PEDESTRIAN MODELLING: DISCOMFORT ASSESSEMENT

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ABSTRACT

A bad design of a pedestrian infrastructure hardly achieves congestion in the pedestrian flow, it is easier than it causes only bother among the pedestrians. Nevertheless infrastructures bad planned might result not accessible to particular classes of consumers in normal situations or might provide low levels of service linked to low comfort in using them.

The authors are developing a microscopic simulator that aims at analyzing virtual indoor and outdoor pedestrian environments in order to assess the quality of their design. The quality of the design is based on the comfort of people moving around the environment and is a function of the level of satisfaction of every pedestrian.

The paper proposes a methodology for assessing the discomfort resulting from interactions between pedestrians, in a given physical environment, in terms of personal space lost and low quality of communication. The proposed methodology has been applied to a real case of study. Pedestrian positions have been obtained by a photogrammetric survey.

Keywords: pedestrian discomfort assessment, personal space, communication space, quality of communication, interpersonal distances, object-oriented simulation.

1. INTRODUCTION

The research aims at developing a simulator for the analysis of virtual indoor and outdoor pedestrian environments (like museums, commercial centers, public transport stations) in order to assess the quality of their design. The quality of the design is based on the comfort of people moving around the environment and should be a function of the level of satisfaction of every pedestrian and not of the level of service related to the mean characteristics of the pedestrian traffic flow (Cepolina and Tyler, 2004). The comfort is also linked to the possibility to maintain a free space, during the motion, that every pedestrian requires around itself, and to the possibility of continuity of the communication with other pedestrians, if the pedestrian is part of a group.

Owing to these aspects, the simulation model we are developping is different from other microscopic simulation models of pedestrian behaviour: Pedflow (Kerridge and McNair, 1999), the agent based models developed by the Centre for Advanced Spatial Analysis at University College London: SimPed (Leal et al., 2005), the 'social force' model (Helbing and Molnár, 1995)), the 'self-organization' model (Helbing and Molnár, 1997) and the Gwenola model (Gwenola, 1999).

The simulator 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 simulator environment is written in MODSIM III language. The main input and output data have been reported in Figure 1.

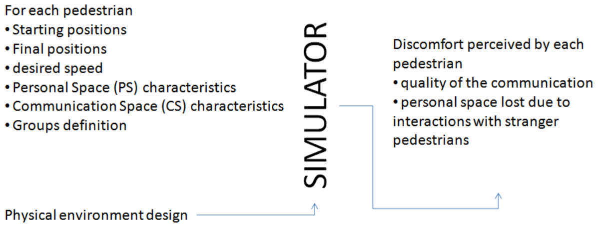
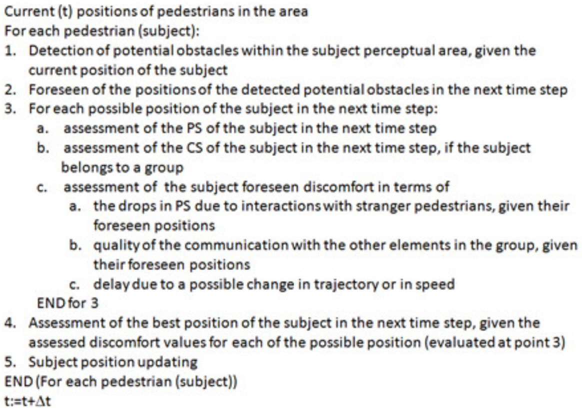


Figure 1 - Simulator input and output data



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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
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Figure 2: Main methods of the pedestrian object definition

The paper concerns a methodology for assessing, given the pedestrian positions:

- the drops in personal space that lead to discomfort (point 3. c. a. in Figure 2) and
- the quality of conversation that depends on the relative positions of group members (point 3. c. b. in Figure 2).

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.

2. INTERACTIONS BETWEEN STRANGER PEDESTRIANS

Each pedestrian has a personal space (PS), as described in Cepolina, Cervia and Gonzales (2015). If during the motion in a physical environment, the pedestrian is able to keep the whole personal space, the comfort is maximum (=1). If some cells of the PS drop due to the interaction with stranger pedestrians, the pedestrian feels a reduced comfort given by equation (1).

The proposed methodology aims to assess the extension (m^2) of the cell k that drops due to interactions with stranger individuals.

The methodology is based on the Voronoi cells. In mathematics, a Voronoi diagram is a partitioning of a plane into regions based on distance to points in a specific subset of the plane. That set of points is specified beforehand, and for each seed there is a corresponding region consisting of all points closer to that seed than to any other. These regions are called Voronoi cells (Wikipedia).

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

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.

Given the current positions of the centers of mass of pedestrians, we assess a Voronoi cell for each pedestrian walking alone and for each group of pedestrians. To do it, we used Grasshopper which is a graphical algorithm editor tightly integrated with Rhino's 3-D modeling tools.

The following figure refers to 2 stranger pedestrians that interact due to the small interpersonal distance. The center of mass positions and pedestrians' personal spaces are shown on the left side as well as the segment that links the 2 centers of mass and the orthogonal line that define the 2 Voronoi cells. The line that defines the Voronoi cells cuts the 2 personal spaces and thus, defines the personal space areas that drop due to the interaction ($PSarea^{dropped}$). The personal space area that does not drop due to the interaction is shown on the right side of the Figure 3.

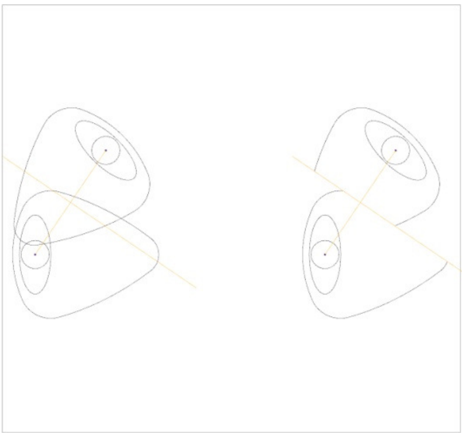

Figure 3: Assessment of PS drops due to the interaction with a stranger pedestrian

Figue 4: Assessment of PS drops due to the interaction between a stranger pedestrian and a group

Figure 4 refers to a stranger pedestrian that interacts with a group of pedestrians. The personal spaces of all the pedestrians are shown: in red the one of the stranger pedestrian, in blue the ones of the group members. The center of mass position of the stranger pedestrian is shown; the group's center of mass position has been assessed. Given the positions of the two centers of mass, it is possible to build the segment that links the two centers of mass and thus the orthogonal line that defines the two Voronoi cells, as shown in figure 4. The line that defines the Voronoi cells cuts the stranger's personal spaces and the personal space of one of the group members. The personal space area that does not drop due to the interaction is shown on the right side of the figure.

3. INTERACTIONS BETWEEN GROUP MEMBERS

Pedestrians belonging to groups have a communication space (CS), as described in Cepolina, Cervia and Gonzales (2015). According to the relative positions of the group members, the individual discomfort due to a low quality communication is assessed.

If during the motion in a physical environment, a pedestrian is able to keep the other group members in the CS's 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, the pedestrian feels a reduced comfort (<1) given by equation (2):

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

Where:

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

$\mathrm{CellStatus}_k$ 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. EMPIRICAL DATA

Experiments have been organized at the University of Pisa. 40 students participated to the experiments. Some participants have been divided in groups of different dimensions and have been asked to cross a pedestrian street inside the university campus and to talk with the other group members while walking. Some other participants have been asked to walk alone along the street as "stranger" pedestrians and to interact with the groups.

Data relating to the pedestrians positions against time have been collected.

The target was to apply the methodology proposed in sections 2 and 3, in order to assess the discomfort resulting from interactions between pedestrians in terms of personal space lost and low quality of communication.

Pedestrians have been assumed homogeneous with respect to personal space and communication spaces. The dimensions of these areas have been assumed according to average values provided in Cepolina, Cervia and Gonzales (2015).

4.1. Photogrammetry for pedestrian route surveying

In order to obtain the coordinates of the canters of mass of each pedestrian in each time step, a photogrammetric survey has been performed. In detail, since for the research purposes the road surface on which pedestrians move can be assumed as planar, a monoscopic photogrammetry survey has been performed, with subsequent homography data processing.

4.1.1. Homography

A photographic image is a center perspective view of an object, where different elements have variable scales, and therefore image objects may not be directly measured.

Photogrammetry techniques allow to solve this problem by means of stereoscopy, i.e. by surveying the same scene at the same time from two different viewpoints it is possible, by way of collinearity equations (3), to compute internal and external orientation parameters of the camera (X0, Y0, Z0, rij, ξ0 , η0 and c).

$$X = X_0 + (Z - Z_0)\frac{r_{11}(\xi - \xi_0) + r_{13}(\eta - \eta_0) - r_{13}c}{r_{31}(\xi - \xi_0) + r_{32}(\eta - \eta_0) - r_{33}c}$$

$$(3)$$

$$Y = Y_0 + (Z - Z_0)\frac{r_{21}(\xi - \xi_0) + r_{22}(\eta - \eta_0) - r_{23}c}{r_{31}(\xi - \xi_0) + r_{32}(\eta - \eta_0) - r_{33}c}$$

These parameters define the internal reference system of the camera and set the six degrees of freedom in space, framing the camera in the real world reference system of the survey object. Subsequently, by way of the same equations it is possible to obtain the 3D coordinates (X, Y and Z) of each point of the scene from its pixel coordinates (ξ, η) digitized on a pair of images.

If the survey object lies entirely on a plane, the collinearity equations are simplified in homography equations (4). These allow, once the 8 parameters (ai, bi e ci) have been computed, to define planar X and Y coordinates on the basis of ξ and η digitized on a single image.

$$X = \frac{a_1\xi + a_2\eta + a_3}{c_1\xi + c_2\eta + 1}$$

$$Y = \frac{b_1\xi + b_2\eta + b_3}{c_1\xi + c_2\eta + 1} \quad (4)$$

In order to assess the 8 parameters, the coordinates of at least 4 points of a plane object should be known.

4.1.2. Photogrammetric survey

In order to collect images from which pedestrian canter of mass coordinates could be obtained, a SLR Nikon D700 still camera, fit with a fixed 20mm lens has been placed about 10m above the road plane, with the focal axis roughly orthogonal to this.

At this height, ground coverage on the wide side of the image was roughly 20m, with a Ground Sampling Distance (GSD), i.e. the ground-level size for each pixel, of about 5mm.

The camera position did not vary during the survey; shots were triggered in time lapse every second, with a total duration of 10 minutes.

Besides, in order to solve the homography equations, coordinates of 10 Ground Control Points (GCP) lying on the road plane have been surveyed and framed in a local reference system, allowing to compute the 8 unknown parameters (Figure 6).

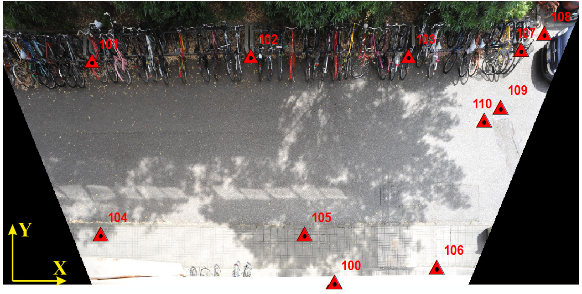

Figure 6: GCP on rectified image

4.2. Interface for data digitization

As already stated in paragraph 2.2.1, once the 8 unknown homography parameters have been computed it is possible to obtain the actual X and Y coordinates of any point on the object plane from image coordinates.
In order to build the required data base, a dedicated software has been implemented in the Matlab environment.
A GUI enables operators to sequentially view images and to digitize pixel coordinates of pedestrians' feet, also associating any information required for the subsequent modelling step (Figure 7).

Figure 7: Pedestrian foot digitalization interface

In detail, the GUI assigns a univocal ID to each pedestrian, indicates its gender, labels it as a single pedestrian or a group member: in this case, it links the pedestrian's ID with the ID of the other group members. This information is then entered in a worksheet, in which homography equations compute the actual coordinates; these, in turn, yield the data required for modelling, including the trajectories of each pedestrian (Figure 8).

Figure 8: Pedestrian trajectories

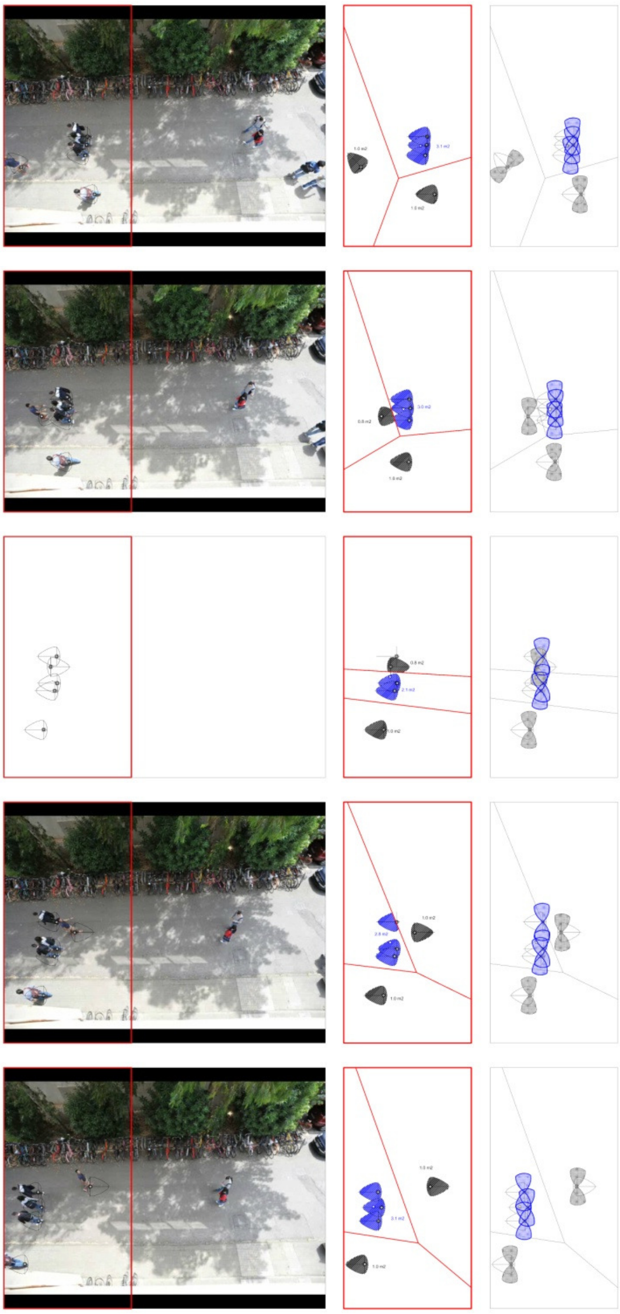

Figure 9: Comfort assessment in scenario 1

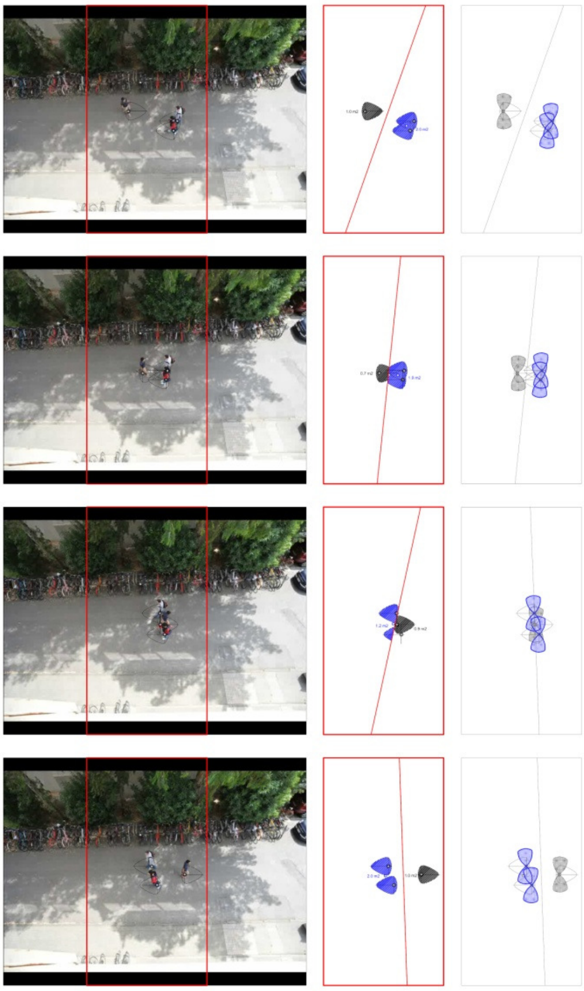

Figure 10: Comfort assessment in scenario 2

4.3. Results

Given the data base built with the methodology described in the previous section, we applied the proposed methodology for assessing the personal space lost due to interactions with stranger pedestrians and the comfort in communication for group members.

Two scenarios are here reported: the first one refers to a stranger pedestrian that crosses the street and interacts with a group of 3 individuals walking in the opposite direction. The second scenario refers to a stranger pedestrian that crosses the street and interacts with a group of 2 individuals walking in the opposite direction.

As it concerns the personal space drops, the Voronoi cells construction and the resulting personal space drops are shown in the middle part of the Figure 9, for scenario 1 and Figure 10 for scenario2.

As it concerns the assessment of comfort in communication for group members, the CS of each group member has been built given the subject position. For each cell k of subject's CS, the $\mathrm{CellStatus}_k$ value has been assessed given the positions of the centers of mass of the other group members. The assessment of the comfort related to the quality of communication is shown in the right side of the Figure 9, for scenario 1 and Figure 10 for scenario2.

5. CONCLUSIONS

The paper proposes a methodology for assessing individual comfort for pedestrians walking in a given physical environment. The characteristics of the individuals in terms of PS and CS have been assumed to be the same for all the pedestrians since we did not have data for assessing potential differences. Experiments have been organized in the university campus in Pisa in order to have a database for testing the proposed methodology. In order to obtain the pedestrians' coordinates, a photogrammetric survey has been performed and data have been analyzed. The resulting individual comfort is realistic and the methodology resuted able to cope with all the typologies of pedestrian interactions that occurred in the field.

In the next future we are interested in implementing in a simulator the proposed methodology in order to simulate the pedestrian positions against time and the related individual comfort. This will allow to analyze different designs for a given physical environment with different pedestrian loads (in terms of flows).

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