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선분분류를 이용한 실내영상의 소실점 추출

Vanishing Points Detection in Indoor Scene Using Line Segment Classification

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요약

본 논문에서는 선분분류를 이용하여 실내영상의 소실점을 검출하는 방법을 제안한다. 실내영상을 효율적으로 검출하기 위하여 2 단계로 소실점을 추출한다. 1 단계에서는 이미지가 1 점 투시인지 2 점 투시인지 판별한다. 만일 이미지가 2 점 투시이면, 선분분류를 위하여 검출된 소실점을 지나는 수평선을 구한다. 2 단계에서는 선분분류를 이용하여 2 개의 소실점을 정확히 검출한다. 또 본 논문에서는 인공영상과 이미지 DB를 이용하여 제안한 방법을 평가하였다. 노이즈를 첨가한 인공 영상에 대해서는 노이즈가 60%를 차지할 때까지 검출한 소실점과 실제 소실점과의 차이가 16 픽셀 이하였다. A. Quattoni 와 A. Torralba가 제안한 이미지 DB를 이용한 평가에서는 87% 이상의 이미지에 대하여 소실점을 검출하였다.

■ 중심어 : | 소실점 | 소실선 | 탈레스 정리 | 선분분류 |

Abstract

This paper proposes a method to detect vanishing points of an indoor scene using line segment classification. Two-stage vanishing points detection is carried out to detect vanishing point in indoor scene efficiently. In the first stage, the method examines whether the image composition is a one-point perspective projection or a two-point one. If it is a two-point perspective projection, a horizontal line through the detected vanishing point is found for line segment classification. In the second stage, the method detects two vanishing points exactly using line segment classification. The method is evaluated by synthetic images and an image DB. In the synthetic image which some noise is added in, vanishing point detection error is under 16 pixels until the percent of the noise to the image becomes 60%. Vanishing points detection ratio by A.Quattoni and A.Torralba's image DB is over 87%.

■ keyword : | Vanishing Point | Vanishing Line | Thales' Theorem | Line Segmentation Classification |

I. Introduction

Vanishing point (VP) is an important element in computer vision in that it can provide the stereo information lost when a 3D scene projects to a 2D scene. So VP detection is widely used in 3D reconstruction, stereoscopic image generation, camera calibration and image orientation recovery. Min-Gu Hwang[1] proposed an algorithm to extract subject size by recomposing the still image into a 3D image,

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and vanishing point is the basis of this recomposition. In the 2D-3D video conversion of Chan-Hee Han's paper[2], the vanishing point is used to distinguish background from objects. Huy Phat Le's paper[3] proposed a method to restore the perspective rectangular object in the image in which vanishing point supports the information about the 3D structure of a scene.

In the 2D image, parallel lines in the real world are projected to a cluster of lines intersecting in a point called VP, and the cluster of the lines is called vanishing line. The number of vanishing line clusters and VPs vary from different perspective methods.

Many VP detection algorithms have been proposed so far. Among them there are two prime trends making use of histogram and Gaussian sphere, both of which are based on Hough Transformation and voting of intersection of vanishing lines. The difference is the space of voting; one is on histogram and the other is on Gaussian sphere. The latest papers of these two methods are[4][5]. Mahzad Kalantari proposed an algorithm[6] different from the methods above which works on the image space directly. Kalantari's algorithm is based on Thales' theorem with high accuracy for urban scenes. In particular case, Algorithms of VP detection in indoor scene are proposed. D. Gerogiannis proposed an indoor scene VP detection algorithm[7] fast and efficient but only one vanishing point can be detected. For orthogonal vanishing points, S. Sridhar proposed a hybrid method[8] which combines algorithms of Rother' and Tardif's.

VP detection is the basic step in computer vision applications listed in the beginning. The detection algorithm chosen for certain application should fit the factors of application, for example, how many VPs are required. In this paper, our application area is limited to generate the depth map for indoor stereoscopic image. The indoor scenes are different from outdoor ones with walls and ceiling. Usually, as an indoor space has limited height, the vertical VP of the image is seen as the VP at infinite distance. If a VP is at infinite in a real scene, the influence of the VP in the image is low. The region belonging to this VP lies equidistantly from the camera. Namely, the depth of the image is almost the same. Therefore, the detection of the vertical VP at infinite from the image can be omitted.

This paper proposes such a method to detect multiple vanishing points in indoor images using line segment classification. The approach of the method is the two-stage VP detection. In the first stage, we find almost all of the line segments in an image and detect a VP by Thales' theorem. Then we decide whether the image is a one-point perspective or a two-point perspective by position of the VP in the image. In the case of two-point perspective, we classify the line segments into right side and left side and calculate the exact VPs in the second stage.

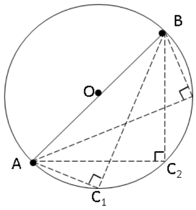
The remainder of this paper is organized as follows. VP detection by Thales' theorem is outlined in section 2. Proposed two-stage VP detection method is explored in section 3. The experimental results for synthetic image and different kinds of indoor images are given in section 4. Finally, the conclusion of the paper is presented in section 5.

II. VP Detection by Thales' Theorem

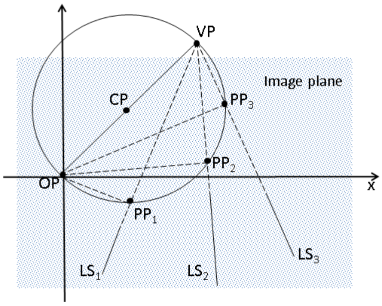
Thales' theorem is a special case of the inscribed angle theorem. It states that if the line AB is a diameter of the circle and C is a point on this circle, the angle ACB is a right angle. It means that every point on a circle can form a right triangle with the diameter of this circle, as shown in [Figure 1](a).

With this property, Thales' theorem can be used in VP detection.

VP is the point where a bundle of vanishing lines intersect together. The geometric principal of Thales' theorem based VP detection is shown in [Figure 1](b). Note that we set the origin (OP) of the circle to an arbitrary point in the image. LS_1, LS_2 and LS_3 are line segments, which are vanishing lines in the image. The extensions of entire vanishing lines intersect in the point VP. If we draw lines perpendicular to LS_1, LS_2 and LS_3 from origin OP. PP_1, PP_2 and PP_3 are the foot of the perpendicular lines. According to Thales' theorem, PP_1, PP_2 and PP_3 are on the same circle, the center of which is CP, and OP-VP is the diameter of this circle.



(a) Thales' theorem



(b) geometric principle of VP detection

Figure 1. VP detection by Thales' theorem

There are 4 steps in Thales' theorem based VP detection:

(1) Extracting line segments in the image.

(2) Deciding the origin and calculating the foot of the perpendicular lines from origin to extracted line segments.

(3) Extracting a circle from foot of the perpendicular lines.

(4) Calculating the VP.

III. VP Detection by Line Segments Classification

Because of the space limitation of indoor scenes, the images of indoor scene DB have two features. There is less obvious vertical VP, and if one horizontal VP stays around the center of image, the other horizontal VP is far away from the image. So indoor scenes are classified in two cases; one-point perspective and two-point perspective[Figure 2]. The vertical VP is not considered in both cases. In the former case, all of the vanishing lines intersect into a single vanishing point. In the latter case, some of the vanishing lines intersect in one VP and the others intersect in the other VP.

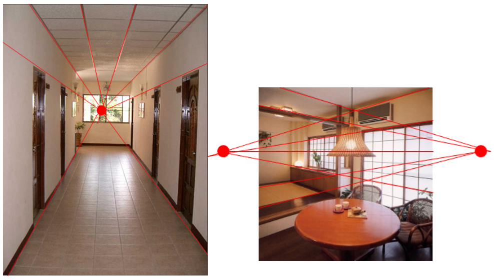


Figure 2. Left is a one-point perspective and right is a two-point perspective

To detect VPs in those two cases, we proposed a method with two stages of detection. The flow chart of the proposed method is shown in [Figure 3].

In an indoor image, house furnishings, texture on the walls and ceilings provide abundant information of vanishing line, but on the other hand, they make

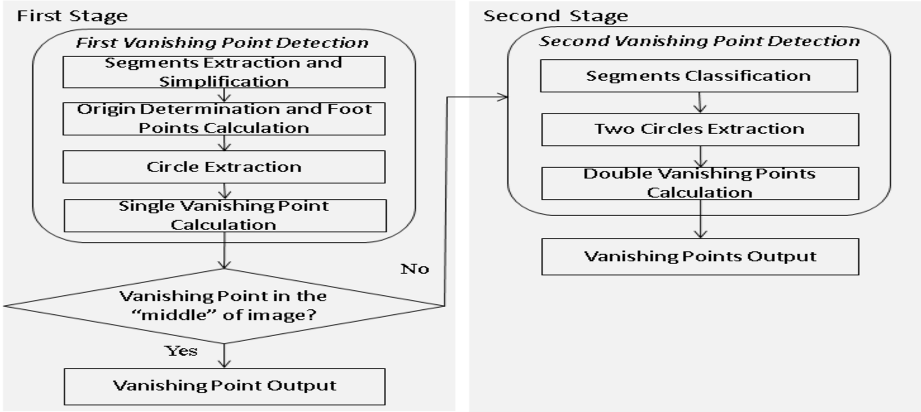


Figure 3. Flow chart of proposed method

scene complex, a number of false line segments should be detected. For this reason, the algorithm proposed by C. Akinlar[9] which controls a number of false line segment detection is used to extract segments. In our case, because vertical VP and VP at infinity are not considered, lines approximate to horizontal and vertical make a disturbance in the process of circle extraction. The horizontal lines and vertical lines are deleted before foot point calculation.

The origin of plane-coordinate system is randomly assigned as any point on the image, and the line equation of each segment is the following

$$y = a_i x + b_i \tag{1}$$

where a_i, b_i are slope and intercept of a line segment respectively.

The foot point (x_{pi}, y_{pi}) of segment are calculated by

$$x_{pi} = \frac{-a_i b_i}{1+a_i^2} \tag{2}$$

$$y_{pi} = \frac{b}{1+a_i^2} \tag{3}$$

In geometry, a circle is decided by three points which are not on the same line. So the circle used to detect VP is obtained by origin and any other two points among foot points. The process of circle extraction is:

(1) Choosing two foot points closest to each other and deciding a circle with origin.

(2) Calculating the distance between circle center and each foot point. The foot point is deleted if the difference between the distance and circle radius is more than a threshold. Here, we use the median of distance between every two foot points as the threshold.

(3) Summing the remaining differences.

(4) Repeating (1), (2) and (3) until every part of foot points is tested and choosing the circle with minimum difference.

At last, as origin and VP are the endpoints of circle diameter, the VP can be calculated easily.

After a single VP is extracted in the first detection stage. We can infer which perspective projection the image belongs to by observing the extracted vanishing point. In the one-point perspective case like the left image of [Figure 2], there are three walls of the room and the vanishing point is projected on the middle wall which is just opposite to our eyes. We divide the image into three equal parts vertically: left, middle and right part. In most of the cases, an one-point perspective vanishing point is located in the middle part of the image. If a VP exists around the center of image, the other VP is at infinite and can be omitted. So it enables us to give a simple but efficient method to judge number of VPs that should be detected, considering the limitation of viewing angle and viewer's position, Our experimental results shows that this idea is valid.

In the first stage, if a vanishing point is in the middle part of an image, we consider it an one-point perspective image and terminate the algorithm. If not, we perform second VP detection stage. In the second VP detection stage, all of the segments are first classified into two classes as shown in [Figure 4]. VP is the vanishing point detected in the first VP detection and LineVP is the horizontal line through VP.

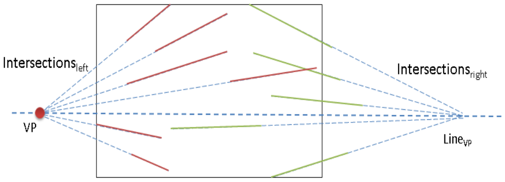
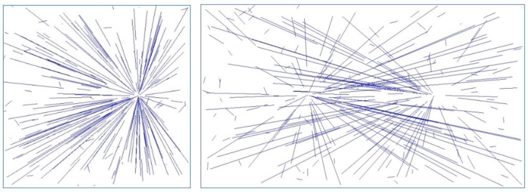


Figure 4. Segment Classification for left and right VP

Vanishing lines (line segments) for left VP and right VP intersect with LineVP on the left side and the right side respectively. Suppose that we got the intersection points of all line segments and LineVP. Then, if the point is on the left side, the line segment is for the left VP and if the point is on the right side, the line segment is for the right VP. After segments classification, circle extraction and vanishing point calculation are done on two classes of line segments respectively like the first stage.

IV. Experimental Results

Implementation examples of our method and their illustration are shown in this section. To evaluate the error of proposed VP detection method, we tested through synthetic images with lines and known VP location. The VPs are detected easily and accurately in the image with vanishing lines only. But in real practice, with the increasing of scene complexity, more noise lines disturb VP detection. To reflect that situation, we added noise lines in the vanishing lines in different proportions. [Figure 5] are examples of synthetic line images.



(a) Image with one VP (b) Image with two VPs

Figure 5. Examples of synthetic line image with 15% noise lines

The size of test image is 512×512 for one VP projection and 512×1024 for two VP projection. The VPs and vanishing lines are produced randomly, and noise lines are with random direction and random length(short line). For different noise line proportions, we tested 100 synthetic line images for one VP and two VPs respectively.

The result graph of noise proportions and error is shown in [Figure 6]. When the percent of noise line to the vanishing line is lower than 60%, VPs are detected in a low error less than 16 pixels, where the error means the pixel difference of the true VP and its detected VP. If more noise lines than those are added in, the error is out of control and VP detection is failed. We can infer that the VP detection fail is caused by a circle detection fail. The VPs calculated from the fallacious circle is far from the correct one.

We also do the test for real indoor scene. [Figure 7] illustrates the steps for finding one VP, and [Figure 8] illustrates for finding two VPs. Some special cases cannot be detected exactly, which are retouched image, distorted image, dark image and close-up image.

In the process of deciding whether a VP is in the middle part of an image or not, if the VP is in 1/6 of the image size from center of it in horizontal, we consider it an one-point perspective image. In the two-point perspective image, our method classified the line segments into two classes for left VP and right VP before two circles extraction. The line segments that are classified into two classes by the proposed method are shown in [Figure 8](e).

We also tested the proposed method on various kinds of indoor scenes using the database provided by A. Quattoni and A. Torralba[10]. We classified the images into four types:

- ▶Home: living room, kitchen, dining room, bathroom, bedroom, child's room, game room, garage, and nursery. The images of this type consist of complex objects like general home scenes.
- ▶Public: classroom, computer room, dental office, bowling alley, gym, hair salon, hospital room, jewelry shop, kindergarten, wet laboratory, and elevator. Repetitive objects are the features of this type of image.
- ▶Shelf: bookstore, closet, library, wine cellar, pantry, shoe shop, video store. The images of this type have the feature of being full of many vanishing lines.
- ▶Corridor: a simple indoor scene with a few long objects.

The success rates of VP detection are shown in Table.1. The single VP detection is the premise of two VPs detection. So the fail of the former result is equal to fail of the latter. By this reason, success rates are measured together. Some examples are shown in [Figure 9] and [Figure 10]. The VP of indoor scenes with simple objects is detected better than those with complex scenes. The success rate of Home and Public is slightly lower than Shelf and Corridor but stays above 87%. The success rate of Public is higher than that of Home because of organized vanishing lines of repetitive objects.

We also compared proposed method with other VP detection algorithms in [6][7] and [8] in [Table 2]. The proposed method is effective to detect VPs of indoor scene ranging from structured environment (shelf) to complex environment (room). But it is necessary to improve our method. For example, when judging whether VP is in the middle of an image or not, the threshold should be changed depended on image types. In this test, we set the threshold to 1/6 of image width distance from middle line of image.

V. Conclusion

In this paper, we proposed a VP detection method for an indoor scene. This method is based on Thales' theorem and we improved it with line segment extraction method proposed by C. Akinlar, two-stage detection, and line segment classification. It can detect almost all the VPs automatically for one-point perspective images and two-point perspective images. The VP of an indoor scene composed of complex objects can be detected by the proposed method with over 87% success rate. In the synthetic image added noise, vanishing points are detected with little error until the percent of the noise to the image becomes 60%. The follow-up studies are the depth generation with detected VPs and depth based stereoscopic image generation from single 2D image.

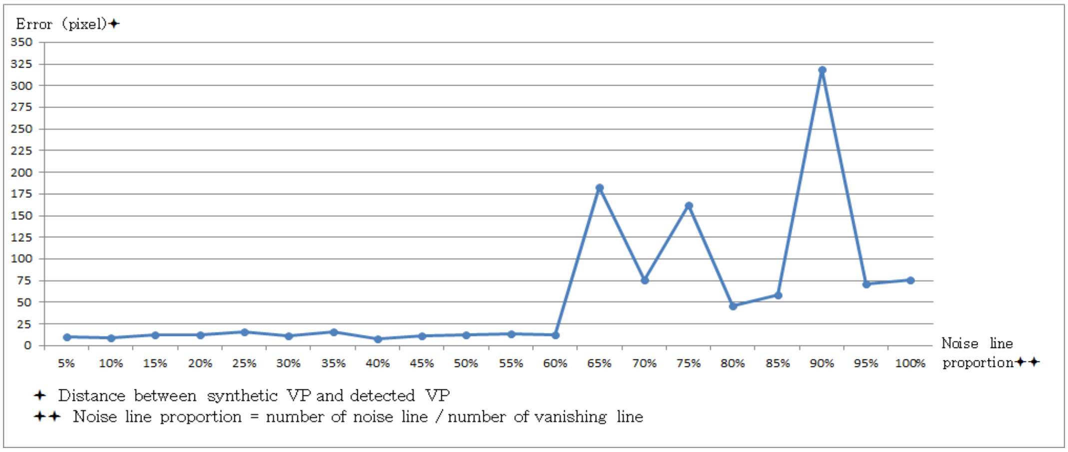


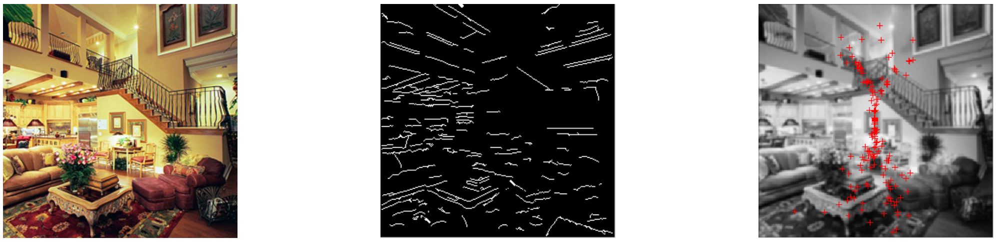
Figure 6. Error of VP detection

Table 1. Success rate of each kind of indoor scene

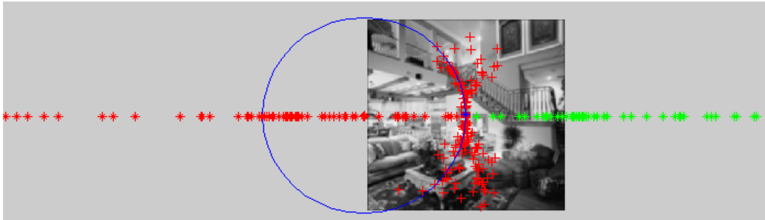
Type of Images	Number of Images	Number of Images Detected VP	Success Rate
Home	193	168	87.05%
Public	190	170	89.47%
Shelf	180	171	95.00%
Corridor	80	74	92.50%

(a) Original image (b) Segment map (c) Result image (d) Enlarged view

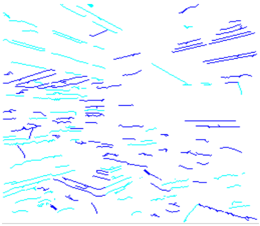
Figure. 7 Example of one vanishing point. Red “+” is the H-point and red “*” is the center of detected circle (blue circle). Blue “*” is the center of image and blue “+” is the VP



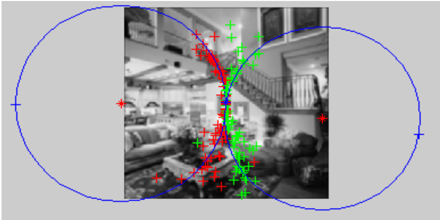
(a) Original image (b) Segment map (c) H-point map



(d) Segment intersection map. Red "*" is the intersection of vanishing line for left vanishing point and green "*" is the intersection of vanishing point for right VP.



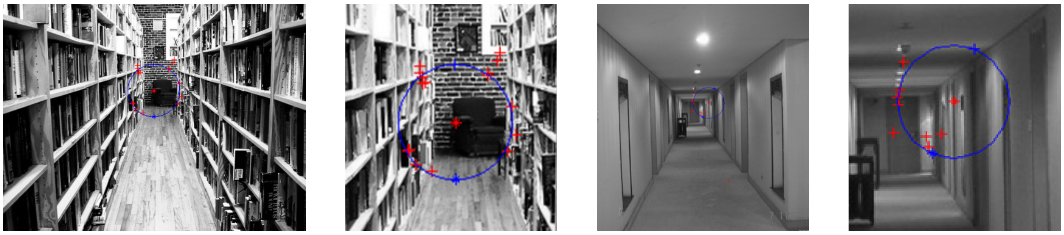
(e) Segment classification map.
Light blue: vanishing lines for left VP.
Deep blue: vanishing lines for right VP.



(f) Result image. Red "+" is the H–point for left VP, and green "+" is for right VP.

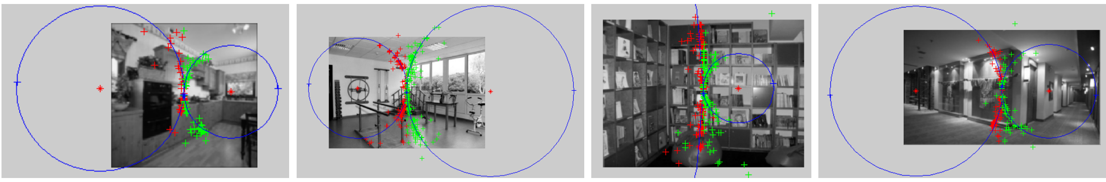
Figure. 8 Example of two vanishing points

(a) Room (b) Enlarged view of (a) (c) Public (d) Enlarged view of (c)



(e) Shelf (f) Enlarged view of (e) (g) Corridor (h) Enlarged view of (g)

Figure. 9 Examples of each kind of indoor scene results (one VP)



(a) Room (b) Public (c) Shelf (d) Corridor

Figure. 10 Examples of each kind of indoor scene results (two VPs)

Table 2. Performance comparison with other VP detection algorithms

Algorithm	Image content	Number of VP	Error (pixel)	Success rate	Execution time	Implementation details
Mahzad Kalarntari's	Urban scene	3	--	92% in horizontal, 100% in vertical	--	Intel Xen processor, 1.60GHz and 2GB RAM
Tardif's	Indoor scene (structured environment)	3	--	--	0.06s ~ 1.01s	OpenCV and MATLAB
Demetrios Gerogiannis's	Indoor scene (corridor)	1	5.4 ~ 15.4	--	0.1s ~ 0.2s	MATLAB
Proposed	Indoor scene	1 ~ 2	1.8 ~ 16	87% ~ 95%	0.5s ~ 0.7s	Inter Core i5, 3.10GHz and 4GB RAM / MATLAB

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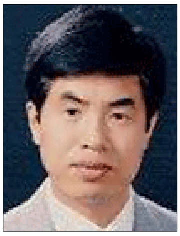

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