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New advances in obtaining three-dimensional models from conical perspectives

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ABSTRACT

In a previous work we presented algorithms which allow obtaining three-dimensional models from graphs which represent a projection in conical parallel perspectives and conical oblique perspectives of polyhedral models with normalon and quasi-normalon typology.

In this paper the new advances that we have achieved in this field are presented, allowing increasing the set of models which can be reconstructed to other typologies different from the normalon and quasi-normalon ones. Moreover, we present a new technique which extends the previous work in order to be implemented to conical perspectives with three vanishing points, and the method proposed for the detection of the type of conical perspective represented by the graph, including the detection and subsequent reconstruction of graphs which represent a flat shape, has been improved.

The results obtained on a total of 336 tests, with a success ratio of 100%, make the method a proposal to be considered for obtaining models from conical perspectives automatically.

1. Introduction

The automatic obtaining of three-dimensional models from graphs which represent one of their projections is a field of great interest for the scientific community as evidenced in the continuous investigations carried out from the 1960s with the work done in [1] until now with the recent work published in [2].

From the approach of reconstructing models from conical perspectives, on which this work is focused, we can group them, paying attention to the technique used, in two blocks: labeling methods and perceptual methods.

Labeling methods are based on a classification of the vertexes according to the directions of the edges which come together in each corner. The first valid labeling methods are presented in the work carried out in parallel in [3,4] where the vertexes of a cube were classified after considering all the corners from all possible viewpoints of an axonometric perspective. From this work, new methods were developed in order to improve and expand the procedure of labeling [5,6], but all of them were based on heuristic rules and restrictions were presented.

In [7] a new labeling scheme of drawings, including non-necessarily polygonal objects, was developed. However, the procedure allows labeling the same drawing in more than one way, which contrasts with human perception in which a projection has very few ways of dimensional interpretation.

The latest contributions in this line are the labeling methods as shown in [8,9] where the geometry of the hidden parts can be established, and where the front model geometry can be defined.

A reference in the reconstruction of models from conical perspectives based on labeling models is the work presented in [10] where the quantitative reconstruction of the 3D structure of a scene from a line drawing, by using the geometrical constraints provided by the location of vanishing points, is investigated. In this work the design of an algorithm, which has several advantages with respect to the usual approach based on a reduction to linear programming, is presented. These advantages range from a lower computational complexity to error tolerance and exact reconstruction of the 3D-geometry of the objects.

The perceptual methods are characterized by trying to implement, through the sequential language of computers, the way humans perceive. In [11] the first perceptual method is designed based on the proportionality between the projection and the three-dimensional model, starting from a labeling method that allows us to obtain a graph of adjacency to define the orientation of each edge regarding the main axes. In their algorithm, the parallel lines of the projection are parallel in the model and the parallel edges to the main axes are drawn proportional to the actual dimensions, thus allowing us to define parallelograms with faces parallel to the planes of projection. Although the method allowed flexibility to inaccuracies in the drawing, the algorithm is characterized by a high

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degree of user interaction needed to designate the principal axes (intersection of the planes of projection). Furthermore, the method was very limited since rebuilding models should not contain hidden edges given the ambiguities that the representation of these edges causes.

The other methods have been based on perceptual optimization methods. It is considered that such methods are the mathematical process that more closely resembles the way humans interpret a projection. The strategy called "inflation", applied to an axonometric projection of a model, works assigning coordinates "Z" to vertexes of a projection while maintaining its coordinates (x, y) by minimizing an objective function.

The function to be optimized has been modified and extended by different authors. In [12] the objective function is formed by a single component, the MSDA (minimum standard deviation of angles) in [13,14] the mentioned objective function was expanded with the DP (deviation from flatness of the faces of a model) and [15–18] propose an objective function composed of a sum of subfunctions representing regularities of the projection, i.e. characteristics of the model that can be deduced from the observation of the projection.

However, the reconstruction algorithms based on optimization present common difficulties: given the non-linearity of the objective functions proposed, there is a high number of local minimums, therefore the solution reached does not always represent the desired model (the own projection of the model that constitutes the starting point for the optimization is in many times a local minimum).

Focused on these problems, some authors have tried to propose models which allow obtaining a tentative initial model which approaches the desired model as much as possible, so that the optimization process reaches the global minimum [19,20].

In [21] a new method based on an iterative optimization process, in which, once the reconstruction has been performed, the model obtained is projected on a plane and compared with the starting projection, is proposed. If both projections do not coincide in a preset threshold, the restrictions are readjusted and the reconstruction process is repeated. However, the computer cost of the process is not mentioned.

A reference of the implementation of methods based on optimization for the reconstruction of conical perspectives can be found in [22], where the problems derived from the use of non-linear functions in the optimization processes are highlighted. This non-linear function is owing to the fact that the flatness of the faces is usually expressed according to the vertexes which define it. In their work an objective function, defined from a set of linear restrictions, is proposed. The algorithm can process perspectives with or without representation of hidden edges, and uses the algorithms given in [23,24] to determine the faces defined in the model from its projection.

Another trend, which has as its final aim the reconstruction, is focused on the division of complex models into simpler parts to later, once they are reconstructed, put them together again in order to form a single solid. However, most of the works presented from this view [25–29] need, as starting information, the faces defined in the model. In [30] a division algorithm, which does not need the previous detection of the faces, is presented, but its results are not always the expected ones.

Most of the algorithms and strategies proposed for the reconstruction use as starting information the faces defined in the model. However, in spite of the great number of investigations directed towards the identification of faces from the projection of a model which have extended from the pioneering work given in [17] until more current woks like the one carried out in [31], the problem has not been solved completely. Although the existing methods can find faces in most cases, there is not a mechanism to determine if the result is right, leaving this decision to the user.

Therefore, the reconstruction methods that need a previous identification of the faces must be considered as semi-automatic models, and in no case it is possible to talk of automatic reconstruction of models.

In the work presented in [11], and later revised in [32], an algorithm that starts with the calculation of the coordinates of a vertex on an orthogonal corner is proposed, and it is proved that, knowing these coordinates, it is possible to determine the coordinates of the rest of the vertexes through an expansion tree that uses the equations of the plane which define the faces of the model. However, the faces defined in the model are used as starting information again, it is assumed that the projection always corresponds with a conical perspective with three vanishing points, and the projections cannot contain hidden edges.

Focused on improving the proposals presented by these authors, in [33] it is presented a work which allows the automatic reconstruction of polyhedral models with normalon and quasi-normalon typology from parallel and oblique conical perspectives with two vanishing points which do not need the previous detection of the faces and can or cannot contain hidden edges.

This paper represents an improvement of the work presented in [33]. On the one hand, the set of models that can be reconstructed is increased and they do not need to be of normalon or quasi-normalon typology any longer. On the other hand, the reconstruction method proposed widens including conical perspectives with three viewpoints. The system, completely automatic, does not require obtaining the faces of the model.

2. Previous work

The work presented in [33] is focused on the reconstruction of graphs with normalon and quasi-normalon typology defined as:

- *Normalon graph:* The name is a generalization to the world of polyhedra, related to the normalon polygons concept, such as those with the property in which all angles between two concurrent edges are 90°. In Fig. 1 we can see a graph of this type since all edges converge towards three vanishing points (one improper).
- *Quasi-normalon graph:* In these graphs, despite not belonging to the normalon type, it is possible to reach all vertexes, exclusively through edges that are parallel to three directions, and which form 90° to each other. That is, they are graphs that meet the condition where the elimination of all non-parallel edges to these three directions does not imply the loss of all vertexes, also allowing them to remain connected. We name them main directions. In Fig. 1 we can see a graph of this type in which the removal of non-parallel edges in three main directions (1–2, 1–5, 4–6, 5–7, 7–12, 5–12, 5–8, 1–8, 1–9, 2–9) does not imply the loss of vertexes and they remain connected (there is only one graph).

For the reconstruction of graphs we propose a method based on [32] with the advantage of not using, as starting information, the defined faces in the model. Knowing the three-dimensional coordinates of the vertexes of an edge of the model (edge AD in Fig. 2), it is possible to determine the coordinates of the vertexes connected to it by edges oriented according to the main directions, like the intersection of the perpendicular plane to the edge in one of its vertexes and the straight line that joins the viewpoint with the projection of the vertexes (vertexes B and C in Fig. 2).

The method proposed can be expanded following the edges of the graph oriented according to the main directions until the complete reconstruction of the model. The evaluated vertexes are