Visual urban space assessment from sky shape analysis

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Abstract

Most of existing computer methods to analyse the perception of the open spaces do not consider the Gibsonian *motion perspective*, i.e., the gradual changes in the visual field in the rate of displacement. This paper describes a new approach considering this motion perspective to analyse paths and routes in urban environments. Based on Teller's spherical metric, it proposes to use the skeletonisation as a way to trace the variations of the sky shape between successive views. It is thereby possible to structure the route into sequences, according to its potential interest in the urban environment.

1. Introduction

The heart of the urban life takes place in the open spaces of cities, i.e., streets, city squares, a variety of green spaces, and so on. These urban open spaces are characterised by a relation of strict duality with the 'filled elements' that surround them, like the buildings, the vegetation or fences (Teller 2003). However, they are 'abstract' by nature. The open spaces are not an element of the physical world, and their boundaries are quite fuzzy or contestable. In order to characterise the shape of the urban open spaces, Teller has developed a computer-based metric which proposes a *field-oriented* analysis of their configurations (Teller 2003). It is based on spherical analysis so as to take into consideration the 3D properties of urban open spaces. It is proposed to build upon this preliminary approach, in a view to address the perception of observers in motion.

Several techniques have already been proposed to study the visual perception of the urban environment along a route or a path (Sarradin 2002). Some of them are based on the Gibson's concept of *motion perspective* (Gibson 1950). According to this theory, the observation cannot be understood without movement. Hence, the motion is a part of the visual perception. The motion perspective refers to the gradual change in the rate of displacement of contour lines of the visual field. In this paper, we propose to develop a computer based method to analyse urban open

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spaces, with respect to the motion perspective. Our method is based on Teller's spherical metric and it takes advantage of skeletonisation and Hausdorff distance—techniques heavily used in image analysis—in a view to partition routes into sequences.

Section 2 briefly reviews existing computer methods to analyse the visual perception of urban environments. Section 3 gives a description of our method, based on a combination of spherical projections and skeletonisation technique in order to analyse the motion perspective. Some measures, derived from our method, are described in section 4. An interpretation of preliminary results is proposed. It is especially discussed how these measures can help to determine sequences in the observer route. Section 5 is a conclusion about the presented measures and their application.

2. Background

Different field-oriented methods have been proposed to relate the visual attraction of an urban environment, the way we see it, and its morphology (Sarradin 2002). Following Gibson's perception theory (Gibson 1950), Benedikt developed isovists which compute the shape on a plan of our visual field in order to study its geometrical surface (Benedikt 1979). Space syntax theory, developed by Hillier and Hanson proposes graph analysis of visibility relationships within buildings and urban configurations (Hillier 1984). Visibility graphs from (Turner, 2001) build upon this kind of analysis combined with isovist. It links the potential locations of an observer between them if they are visible one from the other. E-partitions divide the space into visually homogeneous regions, which enable to study the visual events in urban spaces (Peponis 1997).

Teller's spherical metric proposes to consider the shape of the sky perceived from given locations within the open space (Teller 2003). The variation of some parameters of this sky shape, as for instance its opening, is used to highlight the underlying structure of urban open spaces—limits, central area, main axes. The main advantage of this technique, when compared to the previous ones, is to consider the third dimension of urban open spaces while allowing to cope with its non-bounded character (the sky is assumed to be at an infinite distance from the ground). Several indicators of urban open spaces can be defined, which estimate the opening of sky shape, its eccentricity or its spreading.

All of these methods are based on a field-oriented approach of the urban open space. They are intended to highlight variations within the open space, which is no longer considered as static. They hence constituted an important step towards a better consideration of the dynamics of perception. Still none of these methods have been designed to characterise the dynamic variation of the visual environment, its progressive expansion, as it is perceived by an observer in motion. This effect,

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defined as the *motion perspective* by Gibson, would typically require to trace the deformation of visible shapes and apparition of new ones during movement. In this paper, we present a new method which consists in following these dynamic variations.

3. Analysis of sky shapes

The method we propose is based on spherical projection analysis of open spaces. In spherical views, all the urban environment visible from a given point can be represented within a single view and the sky is central to the figure. Projections are computed from urban 3D models and produce discrete images. Our method consists in extracting the shape of the sky from the picture and generating a simplified representation of it, defined as the skeleton or medial axis transform (**MAT**). According to the definition in (Blum 1967), let $S \subset R^2$ be a shape,

$$\mathbf{MAT}(S) = \{(p,r) \in R^2 \times [0, \infty)|\ B_r(p)\text{: maximal inscribed circle in } S\}, \qquad (1)$$

where p is a skeletal point and r the associated radius. More explicitly, **MAT**(S) is the set of all pairs of centres of the maximal inscribed circles in S and their radius. **MAT** keeps the geometrical and topological information of the original shapes. It is heavily used to decompose shapes in image analysis, but it has not yet been used to analyse the urban environment. Figure 1 represents the three first steps of our method: the route selection in a virtual urban environment, the spherical projections from successive points of the route, and the skeletonisation of the projection on each point. The next step of our method consists in analysing the deformation of those skeletons from one view to another one.

(1) (2) (3)

Figure 1
Computation of urban skeletons.

Several algorithms have already been proposed in the literature to compute skeletonisation of images. We decide to use the one developed by Pavel and Siddiqi, which is called Hamilton-Jacobi skeletonisation (Siddiqi 2002). It provides the most accurate skeletons, according to the Blum's definition. According to the Teller's

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spherical projection and the Blum's definition (equation 1), it provides the most accurate skeletons of the perceived shape and the less sensitive one to the noise of the boundary.

The sky shape boundaries are actually characterised by some *noise*, essentially due to the discretisation process and the lack of consistency of most urban 3D models. Effects of noise upon the results have to be strictly controlled even if spherical views tend to naturally reduce it (they give a greater importance to what is near the observer, which appears in detail, and compress what is far from the observer).

4. Measures and interpretations

We propose to analyse the skeleton sequences by the means of two measures: the greatest maximal disk (**GMD**) and the Hausdorff distance. In order to study them, they will be tested along a route in a model of *rue Xavier-Neujean* in the city of *Liège* (figure 2). This route has four interesting sections: S1 is a church, S2 is a place, S3 is an open parking lot, and S4 is crossroads behind a theatre. A projection of the sky is calculated every 5 meters on a route of 245 meters.

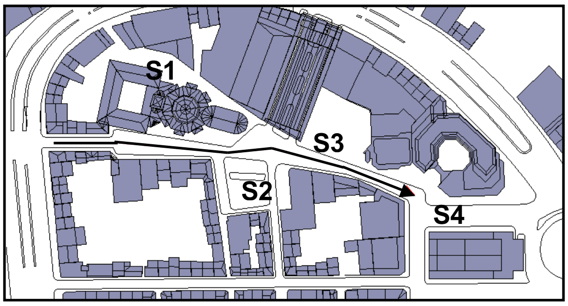

Figure 2
The route in *rue Xavier-Neujean* in *Liège*.

4.1 Greatest maximal disk

The **GMD** is the skeletal point with the higher minimal distance from the boundary. Given $S \subset R^2$ a shape, **GMD**(S) is a pair of skeletal point and radius $(p, r) \in$ **MAT**(S), such as for all $(p', r') \in$ **MAT**(S), $r > r'$. The **GMD** highlights the local opening in the close visual environment of an observer. Along a route, the **GMD** can be located in the front or in the back of the observer, with respect to his direction. Hence, it is possible to determine at which time he can perceive the most important local opening.

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Figure 3 shows the rear-front location measure of the **GMD**, in the environment represented in figure 2. It is computed according to the centre of the projection and the observer orientation in the route. When the value is superior to 0, the observer sees the **GMD**, otherwise it is in his back. From the graph of figure 3, we can notice the four series of peaks (locations 3–9, 19–27, 34–39, and 44–49). These are due to the appearance of the four openings: before the church (S1), about the place (S2), about the parking lot (S3), and the crossroads (S4). For example, between positions 19 and 27, the observer can see an opening on his front before his entrance in the place (S2). The entrance starts at the image 22. After image 27, the observer is still in the place but his visual field contains the narrow part between the place and the parking lot. This narrow part is a transition. Hence, the rear-front **GMD** location provides a mean to situate the local opening from a given location. In the route context, it highlights interesting visual events which are the appearance and disappearance of openings in the stream of urban shape variations.

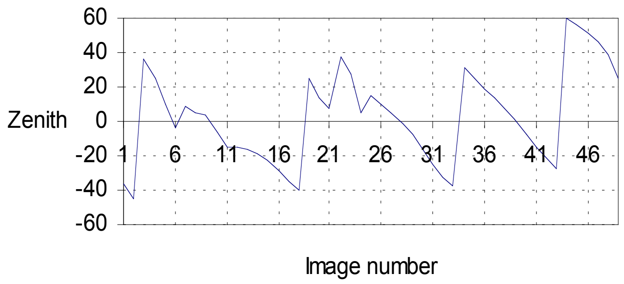

Figure 3
GMD rear-front location graphic for the route in figure 2.

4.2 Hausdorff distance

The comparison between skeletons brings a metric to estimate the visible variations of the built shapes in urban open spaces. The Hausdorff distance is one of the most used metric to compute likeness of two point sets (Rucklidge 1996). We propose here to use this metric to compare successive skeletons generated along an urban route.

Given two point sets S and T on a plane, the Hausdorff $H(S,T)$ distance between S and T is defined as

$$H(S,T) = \max\ (h(S,T),\ h(S,T)), \qquad (2)$$

with $h(S,T) = \max_{p \in S} \min_{q \in T} d_E(p,q)$, and here d_E represents the Euclidean distance. The computation of the Hausdorff distance between two successive spherical projections needs for each skeletal point to consider its coordinates on the

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plane and its radius as a third coordinates. As it depends on the Euclidean distance, the maximum of the Hausdorff distance is equal to the disk projection diameter.

Figure 4 gives the Hausdorff distance variations between the urban skeletons along the route in the environment of the figure 2. The x-axis represents the position in the route and the y-axis is the Hausdorff distance percentage value with respect to its theoretical maximum. At location *p* in the graph, the Hausdorff distance is computed for the urban skeletons at locations *p* and *p*+1. The smallest value are above 7%. This is due to the fact that both the observer walks and the environment is not homogeneous, i.e., a lot of concavities and convexities appear along the sky boundary. First series of peaks between location 1 to 16 are due to the unevenness of the buildings, where the last (location 13) corresponds to the full appearance of the church (S1). An important change appears around position 21. It fits with the arrival of the observer in the place (S2). Then, a long change is represented from location 31 to 36, the time to the parking lot (S3) to become visually dominant over the place. Nothing is happening, till the observer enter in the street between S3 and S4 (location 41). The peak can be interpreted as the location where the observer is entering in this street. Finally, a second important peak appears at the end of the route, due to the entrance of the observer in the crossroads behind the theatre (S4).

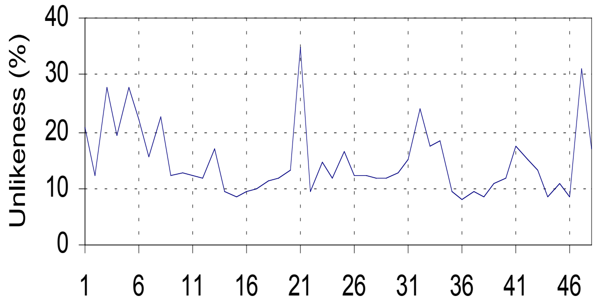

Figure 4
Hausdorff distance graphic for the environment in figure 2.

Unlike the **GMD**, the Hausdorff distance deals with the successive modifications in the sky shape, it analyses the entire shape and it is not tied with the observer direction. The Hausdorff distance provides a mean to measure the variations in the visual field of the observer by considering the likeness of the successive urban skeleton.

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4.3 Route partition

Figure 5 represents the route partition according to the graphs in figures 3 and 4. It highlights the part of the route where the **GMD** is in the visual field of the observer, with lines in bold, and the part where the Hausdorff distance reaches its local maxima, with ellipses which size depends on their magnitude. At the beginning, there is an interesting effect. This part is disturbed due to the unevenness of the surrounding building. The part of the route in the place (S2) is one of the most important. On the one hand, according to figure 3, it is characterised by a wide opening perceived by the observer on his right during a long time. On the other hand, according to figure 4, there is a caesura at its entrance: this place appears suddenly. Just before, for approximately the same time, the observer perceives a narrowing between the church (S1) on his left and the building on his right. This church "follows" the observer during a long time. After, at the end of the place, the observer begins to see another narrowing before to arrive near the parking lot (S3). The effect between S2 and S3 is a kind of competition between these two openings. Finally, according to the graph 3, the opening in S4 is seen directly in the visual field of the observer. It seems that the skeletonisation, with the help of both the **GMD** and Hausdorff distance, enables to determine the delimitations of each open spaces crossed along a route.

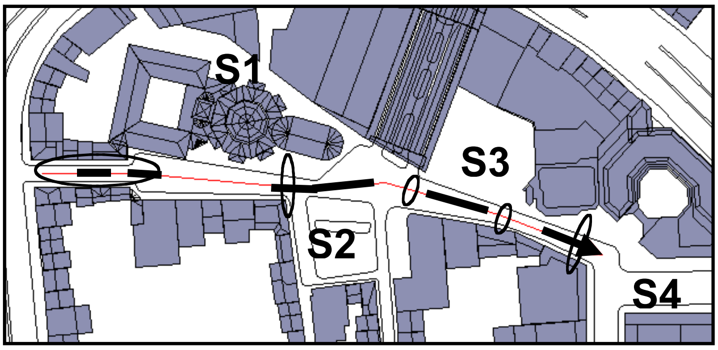

Figure 5
The route partition in *rue Xavier-Neujean* with respect to graphs in figure 3 and 4.

5. Conclusion

A new method to analyse urban open spaces has been introduced and discussed in this paper. It is based on the study of the sky shape variations in the visual field of the observer along a route. This method uses spherical projections and skeletonisation, which brings a new approach to analyse the Gibsonian motion perspective.

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The proposed measures are based on the extraction of the **GMD** and the computation of the Hausdorff distance. The former detects the local opening in the visual field of the observer and is able to locate it. The latter deals with the global variations of the whole of the visual field. Both enable to partition urban routes into sequences, with respect to the potential interest of the observer or to the likeness of the space view.

The method presented in this paper is dedicated to the characterisation of dense urban spaces. It gives a dynamic assessment of urban visual quality, and can help to enhance existing tools which analyse the urban environment location by location. We hope that the association between the spherical projection and the skeletonisation will provide at the end more accurate tools for the qualification of the open spaces.

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