PEDESTRIAN MODELLING: AUTONOMY AND COMMUNICATION NEEDS

Elvezia M. Cepolina[(a)], Silvia Cervia[(b)], Paloma Gonzalez Rojas[(c)]

[(a)] University of Pisa, Department of Civil and Industrial Engineering
[(b)] University of Pisa, Department of Social Sciences
[(c)] Massachusetts Institute of Technology, Department of Architecture

[(a)] elvezia.cepolina@ing.unipi.it, [(b)] silvia.cervia@unipi.it , [(c)] palomagr@mit.edu

ABSTRACT
A better understanding of pedestrian movement can lead to an improved design of public spaces, to the appropriate dimensioning of urban infrastructure (such as airports, stations and commercial centers), and, most importantly, to a design that is more responsive to people and to that very fundamental human activity: walking.
Walking is a highly communicative and social activity: we walk with other people and meet strangers, friends and neighbors. The potential for such communication is in itself a measure of the quality of the space. However social integrations among pedestrians have been largely neglected in the analysis and in the planning process.
The research aims at modeling pedestrian needs, taking into account a more inclusive spatial behavior which includes both autonomy needs of pedestrian walking alone towards a target and communication needs of people walking in groups towards a target.

Keywords: pedestrians, groups of pedestrians, pedestrian communication needs, pedestrian autonomy needs, pedestrian modeling and simulation, heterogeneity in pedestrian needs.

1. INTRODUCTION
The literature about pedestrian locomotion could be roughly divided in two parts: engineering, physics and mathematicians focus on pedestrian obstacle avoidance behavior whilst sociologies and psychologies study human spatial behavior taking into account communication needs.
Human interactions between independent pedestrians have been extensively described in terms of collision avoidance behavior. As reported by Karamouzas et al. (2014), in terms of its large-scale behaviors, a crowd of pedestrians can look strikingly similar to many other collections of repulsively interacting particles (Helbing et al., 2001). These similarities have inspired a variety of pedestrian crowd models, including cellular automata and continuum based approaches (Hoogendoorn and Bovy, 2000), as well as simple particle or agent based models (Hoogendoorn and Bovy, 2003; Fajen and Warren, 2003; Reynolds, 1987). Many of these models conform to a long-standing hypothesis that humans in a crowd interact with their neighbors through some form of "social potential" (Helbing and Molnar, 1995), analogous to the repulsive potential energies between physical particles. Many simulation models are based on the Social Force model as presented in Helbing and Molnar (1995). The principle of the Social Force model aims at representing individual walking behavior as a sum of different accelerations: the acceleration of an individual towards a certain goal: it is defined by the desired direction of movement with a desired speed. The movement of a pedestrian, influenced by other pedestrians, is modeled as a repulsive acceleration. A similar repulsive behavior for static obstacles (e.g. walls) is represented again by accelerations. There exist several different formulations of the Social Force model in the literature: the first model from Helbing and Molnar (1995) is based on a circular specification of the repulsive force; the second model uses the elliptical specification of the repulsive force; in the third model the repulsive force is split into one force directed in the opposite of the walking direction, i.e. the deceleration force, and another one perpendicular to it, i.e. the evasive force.
In all these models human communication needs are neglected and pedestrians are represented as independent individuals that walk towards a goal. In doing that, autonomous individuals may be disturbed by other individuals and in this case they interact in order to avoid each other.
In social science instead, interpersonal distances have been analyzed not only as a consequence of repulsive accelerations due to other individuals, but in a wider context in terms of:

- Communication needs: interpersonal distance is viewed both as communicating information and as determining the quantity and quality of information exchanged
- Stress and overload: an individual maintains a preferred interaction distance from others in order to avoid excessive stimulation
- Constraints: personal space serves to provide an optimal level of behavioral freedom
- Ethology: interpersonal distance is adopted to protect against threats of physical attack.

The proposed research is a first step in the direction of developing a microscopic simulator able to reproduce pedestrian interactions in a given physical environment and the related discomfort. The simulation model we are developing is microscopic in the sense that every pedestrian is treated as an individual entity. The explicit and detailed modeling of individuals allows introducing subjective aspects characterizing specific motion, sensitive abilities and specific comfort needs. These are decisive elements for introducing individual heterogeneity in the model, in order to make it sensible to the behavioral variation related to the difference of gender, age and physical ability.

The paper aims at modeling pedestrian needs in terms of space, taking into account a more inclusive spatial behavior which includes both autonomy needs of pedestrian walking alone towards a target, and communication needs of people walking in groups towards a target. We'd like to underline the importance of modeling groups since a small amount of pedestrians walks alone (only one third of the pedestrians observed by Moussaïd et al. 2010) and pedestrian groups have an important impact on the overall traffic efficiency.

In the following, the term "group" is used here in its sociological sense, that is for indicating individuals who have social ties and intentionally walk together, such as friends. The term "stranger pedestrian" is used to indicate a pedestrian who walks alone and has not social ties with the other pedestrians.

When pedestrians are not able to keep their desired personal space, due to the interactions with stranger pedestrians, personal space drops and/or speed changes and/or changes in the trajectories occur. Depending on these reactions a discomfort results. In the case of personal space drops, the discomfort is related to the extension of the personal space that drops.

When pedestrians walking in a group are not able to keep conversation due to the absence of their friends in the communication area, discomfort results.

The paper has been structured in the following way: section 2 describes pedestrian needs in terms of space and proposes a model for personal space and communication space. Section 3 concerns the impact of personal space and communication space on the pedestrian's comfort. Section 4 outlines the simulator structure. Conclusions follow.

2. PEDESTRIAN SPACE MODELLING

Edward T. Hall in his study of human behaviors in public spaces (Hall, 1959, 1966) found that every person holds unconsciously a mobile territory surrounding him like a bubble. The violation of this space by a tierce person results in an effective reaction depending on the nature of relationship between two persons.

The space around a person could be divided into four areas: the intimate, personal, social, and public spaces as shown in Figure 1.

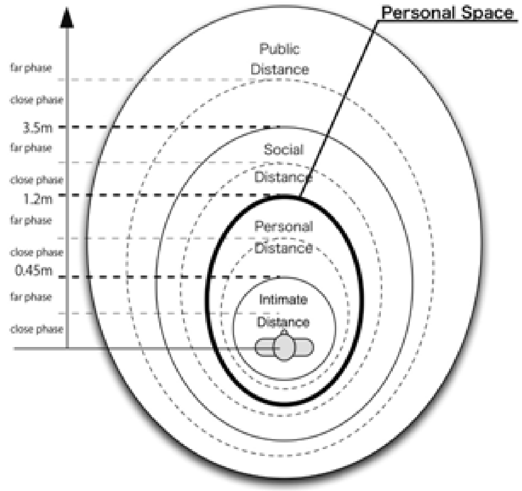

Figure 1: Structure of the space around a person (asaikarate.com).

The shape of the space around a person is affected by several parameters: intrinsic and extrinsic factors. Intrinsic factors include gender and age. Extrinsic factors are related to the social relationships that people maintain including: friendly relationship and stranger relationship. The effect of the main parameters have been analyzed in http://martintolley.com/environment/PersSpaceEnvPsy7.html and summarized in the following.

Gender: males interacting with other males require the largest interpersonal distance, followed by females interacting with other females, and finally males interacting with females. However it probably depends on the situation, or the relationship, or the age group and so on as well.

Age: some evidence suggests that the space around a person gets bigger as we grow older. Children tend to be quite happy to be physically close to each other, something which changes as awareness of adult sexuality develops. In addition the gender difference does tend to also appear at this time.

Culture: Hall (1959) identified the importance of cultural variation. He suggested that while all cultures use space around a person to communicate, and tend to conform to the different categories, the size of the space within the categories varies across cultures. Hall also identified the essential issue in inter-cultural difference as the tendency to interpret invasions of personal space as an indication of aggression.

Personality: there is some evidence of personality difference but effects here need to be treated with caution given the situational dependence of traits. Extraverted and gregarious persons tend to require smaller space, while cold and quarrelsome people require a larger interpersonal distance.

Situational effects on personal space: it is generally found that where attraction between individuals is strong, where friendships exist and where the general tone of the interaction is friendly, we are more willing to decrease our personal space requirement.

Alternatively where people dislike each other, and where the tone of the interaction is unfriendly, people move further apart.
Status: the general finding for status focuses on differences in status and it appears that the greater the difference in status between individuals, the larger the interpersonal distance used. There doesn't seem to be any evidence regarding personal space between same status individuals at different levels.

2.1. Autonomy Needs and Personal Space

The normal pedestrian behavior, according to Canetti (1984), is based upon what can be called the fear to be touched principle: “There is nothing man fears more than the touch of the unknown. He wants to see what is reaching towards him, and to be able to recognize or at least classify it.” “All the distance which men place around themselves are dictated by this fear.”
Personal Space (PS) has been defined as “an area with an invisible boundary surrounding the person’s body into which intruders may not come” (Sommer, 1969).
Humans have large multi-joined bodies, and because the clearance should be provided for all body parts to avoid contacting elements during locomotion in a confined and cluttered environment, avoiding collisions becomes more complex than just adjusting heading directions (Graziano et al., 2006).
It has recently been suggested that personal space is used by the locomotor control system to navigate safely around obstructions (Ge´rin-Lajoie et al., 2006). The same work showed that, for the rightward circumvention of a human-like obstacle at a natural walking speed, the left hemi PS had an elliptical shape with longitudinal and lateral radii representing on average approximately 2 and 0.5 m, respectively. People enlarged their PS when their attention was divided between the avoidance task and auditory stimuli. This effect was shown to be even greater in older adults.
Personal space has been measured in shape and size in ten adults as they circumvented a cylindrical obstacle that was stationary within their path (Figure 2).

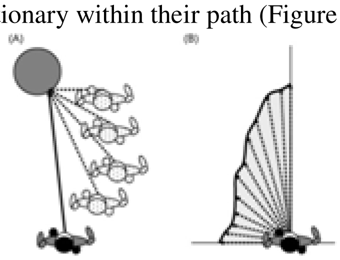

Figure 2: Personal Space experiments (Ge´rin-Lajoie et al., 2006)

The amplitude of personal space was not found to be a function of the walking speed since it resulted always equal to about 1 square meter. There was a main effect for the size of the PS with respect to the avoidance side, with the right side being smaller than the left side.
Many previous studies suggested that the shape of the PS varies with the face orientation. For example, the PS is twice wider in the front area of a person than in the back and side areas.
According with these empirical results, neglecting the asymmetric nature of personal space, assuming that the characteristics of personal space do not change during fixed and mobile obstacle circumvention, we assumed that each individual has the personal space shown in Figure 3.

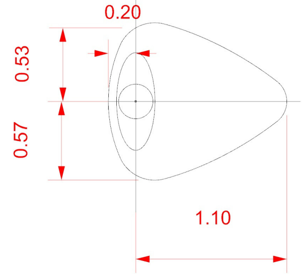

Figure 3: Model of Personal Space

2.2. Communication Needs and Communication Space

In the data collected by M. Moussaïd et al. (2010) at low density, group members tend to walk side-by-side, forming a line perpendicular to the walking direction, thereby occupying a large area in the street. Hence, when the local density level increases, the group needs to adapt to the reduced availability of space. This is done by the formation of 'V'-like or 'U'-like walking patterns in groups with three or four members, respectively. These configurations are emergent patterns resulting from the tendency of each pedestrian to find a comfortable walking position supporting communication with the other group members (Moussaïd et al. 2010)

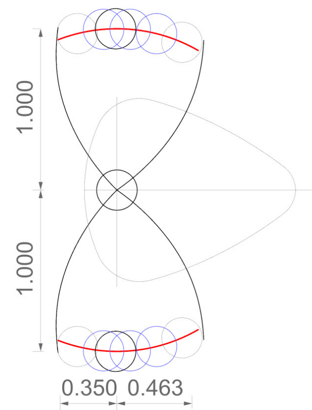

Figure 4: Model of Communication Space

Figure 4 shows the models we propose for the communication space and the personal space of a pedestrian. The communication space (with a shape like butterfly wings with the subject in the middle) include the possible positions of other group members when they communicate with the subject while walking. The proposed communication space model is based on empirical observation about average angle and distance values between group members, for different group size and density level, provided in Moussaïd et al. (2010).

3. IMPACT OF PERSONAL AND COMMUNICATION SPACES ON THE SUBJECT'S COMFORT

3.1. Interactions with stranger pedestrians

Since different regions in the PS, with the same extension have different impact on the pedestrian's discomfort, we divided the personal space in cells. A weight w_K is assigned to each cell k. The weight is proportional to the importance of the cell space for the comfort of the subject.

Figure 5 refers to the case a pedestrian walks alone and shows the subject's comfort (on the y axis) as a function of the distance of the PS's cells from the subject (which is represented on the x axis). So, if a cell very close to the subject drops, the comfort is zero; if a cell on the border of the PS drops, the comfort is high even if not at the maximum level. The comfort is maximum only if there is not any drop in PS.

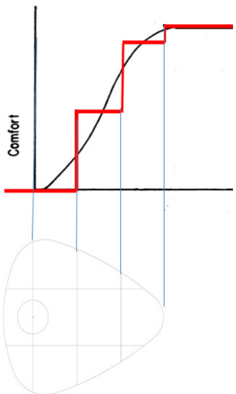

Figure 5: Impact on comfort of the PS's cells

Weights have been assigned to each cell. First, we assigned a weight (from 1 to 3) to each main direction around the subject (forward: 3, lateral 2, backwards 1); secondly we assumed that the weight decreases increasing the distance from the subject (with a rate of 1 point on each cell). Finally, we normalized the resulting values. The resulting weights are shown in Figure 6.

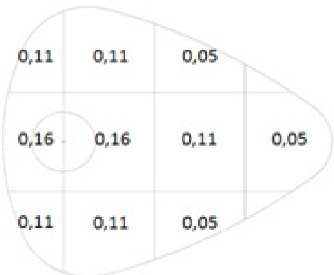

Figure 6: Weights of the PS cells

If a drop in PS occurs due to interaction with stranger pedestrians, a subject perceives a discomfort which increases as the dropped PS area increases.

In this case, the subject's comfort is assessed according to equation (1) :

$$COMFORT^A = 1 - \frac{\sum_{\forall k\epsilon PS^A} w_k * PSarea_k^{dropped}}{\sum_{\forall k\epsilon PS^A} w_k * PSarea_k^{desired}} \quad (1)$$

Where:

$COMFORT^A \, \epsilon[0,1]$ is the comfort in a given time instant perceived by subject A.

w_k is the weight of cell k. k is a generic cell of the subject's personal space (PS^A).

$PSarea_k^{dropped}$ is the extension (m^2) of the cell k that drops due to interactions with stranger individuals.

$PSarea_k^{desired}$ is the extension (m^2) of the cell k in the subject A's personal space.

The methodology for assessing: the extension of the PS area that drops due to too small interpersonal distances is described in Cepolina et al (2015).

3.2. Low quality of communication

In the case pedestrians walk in groups, if they are not able to keep the conversation they feel a comfort reduction.

Since different regions in the Communication Space (CS), with the same extension have different impact on the pedestrian's communication quality, we divided the personal space in cells. A weight w_K is assigned to each cell k. The weight is proportional to the importance of the cell space for the communication quality.

The impact of each cell of the Communication Space on the subject's quality of conversation is shown in the Figure 7. The figure refers to a subject walking in the direction of the y axis

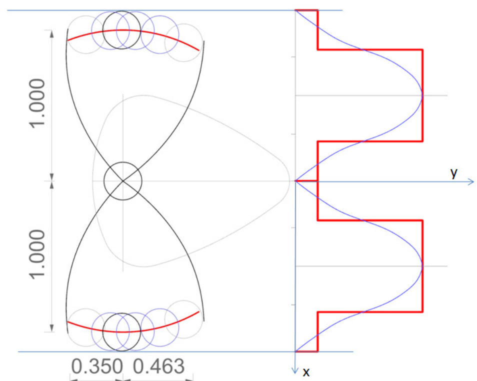

Figure 7: Communication Space and the related impact on the quality of conversation

The red line, on the left side of the figure, represents the comfort related to the quality of communication (on the y axis) against the distance from the subject.

From the subject's position, increasing the distance in the direction orthogonal to the motion direction, the impact of the cells within the communication space on the subject's comfort first, decreases as the distance of

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the cells from the subject increases; secondly, increases as the distance of the cells from the subject increases; and then, again decreases as the distance of the cells from the subject increases. Figure 8 shows the CS and the weights that have been assigned to space inside the CS. A given PS's area with a give weight could be composed by several cells: to each cell the same weight will be assigned.

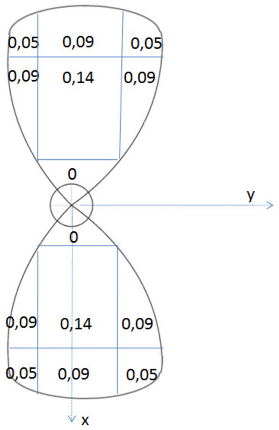

Figure 8: Weights of the CS's areas

If during the motion in a physical environment, a pedestrian is able to keep the other group members in the CS cells characterized by the maximum weight, the comfort is maximum (equal to 1). If not, according to the positions of the group members' centers of mass with respect to the subject's CS, the subject feels a reduced comfort (<1) given by:

$$COMFORT^{A} = \frac{\sum_{\forall k \epsilon CS^{A}} w_k * CellStatus_k}{N * \max_{\forall k \epsilon CS^{A}} w_k} \quad (2)$$

Where:

$COMFORT^{A} \epsilon [0,1]$ is the comfort in a given time instant perceived by subject A.

$CellStatus_k$ assumes a Boolean values: it is 1 if the cell is occupied by the center of mass of a member of the subject's group; it is 0 otherwise.

N is the number of members in the subject's group

4. SIMULATION MODEL

We now discuss a microscopic simulation model (Cepolina and Tyler, 2004) that shows promise of being able to incorporate the conceptual principles discussed so far in this paper; however the target of the following sections is not to be exhaustive on the simulation model since it is under implementation.

The main aim of the research is to simulate pedestrian behaviour in pedestrian physical environments (like museums, commercial centers, public transport stations) taking into account both pedestrians walking alone and pedestrians walking in groups. The phenomena being analyzed refer to the interactions between pedestrians. Each pedestrian has unique space needs: in this way the model is able to include individual pedestrians. Owing to these aspects, this simulation model is different from other microscopic simulation models of pedestrian behavior.

The simulator, which main input and output data are shown in figure 9, is object oriented, specifically suitable for the simulation of parallel processes, flexible and applicable to new scenarios. The simulation model is discrete in time and space. The physical environment is represented in terms of a discrete grid of square cells.

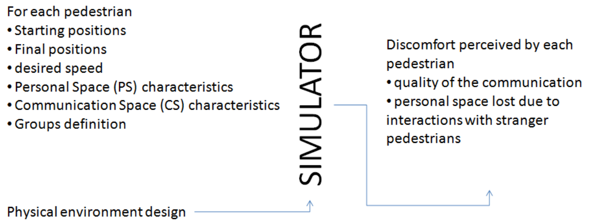

Figure 9: Simulator input and output data

The simulator environment is written in MODSIM III language. The research presented in the paper contributes to the characterization of some attributes (PS and CS) of the pedestrian object. The main methods of the pedestrian object are underlined in Figure 10.

Current (t) positions of pedestrians in the area
For each pedestrian (subject):
1. Detection of potential obstacles within the subject perceptual area, given the current position of the subject
2. Foreseen of the positions of the detected potential obstacles in the next time step
3. For each possible position of the subject in the next time step:
    a. assessment of the PS of the subject in the next time step
    b. assessment of the CS of the subject in the next time step, if the subject belongs to a group
    c. assessment of the subject foreseen discomfort in terms of
        a. the drops in PS due to interactions with stranger pedestrians, given their foreseen positions
        b. quality of the communication with the other elements in the group, given their foreseen positions
        c. delay due to a possible change in trajectory or in speed
    END for 3
4. Assessment of the best position of the subject in the next time step, given the assessed discomfort values for each of the possible position (evaluated at point 3)
5. Subject position updating

END (For each pedestrian (subject))
t:=t+Δt

Figure 10: Main methods of the pedestrian object

5. CONCLUSIONS

Pedestrian flows have been studied through analogies with gases, fluids and granular media. Nevertheless these analogies, the equations are difficult and not flexible. As a consequence, current research focuses on the pedestrian as a set of individuals paradigm. This means microscopic models, where collective phenomena emerge from complex interactions between many individuals (self organizing effects). The motion of individuals is described by mathematical equations that do not reproduce explicitly human behavior but are able to give rise to realistic emerging phenomena of pedestrian flows: in terms of lane formations of uniform walking direction; oscillatory change in the flow direction at bottlenecks in case of bidirectional flows and moderate density; stripe formation in intersecting flows. These mathematical equations allow the computer simulation of large number of homogeneous pedestrians (social force model, cellular automata of pedestrian dynamics and AI based models). Realistic simulation of a crowd of people is a challenging area also of computer graphics. Many of the problems with creating lifelike 3D animated models have been solved, but the difficulty lies in creating behavior that is believable.

The proposed pedestrian simulation model is based instead on a behavioral approach and tries to include socio-physiological aspects that characterize human behaviors.

The paper presents a model of personal space and a model of the communication space, which are input data for the proposed simulator. The paper analyses the state of art and provides average characteristics of these spaces. In the next future empirical research will allow to introduce individual heterogeneity in the proposed models of personal space and communication space in order to make it sensible with respect to age, gender, physical ability.

The overall presented research constitutes a preliminary activity for the simulator development.

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