SYNOPSIS

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Any space provided for human circulation (for example, airport terminals, sidewalks, shopping malls, fair grounds, etc.,) involves movement of pedestrians. Efficient design of facilities catering to pedestrian movement can be achieved only if one understands and can model pedestrian flow. In this thesis work an attempt is made to (i) closely observe pedestrian flow, and (ii) from these empirical observations model this flow.

In the first part of this thesis, experiments are conducted to empirically study pedestrian flow. Pedestrian movement is broadly classified as either movement inside enclosed spaces with few entry–exit points or movement through corridors. So, in this thesis work experiments on these two distinct types of movement are conducted to understand how the flow parameters change spatially and temporally inside the flow space. Also, experiments are conducted to develop the speed–density plot (fundamental diagram) for Indian pedestrians as no such data exists and this is a prerequisite for any pedestrian flow modelling.

In order to develop the fundamental diagram, as is the practice, experiments on single file pedestrian flow without overtaking in a closed corridor are conducted. Flow data is recorded through appropriately located video cameras. Later, the speed–density data is extracted from the recorded flow. This data is analyzed to obtain representative speed–density (or alternatively, distance headway–speed) relationship.

In order to understand pedestrian movement through corridors, an open corridor is constructed. Flow data is recorded using overhead video cameras on a virtual grid superimposed on the corridor. The virtual grid (which the pedestrians do not see or feel) is created on the recorded data using simple techniques which only assume that camera location and orientation remain the same throughout a given experiment. Both uni–directional flow and bi–directional flow are studied by asking pedestrians to move on the corridor (in the same or opposing directions). Pedestrians coming out at one end are asked to enter again from the opposing end. This process continues till a steady flow is achieved. Data is collected at this stage. The impact on flow of geometric variations in the corridor is studied by introducing different modifications to the corridor walls.

In order to understand pedestrian movement inside enclosed spaces, a closed space with variable number and size of exit locations is chosen. However, the exit locations are on one side of the closed space creating broadly uni–directional movement. As before, data is recorded on a virtual grid using overhead video cameras. Subjects waiting inside the closed space (at the end opposite to the exit end) are asked to vacate and data on their movement during the evacuation process is noted. Impact of exit width and number on flow is also studied. The flow space geometry is also changed (by placing obstacles in the space) in order to study impact of geometry on flow. Of course, these sets of experiments are not indicative of a general case of movements in closed space as the movement here is predominantly uni–directional.

The second part of this thesis relates to developing a model for pedestrian flow. Existing models are of mainly two types: (i) force based models which work on continuous space and time, and (ii) decision based models which work on discrete space and time. Force based models involve high computational cost and are often unable to simulate movements of large number of pedestrians; whereas, the available decision based models are based on ad–hoc rule sets and are typically applicable to specific situations. The model proposed here (named as FICAPeD, acronym for ***F****uzzy* ***I****nference based* ***C****ellular* ***A****utomata model for* ***Pe****destrian* ***D****ynamics*) attempts to mimic the human inference system while trying to minimize the computational cost. The model is briefly introduced in the following paragraphs.

The proposed model is a discrete microscopic model that describes the movement of individual pedestrians on a discrete representation of the flow space and time. The flow space is divided into various square cells and time is divided into discrete time steps. The flow space is also occupied by static features (goals and obstacles) and dynamic features (other pedestrians). Each static feature is assumed to create attractive (for goals) or repulsive (for obstacles) potential fields (similar to force field model). Each cell is assigned a resultant potential field obtained by adding all the potentials at the cell due to the various static features. This value remains unchanged.

Pedestrians are assumed to get influenced by dynamic features also. The dynamic features here are the other pedestrians or groups of pedestrians. It is felt that the size of the group and its quality of movement either attracts or repulses other pedestrians from following it. The size of the group is viewed in terms of density and the quality of movement in terms of the general direction and speed of the group as a whole (the definition of the latter needs careful considerations).

While moving a pedestrian implicitly decides, at every instant of time, the direction in which he/she should move and at what speed. Given this and the previous descriptions the basic structure of the model is developed; it is shown in Figure 1.

As seen in the figure, the static and dynamic features are used to infer how beneficial a particular direction is. Depending on this evaluation a direction and subsequently speed are chosen. Of course, these decisions impact the position of the pedestrian in the next instant of time and also the dynamic features. The process is repeated for as long as the pedestrian motion is to be modelled. Before going into briefly describing the inference system, and the direction choice and speed choice modules it should be noted that the basic process shown in Figure 1 is applicable for all pedestrians in a given time step and hence issues of updating scheme, tie breaking between competing pedestrian locations, etc., are important and have been adequately handled. They are

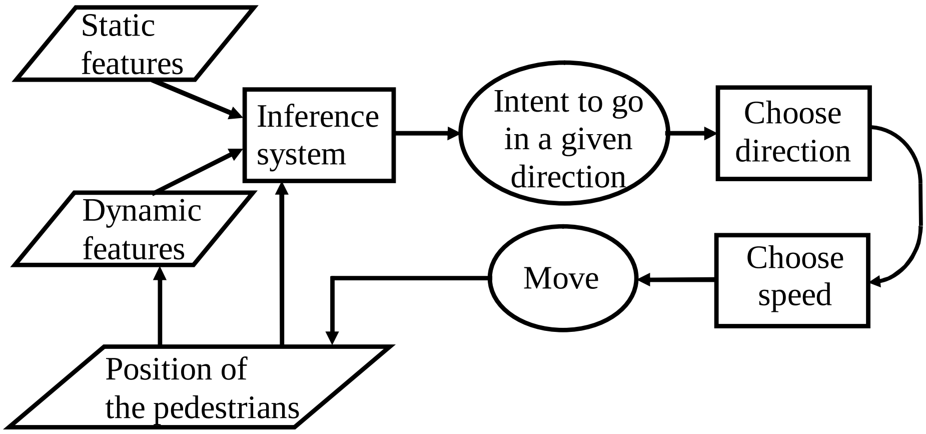

Figure 1: Structure of the model

neither included in Figure 1 nor explained here in the interest of brevity.

The inference of how beneficial a particular direction is, is based on a fuzzy inference system which considers the potential of cells, group size and quality of the group's movement as the antecedents or factors affecting the decision. The consequent is an indication of how intent the pedestrian is on moving in a given direction. Given the intent and the current direction of the pedestrian the pedestrian decides as to whether to continue on the same direction or change to a more lucrative direction. This is evaluated in the direction choice module. Given the chosen direction and the current speed, the speed with which the pedestrian wishes to (should) move is evaluated in speed choice module. This module utilizes the behaviour of pedestrians as illustrated in the fundamental relation.

FICAPeD is embedded in a pedestrian simulation model which is used to determine pedestrian motion in different situations. Observed data is used to calibrate as well as evaluate FICAPeD. Results show that the proposed model is computationally efficient. It is believed that the cellular representation and use of different strategies to represent static and dynamic features improve the computational efficiency. Results further show that FICAPeD predictions are quite accurate for the variety of cases studied here.

The main contributions of this thesis are:

(i) determination of the fundamental relation of pedestrian behaviour for Indians,

(ii) large scale empirical observations on pedestrian behaviour in a variety of different situations at the mesoscopic scale,

(iii) development of a generic model structure for pedestrian motion, and

(iv) development of FICAPeD, a fuzzy inference based microscopic model for pedestrian motion.