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Use of discrete gradient operators for the automatic determination of vanishing points: Comparative analysis

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ABSTRACT

Thales' second theorem can be used for the automatic detection of the vanishing points of an image. This paper explores its reliability and accuracy according to the type of operator used for the detection of edges. An algorithm has been used which processes a photographic image according to the operator selected. The result is a point cloud which is then used to find the desired solution. The comparison between the four discrete gradient operators (Frei-Chen, Prewitt, Roberts and Sobel) has been made taking into account the resolution of the image and the number of vanishing points. The results obtained show that Frei-Chen's operator shows good performance in determining vanishing points with respect to the spatial *X* axis, Sobel's operator is the best for determining the vanishing point with respect to the spatial *Y* axis, Roberts' operator gives good results for calculating vanishing points in both spatial axes, and Prewitt's operator is not appropriate for processing this type of image.

1. Introduction

A monoscopic image is a projection of a three-dimensional scene on a plane, which is performed using a viewpoint and can be expressed as a perspective. However, although the third dimension is apparently lost during this projection, it can be retrieved if the stored information is treated appropriately using photogrammetric techniques or dimensional perspective analysis.

Historically, perspective has been studied by artists seeking to represent more faithfully three-dimensional scenes on flat materials (paintings or prints, among others), but nowadays studies are focused on the three-dimensional representation of objects from a bi-dimensional image.

The most well-known perspective effect is that in space parallel lines converge at a common point known as a vanishing point, and if the set of lines is parallel to one of the three main axes (*X*, *Y*, *Z*), this point is known as a main vanishing point. Knowledge of these points gives information about elements of an image, which means that a qualitative and/or quantitative analysis of the image can be carried out. Qualitatively, vanishing points can be used to group common lines in adjacent images which need to be merged, and quantitatively, vanishing points are used for automatic calibration of a camera, dimensional analysis of an object or three-dimensional reconstruction.

Therefore, it is very important to define the reliability of the methods and operators used in the detection of vanishing points, and this is one of the main objectives of this research.

1.1. Background

Calculating vanishing points is the nucleus of the majority of modeling work based on a single image. However, the difficulty in determining the position of these points lies in the search for a computational technique which is accurate, reliable, quick and simple. Despite the research carried out until now, the methods which have been developed to detect vanishing points fulfill only some of these characteristics.

Barnard (1983) used the Gaussian sphere instead of gradient space as domain for representing geometric constraints. The Gaussian sphere is symmetric with respect to the view point (in the same way as central or perspective projection) whereas the symmetry of gradient space is the same as orthographic projection. In addition, the use of a closed or finite space such as a sphere as opposed to an open or infinite space such as that of the gradient has advantages from a computational point of view.

Magee and Aggarwal (1984) developed a computationally inexpensive algorithm for the determination of vanishing points, both on an image plane or in the infinite. For this, the algorithm uses a series of cross-product operations in order to determine that point toward the intersection of line segments in the image plane. These vectors are represented and parameterized on the Gaussian

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sphere. Finally, the number of entries for a given pair of parameters (α, β) is counted, and if the number is large enough, the lines that contributed to the pair are shown.

For Collins and Weiss (1990), the vanishing point computation is characterized as a statistical estimation problem on the unit sphere; in particular as the estimation of the polar axis of an equatorial distribution. For this, the image line segments are previously clustered into groups of convergent lines.

Palmer and Tai (1993) use the Hough transform algorithm to determine the parameters of the lines which intersect to form the vanishing points. In order to measure the accuracy a post-processing of the segments of the straight lines is carried out in order to reject those with greater uncertainty in their parameters.

Straforini, Coelho, and Campani (1993) propose a previous selection of points which converge at a given vanishing point in order to reduce the computational cost associated with the detection of the vanishing point. The solution is to use a polar space in which each line is represented by a point, which allows them to be grouped with a minimal computational cost.

Tai, Kittler, Petrou, and Windeatt (1993) use combinations of three lines whose intersections provide points which may be vanishing points. This method provides probability measures which reflect the likelihood of those points being the vanishing points, and the advantage of this method is that it allows the identification of vanishing points in less structured environments.

McLean and Kotturi (1995) present a method for the detection of vanishing points based on sub-pixel line descriptions which recognizes the existence of errors in feature detection and which does not rely on supervision or the arbitrary specification of thresholds.

Gamba, Mecocci, and Salvatore (1996) designed a vanishing point detection algorithm for non-structured scenes. In the first step, infinite distance vanishing points are detected by simplifying the successive search, that is, all the segments parallel to the plane of the photograph are detected (vertical and horizontal directions). In the following step the rest of the segments are classified according to the vanishing point they belong to, and the cloud obtained is represented using their intersections. A voting scheme is applied to this cloud to rule out incorrect points or those which cannot be the vanishing point.

Schaffalitzky and Zisserman (2000) showed that by grouping the characteristics of an object which provide a geometric relationship it is possible to automate the determination of the vanishing points of the image. For this, they use geometric grouping algorithms which allow the unsupervised detection of the vanishing point.

Almansa, Desolneux, and Vamech (2003) developed a detection algorithm that relies on the Helmotlz principle. This vanishing points detector has a high degree of accuracy, and does not need information about the image of the parameters of the camera.

Kalantari, Jung, Paparoditis, and Guedon (2008) proposed an extraction method for vanishing points of an image obtained with a camera with unknown internal orientation parameters. In order to find the vanishing points the perspective of the camera is located, where the Gaussian sphere is situated, at a standard orthogonal distance from the image plane. This algorithm works in a similar way to monocular human vision, which allows the mental reconstruction of the vanishing points with no prior optical information.

Kalantari, Jung, and Guedon (2009) presented a method based on Thales' second theorem for the automatic and simultaneous detection of an image's vanishing points. Each vanishing point is associated with a circle which relates to a point cloud, which allows the automation of the process. However, this method is only applicable in urban environments.

1.2. Objectives

The objectives of this research are:

1. To show the different methods of detection of vanishing points in scientific literature.
2. To select a detection method for vanishing points in order to assess is effectiveness in photographic images with one and two vanishing points.
3. To develop an algorithm based on the selected method: Thales' second theorem (Kalantari et al., 2009).
4. To analyze the influence of the type of operator selected for edge detection in the results obtained, specifically the discrete gradient operators of Frei-Chen, Prewitt, Roberts and Sobel.

In order to fulfill these objectives this paper is organized as follows. In Section 2, the materials used are presented along with the methodology followed. The stages of work are established, with a flow diagram of the algorithm developed for the detection of vanishing points, and each stage is explained. Then, in Section 3, the results are presented after the algorithm if applied to photographs with one and two vanishing points. Some discussions relating to the type of operator used are given in Section 4 using box plot graphics. Section 5 concludes the paper.

2. Material and methods

2.1. Object selection and material used

In order to carry out this research it has been necessary to take a series of representative photographs in which the algorithm will be applied. These photographs are perspectives with one and two vanishing points. In order for their detection to be possible, the photographs have to contain simple geometric forms such as straight lines. From the geometric characteristics of straight lines in perspective, it is possible to define the position of the vanishing points of the photographic perspective.

Building C5 of the University of Jaen Campus has been chosen (Fig. 1), as it has a very define geometric structure. The design of the façade is composed of parallel and perpendicular lines, which can be aligned according to the three axes of spatial coordinates (X, Y, Z), allowing the photographic viewpoint to be situated in the appropriate place with respect to the object.

The photographs were taken with a Nikon reflex camera, model D200, with a maximum resolution of 3872×2592 pixels, and with an Olympus compact camera, model Olympus-μ5000, with a maximum resolution of 3968×2976 pixels.

2.2. Stages of work

The research was carried out in the following stages:

1. Data collection: In this stage the object to be studied is selected, and the location and orientation of the photographic viewpoints are determined, according to the desired vanishing points. The photographs are taken.
2. Data processing: The photographs are analyzed and processed with a vanishing point detection algorithm (VPD), implemented in Borland Delphi 7.0. The flow diagram is shown in Fig. 2.
3. Analysis of results: Knowledge of the edge operator selected in the results obtained is crucial to discriminate its use according to the characteristics of the image, and therefore, it is important to know which type of operator performs best