Perception based spatial tessellations of pedestrian dynamics

Marija Nikolić
Transp - OR, EPFL
1015 Lausanne, Switzerland
marija.nikolic@epfl.ch

Bilal Farooq
Transp - OR, EPFL
1015 Lausanne, Switzerland
bilal.farooq@epfl.ch

Michel Bierlaire
Transp - OR, EPFL
1015 Lausanne, Switzerland
michel.bierlaire@epfl.ch

Abstract

Traditional way to measure the pedestrian dynamics is through the fundamental diagram, which provides the relation between the flow characteristics, such as pedestrian velocity, density and flow. Nevertheless, the large differences are present regarding this fundamental relation in the specifications of various experimental studies, guidelines and handbooks, suggesting that pedestrian dynamics are still not well understood. Therefore, it is necessary to develop better data analysis methods based on precise empirical data, such as the trajectories of individuals. Owing to a close collaboration between Swiss Federal Railways (SBB CFF FFS) and École Polytechnique Fédérale de Lausanne (EPFL), we are able to study pedestrian dynamics on the basis of microscopic pedestrian data, collected at Lausanne train station using cutting-edge sensors for people tracking. Given the fact that the space representation is certainly the essential aspect affecting the pedestrian dynamics analysis, in this contribution we investigate the impact of underlying space decomposition on aforementioned pedestrian flow quantities, on the basis of individual pedestrian trajectories.

The physical space, within which the pedestrians perform their movement and interactions with each other and with the surrounding environment, could be considered in different ways. In this study we are focused on discretization of the space based on the grid and Voronoi diagram structures. The first method transforms the space into cell regions, where each cell is seen completely homogenous. In this case, one should think about the aspects related to cell size and a partitioning nature (static or dynamic). Another matter to be taken into account is the decomposition of the space at an individual level. For this purpose Voronoi based structures can be engaged. For the given point set (generator set) in the Euclidean plane the ordinary Voronoi diagram represents a tessellation of the plane into a set of the regions associated with the members of a given point set. The spatial tessellation is performed in such a way that all space locations are associated with the closest member of the point set, in respect of the Euclidean distance. The researchers from the transportation field have already used this form of space representation in order to enable a more precise measurement of the pedestrian density and velocity. Nevertheless, the ordinary Veronoi diagram is not the best space representation for capturing the observed real world phenomena. From everyday experience it is well known that a pedestrian movement requires a sufficient area. This area is related to a human perception field, due to the fact that people attach more importance to what is in front of them than to what is behind them, and what they are not aware of. Moreover, the fact that people avoid obstacles while walking is also to be taken into consideration.

Based on these facts we present an improved methodology for a pedestrian dynamics representation. This methodology extends the Voronoi diagram based representation of pedestrian dynamics to explicitly include the human perception of personal space. Thus, we have chosen to utilize the idea of the generalized, additively weighted Voronoi diagram, in which the weights are specified in order to reflect the phenomena observed. The generator set is represented by pedestrians' locations at a specific time. The individual's visible region of interest is incorporated using the Field of View (FoV) and obstacle avoidance strategy. A vector representing the pedestrian direction is associated with each member of the

generator set in order to be used for the FoV based calculation of the weights in space. In that manner, we define the Voronoi diagram characterized by the additively weighted *Voronoi generation distance*:

$$d_p(p, p_i) = \|p - p_i\| - \omega_i$$
$$\omega_i = \vec{v}_{pi} \cdot \vec{v}_{ppi}$$

where $\vec{v}_{pi}, \vec{v}_{ppi}$ represent unit vectors, defining the pedestrian direction, and direction from the pedestrian p_i to a plane location p, respectively, whereas ω_i represents the FoV based weight. Hence, the points along the negative direction of the associated vector $\vec{v}_{pi}$ are penalized more capturing the fact that, from a pedestrian's perspective, they do not contribute to its personal space. On the other hand, higher importance is given to the points from an individual perception field ($0^{\circ} - 180^{\circ}$): the points along the direction of the associated vector $\vec{v}_{pi}$ are closer to the pedestrian p_i using this 'distance' than using the Euclidean one; in the directions perpendicular to the associated vector $\vec{v}_{pi}$ this is still the Euclidean distance.

The perception weighted Voronoi polygon, assigned to the pedestrian p_i in the plane, is defined as:

$$V_p(p_i) = \{p \mid \|p - p_i\| - \omega_i \leq \|p - p_j\| - \omega_j, j \in \{1, \ldots, N_p\} \backslash \{i\}\},$$

and the corresponding bounded Voronoi diagram is:

$$V_{\cap S} = \{V_p(p_1) \cap S, \ldots, V_p(p_{N_p}) \cap S\},$$

where N_p and S represent the number of pedestrians and the geometry of the plane, respectively.

With the perception weighted *Voronoi generation distance* the bisector between pedestrians p_i and p_j is given by:

$$bisector(p_i, p_j) = \{p \mid \|p - p_i\| - \omega_i = \|p - p_j\| - \omega_j, j \in \{1, \ldots, N_p\} \backslash \{i\}\},$$

where N_p represents the number of pedestrians.

The difference between the space decomposition in the case of the ordinary and perception based Voronoi diagram for two members generator set is shown in the Figure 1.

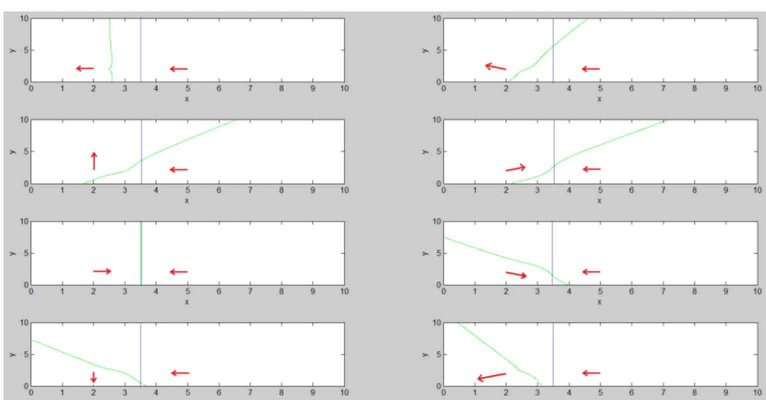

Figure 1. Ordinary and perception based Voronoi diagram (pedestrians with associated movement directions - red arrows; bisector between dominance regions of two pedestrians based on ordinary Voronoi diagram – blue line; bisector between dominance regions of two pedestrians based on perception weighted Voronoi diagram – green line)

The underlying assumption for the proposed space tessellation is that it is possible to connect two generator points by a straight line. This is not true in the case where the plane is not obstacle free. To take into account this particular case we use the *perception-weighted-obstacle-free-shortest-path* as 'distance', in order to create personal regions which do not overlap with obstacles. Excluding the FoV based weight portion, the path contains one part which is defined on the basis of a visibility graph. The visibility graph is the concept from computational geometry and robot motion planning defined by vertexes and edges, where vertexes correspond to the objects in the plane (generator set points and nodes of obstacles), and edges connect the vertexes which are visible with respect to each other (edges do not pass through any obstacle).

In that manner, the bisector between pedestrians P_1 and P_2, separated by an obstacle O, as presented in Figure 2, is defined as:

1. Region R_1 - the points visible from both, P_1 and P_2:
$$bisector(P_1, P_2) = \{p | \|p - P_1\| - \omega_1 = \|p - P_2\| - \omega_2\};$$
2. Region R_2 - the points visible only from P_1:
$$bisector(P_1, P_2) = \{p | \|p - P_1\| - \omega_1 = \|p - O_k\| + \|O_k - P_2\| - \omega_2, k \in \{1,2,3,4\}\};$$
3. Region R_3 - the points visible only from P_2:
$$bisector(P_1, P_2) = \{p | \|p - O_k\| + \|O_k - P_1\| - \omega_1 = \|p - P_2\| - \omega_2, k \in \{1,2,3,4\}\};$$
4. Region R_4 - the points are not visible neither from P_1 and P_2:
$$bisector(P_1, P_2) = \{p | \|p - O_k\| + \|O_k - P_1\| - \omega_1 = \|p - O_k\| + \|O_k - P_2\| - \omega_2, k \in \{1,2,3,4\}\};$$

such that $\|p - O_k\|$ represents the shortest path among all possible paths between plane point p and obstacle nodes O_k, obtained with the aid of visibility graph.

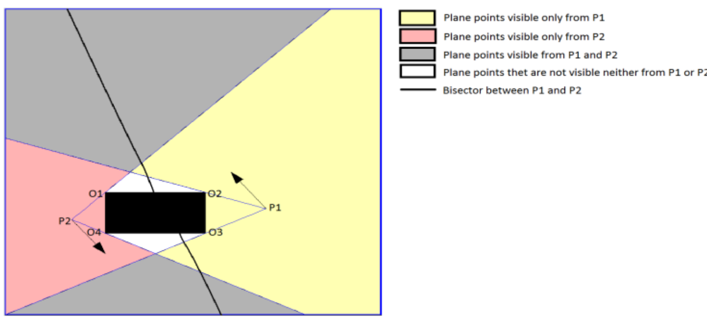

Figure 2. Perception based Voronoi diagram with obstacle

As a result, created personal regions have a perception dimension included and they are consisted of traversable points only. Based on the proposed space tessellation it becomes possible to obtain the fundamental pedestrian flow quantities such as density (inverse of the personal space) and achieved velocity at an individual level, as well as to derive a direct relation between them and therefore explain the pedestrian dynamics. The personal space, generated on the basis of FoV, varies over time by the pedestrian density, the change of direction and the presence of obstacles. Moreover, the flexibility of the concept of weights allows incorporating pedestrian flow and social characteristics, such as velocity and age for instance. As such, presented space decomposition, which accounts for environmental constraints and behavioral aspects, is a convenient underlying framework for future pedestrian dynamics modeling.

The methodology, presented in this paper, aims at better understanding and explaining the pedestrian dynamics in normal situations. The impact of the space representation on the basic flow quantities will be evaluated and the obtained empirical results will be compared to the theoretical models of pedestrians' flows published in the literature, with the aim to improve research on the pedestrian flow theory. Moreover, on the applied side, it will help us develop operational tools for policy makers that can be used for optimizing pedestrian flow in public spaces.

Keywords

pedestrian dynamics – space representation – generalized Voronoi diagram – obstacles – visibility graph