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Obtaining three-dimensional models from conical perspectives

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ABSTRACT

One of the most important challenges in the computer vision has long been to obtain three-dimensional models from the information given by a projection of the model. In this work we show an automatic system which allows obtaining three-dimensional models from entities that represent the conical projection of a polyhedral model with normalon or quasi-normalon typology. The results obtained on a total of 160 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 examination of the surrounding environment is an essential task for the development of the autonomous navigation applications. Its aim is to obtain the three-dimensional reconstruction of the objects which are around us, allowing, in this way, interacting with them from the vision provided by the cameras. This is demonstrated by the numerous studies carried out to date, such as the one presented in [1] where the authors present a geometrical method to locate objects allowing the autonomous robot guidance.

The methods for the reconstruction of models from conical perspectives developed so far can be classified according to the number of captures of images which are available to start the process. The most significant advances have been obtained when there are, at least, two images of a same model available, which is obvious if we consider the increase of information that it implies.

In these terms, we can mention a wide range of work carried out as set out in [2], where a new method for reconstructing environments occurs from stereo images and the obtained results are a pixilated pattern. The work developed in [3] was reconstructed from two images with a proposal based on a hybrid method that combines several existing reconstruction technique models. Other authors have presented works in the line of calibration images obtained from multiple cameras as in [4] where it works with 12 cameras. In [5], the necessary conditions are set to calibrate two identical cameras by identifying four points of the image without knowing if the intrinsic parameters of the cameras are set conditions.

With regard to the methods based on a single image, it must be stressed that most of them have focused on the study of the parallel projection. We can group them, paying attention to the technique used, in four blocks: labeling methods, based on the gradient space methods, based on linear programming 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 [6] and [7] where the vertexes of a cube were classified after considering all the corners from all possible viewpoints. However, this labeling system had a problem, it could only reconstruct polyhedra and also that these could not present hidden edges.

From this work, new methods were developed in order to improve and expand the procedure of labeling [8,9], but all of them were based on heuristic rules and restrictions were presented. In [10] for example, we needed to distinguish between visible and hidden edges. Finally in [11] 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 [12] and [13] where the geometry of the hidden parts can be established, and where the front model geometry can be defined.

Significantly, among the methods based on the gradient space work, we can mention [14]. It is an established method based on the correspondence between the gradients of polyhedral surfaces and lines that make up a projection, and try to determine whether a line drawing is realizable or not. This causes these methods to be

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generally regarded as methods of interpretation rather than reconstruction methods. However, the existence of a gradient image is necessary but not enough for the drawing to be realized. Some examples can be found in [15].

As for the methods based on linear programming, [16] shows a computational mechanism based on linear programming to extract three-dimensional polyhedral structures from lineal drawings achieving a necessary and sufficient condition for that lineal drawing to represent a polyhedral object in terms of linear programming. However, the condition is as mathematically accurate as some drawings that are simply rejected because the vertexes deviate slightly from the correct positions.

In [17] and [18] reconstruction was done in terms of linear programming but this method was based on the labeling scheme presented in [10]. In [19] we can see the problem of reconstruction based on rules of geometry. This method establishes the mathematical formulation of a system of equations that represents a set of geometrical conditions where the 3D model must be verified from the analysis of a projection or a portion of the remains. Topologically, it´s assumed that all vertexes of the object are trihedral and the projection always represents an Eulerian polyhedron.

Finally, the perceptual methods are characterized by trying to implement, through the sequential language of computers, the way humans perceive it. In [20], 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 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 cause the representation of these edges.

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 [21] the objective function is formed by a single component, the MSDA (minimum standard deviation of angles) in [22,23] the mentioned objective function was expanded with the DP (deviation from flatness of the faces of a model) and [24–27] proposes an objective function composed of a sum of sub-functions representing regularities of the projection, i.e. characteristics of the model that can be deduced from the observation of the projection.

Finally in [28–30] they have worked on rebuilding, applying optimization processes trying to reduce the high rate of errors that occur with the application of these methods.

The rapid attainment of a three-dimensional model from a single projection is very practical for developing tasks in which the treatment of a large number of images, as autonomous robot guidance, is required. Therefore, in this paper we have focused on the search of an algorithm that allows us to obtain, with a low computational cost, a valid reconstruction of a three-dimensional geometry of a model. Progress in the reconstruction of images of normalon and quasi-normalon defined types, is according to the proposal given in [31].

2. Reconstruction process

The process of converting the captured image of a three-dimensional model can be divided into two phases. The first of them is focused on the image processing (bitmap) with the objective of determining the set of entities that define the outline of the object (graph). There are several authors with different aims and objectives who have worked in this line [32,33]. The second phase is focused on providing the graph with three-dimensional coordinates in order to turn this into a three-dimensional model (Fig. 1).

This work has been focused on the second phase, that is, assuming that we have a vectorized image and defined from its edges (graph 2D), obtaining the three-dimensional model (graph 3D). Previous works aimed at this reconstruction phase, are based on labeling methods [34] or on the prior detection of the vanishing point [35].

2.1. Typologies of graphs

As we said before, this paper focuses on the study of graphs of normalon and quasi-normalon typologies, which we define as:

- Normalon graph: The name is a generalization to the world of polyhedra, related to the normalones polygons concept, such as those with the property in which all angles between two concurrent edges are 90°. In Fig. 2 you can see a graph of this type since all edges converge toward 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. 2 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).

2.2. Analysis of the principal directions

By definition of typologies and prior to the detection of the type of graph, it is necessary to identify which are the main directions. That is, the three directions among those existing in the graph which are going to be considered as directions corresponding to edges that are mutually perpendicular in the reconstructed model.

As input data, the picture size and distance from the point of view to the picture plane is considered. These parameters are intrinsic variables of the device used to capture the image and can be extracted from the image file itself.

In order to detect the main directions the following considerations have been taken into account. On the one hand, the conical perspective studies the laws to represent accurately what is observed. In photography, it's very similar to the optical system used, where every picture is an image in central projection and, according with the conical perspective foundations, the parallel edges of a three-dimensional model will vanish to a same point of the graph. Therefore, determining the main directions of a graph can be summed up in determining to which the main directions the vanishing points belongs (this study is focused on models which have their base in the geometric plane, which implies, from the view of the conical projection system, focusing on parallel conical and oblique conical perspectives with two vanishing points).

On the other hand, given that it is assumed that the graph comes from the vectorization of a photographic image, it's logical to consider that the main point is centered in the frame that defines the size of