4.11 Speed vs Frequency distribution along a different stretch of the road of 50 m length

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From Figure 4.12, the relationship between pedestrian speed and flow is defined. These curves, comparable to car flow curves, indicate that there is space available to choose greater walking speeds when there are few pedestrians on a path (i.e., low flow levels). But as the interactions between pedestrians became stronger, the speeds started decreasing as flow rises. Moreover, a situation will arise when the flow will become critical, and at this stage, it will be difficult to move, and then both flow and speed will decrease.

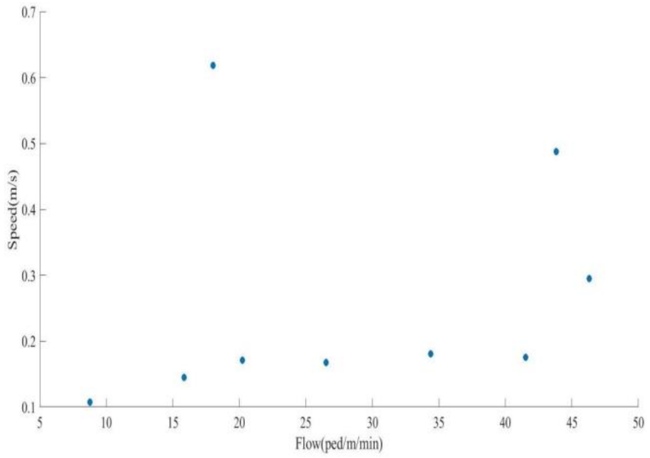

Fig. 4.12 Relationship between pedestrian speed and flow

From figure 4.13, it can be concluded that the graph of pedestrian speed vs density is similar to vehicular traffic. As the density starts increasing, the average speed of the pedestrians starts decreasing as it is difficult to manoveure in the high-density situation because of less space available and also pedestrians generally maintains some distance from the stranger. Therefore, if pedestrian density starts increasing, then the average speed of pedestrians will decrease, and there may be chances of the arising a situation in which there is full jam means no movement at all.

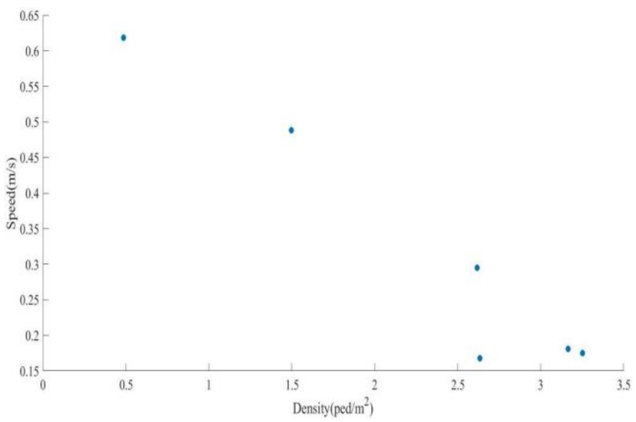

Fig. 4.13 Relationship between pedestrian speed and density

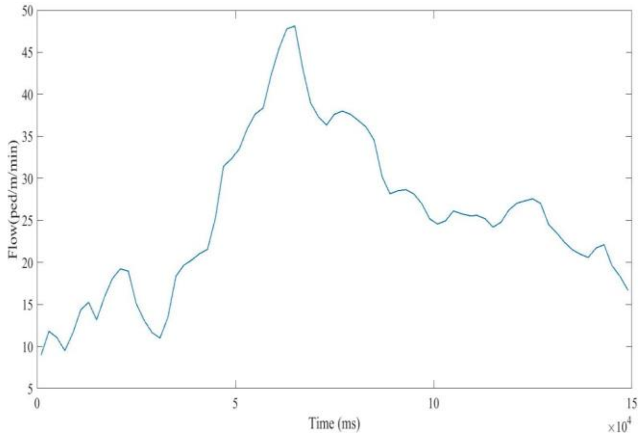

Fig. 4.15 Variation of pedestrian flow over time

From Figure 4.14, it can be concluded that initially, the pedestrian flow was very less at the junction as it was crowded, and no pedestrian was allowed to move. But with the time, more pedestrians entered the length of road for the ongoing event and when the pedestrians were allowed to move then more and more pedestrians passed from the observed section of road to their destination, and pedestrian flow started increasing.

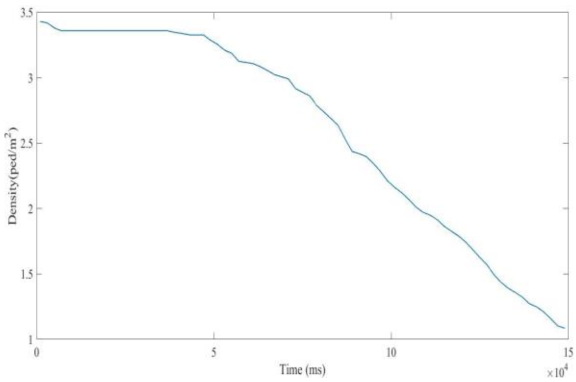

Fig. 4.15 Variation of pedestrian density with time

From Figure 4.15, it can be concluded that initially, pedestrian density is very high due to which the movement for the pedestrian was very slow as the three entry to the game was initially not allowed and everyone was just standing and waiting. Later, the entry to the game was allowed. Therefore flow was very less at the starting of time. After 5 seconds, pedestrians started moving, and the pedestrian density started decreasing because of movement is allowed towards the destination of the pedestrian. Therefore, more space was available for pedestrians after the 2.5 minutes.

4.3 SIMULATION RESULTS

As discussed in the research methodology, pedestrians were simulated using Social Force model. At the initial level, only one pedestrian is simulated with the help of the social force model, and the parameters were calibrated with the help of genetic algorithm with their lower and upper bound limit.

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4.3.1 Simulation of one pedestrian

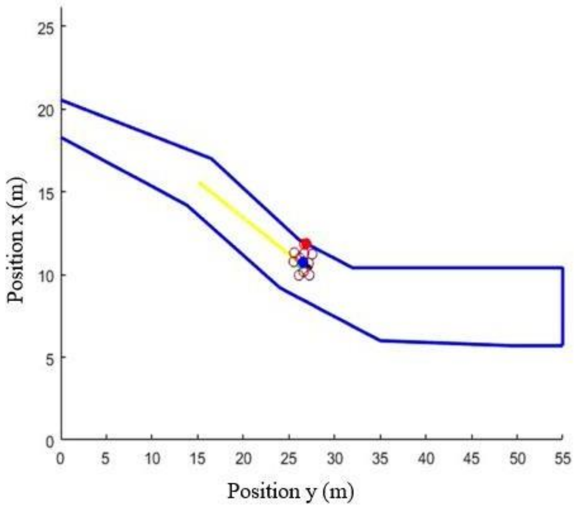

Fig. 4.16 Simulation of 1 pedestrian with Social force model. Blue dot represents the simulated pedestrian while the red dot shows the nearest location on the wall.

In the above Figure 4.16, one pedestrian is simulated, which is moving towards its destination. The other 10 pedestrians were moving based on their actual position. The blue one is the simulated pedestrian position, and the green one is its actual position

4.3.2 Simulation of three pedestrians

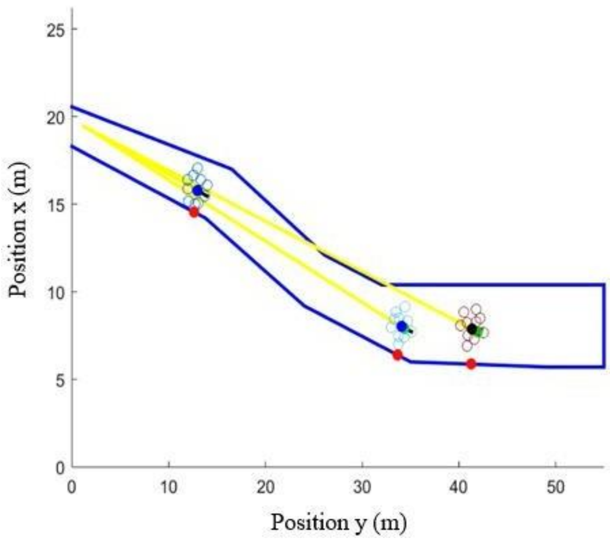

Fig. 4.18 Snapshot of three pedestrians simulated with Social force model

In the above Figure 4.17, three pedestrians are simulated, which is moving towards its destination. The other 10 pedestrians were moving based on their actual position. The yellow line shows its desired direction towards their destination.

4.3.3 Simulation of five pedestrians

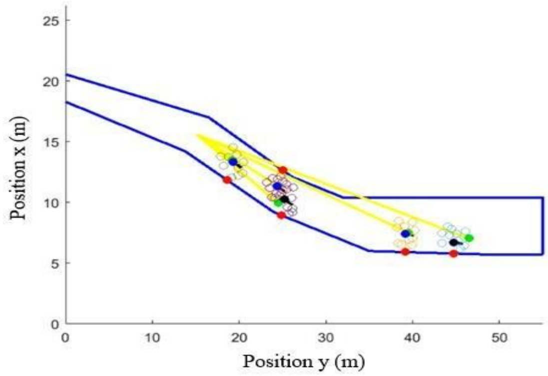

Fig. 4.18 Snapshot of Five pedestrians simulated with Social force model

In the above Figure 4.18, five pedestrians were simulated with the help of the social force model. Black and blue circle represent the simulated positions of pedestrians, respectively. The yellow line is showing the desired direction towards the destination. In this figure, pedestrians are moving approximately to their actual position, which is obtained from video analysis. Therefore, this calibration can be extended to other pedestrians to check whether it is working for large no of the pedestrians or not.

4.4 COMPARISON OF SIMULATED AND ACTUAL POSITIONS OF PEDESTRIANS

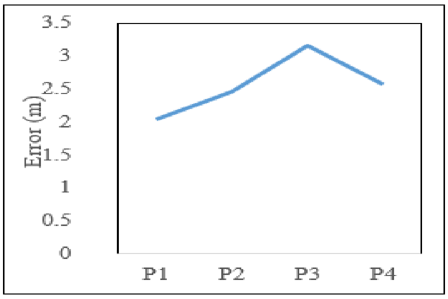

Fig. 4.19 Error obtained in positions of the simulated and actual position of a different set of one pedestrian

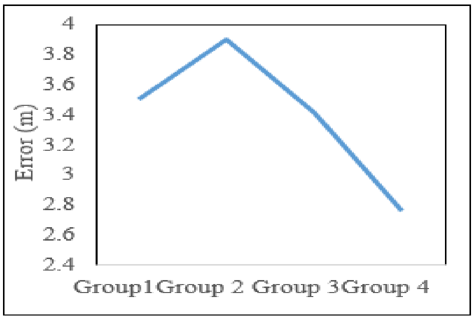

Fig. 4.20 Error obtained in positions of simulated and actual position of a different set of three pedestrians

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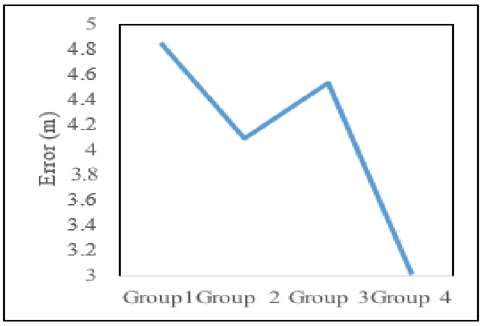

Fig. 4.21 Error obtained in positions of the simulated and actual position of a different set of pedestrians

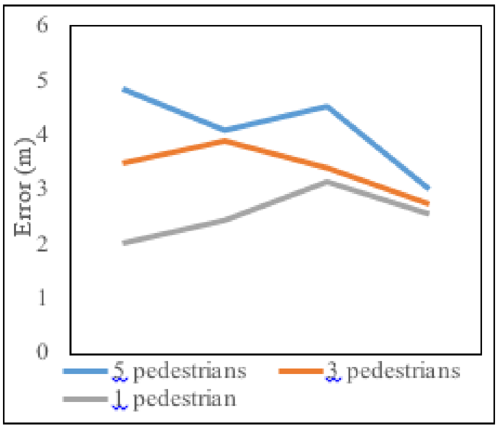

Fig. 4.22 Comparison between three different situations shown above

From the figure 4.22-4.24, it is observed that the error in position is significantly reduced if we applied the parameters which we get from a simulation of three pedestrians to five pedestrians rather than applying the parameters which we get from a simulation of one pedestrian. As it is already discussed that if we chose more pedestrians for simulation, our parameters would work more effectively because they were calculated on the base of all 3 pedestrians considering in the simulation.

Therefore, it will be beneficial to simulate large no of pedestrians, but it generally takes a lot of computation time to calculate the calibrated parameters with optimization. But if we take more and more pedestrians for calibration, then the difference in positional error will be optimized more efficiently and effectively.

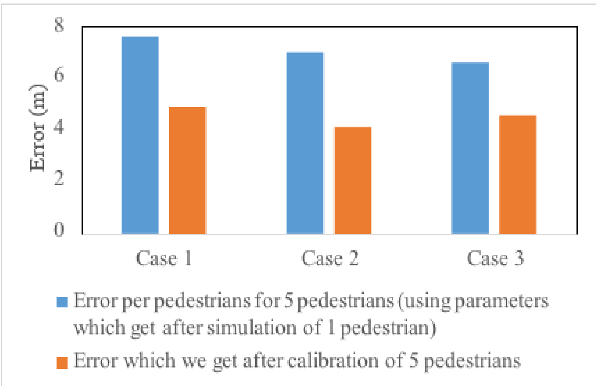

Fig. 4.23 Comparison of error in position after simulated parameters of one pedestrian applied to five pedestrians and actual parameters for five pedestrians

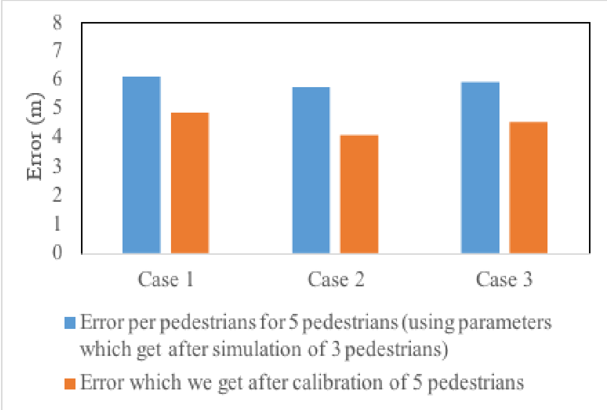

Fig. 4.24 Comparison of error in position after simulated parameters of three pedestrians applied to five pedestrians and actual parameters for five pedestrians

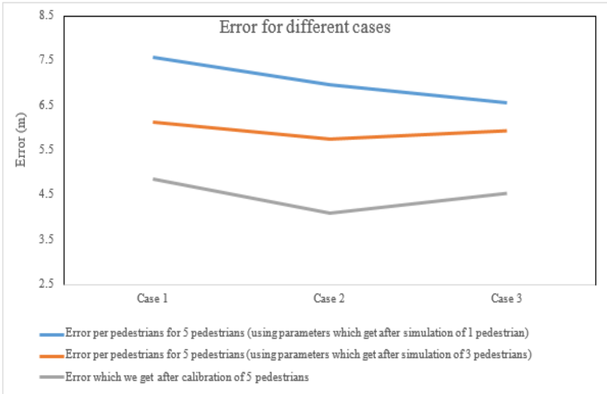

Fig. 4.25 Comparison of error in position after simulated parameters of one pedestrian applied to five pedestrians, simulated parameters of three pedestrians applied to five pedestrians and actual parameters for five pedestrians

5 CONCLUSION

Crowd management is a big issue throughout the world. Therefore, to achieve proper management of crowd, simulation techniques were used. These simulation techniques provide us with a better solution for providing pedestrian facilities in a better and efficient way. In the current work, Social Force model is evaluated for the simulation of a crowded real-world event. Video data of ongoing shocker event was collected from the drone, and pedestrian trajectory data were extracted and analyzed.

From the observed data, it can be seen that the average speed of pedestrian was decreasing with the increase in density, which ultimately can create chaos among the pedestrians. Later, the social force model (SFM) was used to simulate pedestrian movement behavior. The model was calibrated and validated with different parameters of SFM. It was observed that SFM was able to predict the pedestrian movement based on its neighborhood pedestrian condition. Model become robust if it was calibrated with a greater number of pedestrians trajectories simultaneously. Therefore, it can be concluded from this study that SFM has the potential to simulate pedestrian crowd behavior. However, the current study uses a maximum of five pedestrian simulation together for the calibration of the model. Model performance can be improved by simulating more and more pedestrians together to get the

robust values of the SFM parameters to simulate such crowd movement behavior. As the genetic algorithm takes high computational time during the calibration of the model, some other optimization techniques can be explored to minimize the error and to get the calibrated values of the parameters.
The current study can be used to simulate the pedestrian crowd movement during a various religious gathering at different places after proper calibration and validation.

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