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3D Information Acquisition from Spatiotemporal Image Created by a Hyperbolic Slit

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Abstract

A devised spatiotemporal image conversion method using a hyperbolic slit and its application to the acquisition of three dimensional information from car navigation moving images are proposed in this paper. Continuous images taken by a moving camera contain very large quantity of data, their analysis requires too much processing time. The proposed method compresses data by transforming Time-varying three dimensional moving images into two dimensional spatiotemporal images and acquires 3D information about objects in the environment. Edge lines of objects parallel to coordinate axes are first taken as special features and are transformed into two dimensional images using hyperbolic slits,Mathematical conditions for this transformation and the procedure to extract 3D information are then discussed. Simulation experiments reveal the effectiveness of the method.

1 Introduction

A three dimensional spatiotemporal image is a dense sequence of images taken in such rapid succession that they form a single solid block of data in which the temporal continuity from image to image is approximately equal to the spatial continuity in an individual image.

Much work has been done to analyze three dimensional spatiotemporal image to obtain 3D information about the environment of the camera. For straight-line camera motion, tracks of object appear as linear structures on epipolar-plane images(EPIs), which are slices of the spatiotemporal image containing epipolar lines. The distance from the camera to the object is determined from the inclination of tracks. With EPIs analysis, it is much easier to compute the three dimensional positions of object features. Any corresponding problems between images can be solved by the extraction of feature-lines from the EPI[1].

Yasuno and Hamano presented an expansion of camera motion for spatiotemporal image analysis using spherical projection transformation[2]. In their approach, images are projected on a homocentric spherical surface to make a Homocentric Spherical Spatiotemporal Image(HSSI). An object feature is drawn as a curve on a plane containing the longitudinal lines of the HSSI. Then this HSSI is analyzed to acquire the 3D information about the scene.

The three dimensional spatiotemporal image or HSSI is a very huge quantity of data. It takes plenty of time to extract a line or a curve. Zheng and others proposed a method to create a plane image using only the pixels selected from each image taken by the motion camera[3]. They also proved that the image includes spatíal and temporal information.

In this paper we create two dimensional images using a hyperbolic slit from continuous images taken by a camera moving along a straight-line, and we will describe the image with Two-dimensional Spatiotemporal Image(TSI).

Many objects in our living environment are artificial blocks. These objects are featured by many straight-line edges. If we can obtain the spatial information about those straight-line edges we can also determine the objects. In our transformation method , these straight-line edges are projected into TSI straight lines. We will prove that the 3D information about the object can be acquired from the lines extracted from TSI.

The position of hyperbolic slit in an image also has different influence on the obtained 3D information. We also discuss the selection of hyperbolic slit.

2 TSI Creation

Consider the case that the camera faces the direction it is moving at a plane level with a constant speed. It takes pictures while moving along a straight line. We use a hyperbola as slit to create the TSI.

2.1 Coordinate

The global coordinate $O-XYZ$ is defined as shown in Figure 1. The view point, the center of the camera

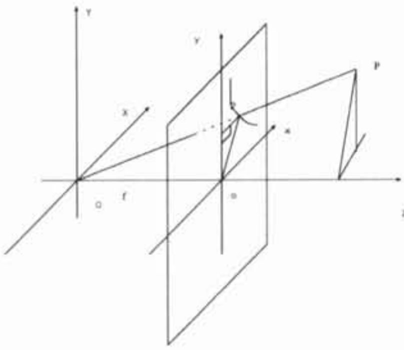

Figure 1: Global Coordinate

lens, is at the point O, the center of the coordinate. It takes pictures while moving along the Z axis in the positive direction at a constant speed. The optic axis is on the Z axis. The image of an object in the running environment is projected on the plane $Z = f$ which is parallel to the XY plane, where f is the focus length of the camera lens.

Suppose the x and y axes of the projection plane coordinate $o - xy$ are parallel to the X and Y axes of the global coordinate, respectively. The center o is the joint point of Z axis and the projection plane and the point $P(X, Y, Z)$ in the global coordinate is projected to $p(x, y)$ on the projection plane.

2.2 Theoretical Analysis

As shown in Figure 1, when point $P(X, Y, Z)$ is projected to $p(x, y)$ on the projection plane, we have the following equation :

$$\frac{X}{x} = \frac{Y}{y} = \frac{Z - vt}{f} \tag{1}$$

v and t represent speed and time respectively. Then we use the hyperbola described with equation (2) as the slit to create the TSI.

$$xy = c \tag{2}$$

From equations (1) and (2) we can obtain the following equation :

$$y = \frac{-vc}{Xf}t + \frac{cZ}{Xf} \tag{3}$$

When X, Z, v and f are constants in equation (3), the quation represents a line on an $y - t$ plane. When X and Z are constants, it is a line parallel to the Y axis in the global space. If we further extract such a line from the $y - t$ plane, we can compute the inclination of the line. As shown in equation (3), c, v and f are known and we can derive the X coordinate of the line. The Z coordinate can be further derived from equation (1) using this X coordinate and the y and t coordinates of some point on the line in the TSI.

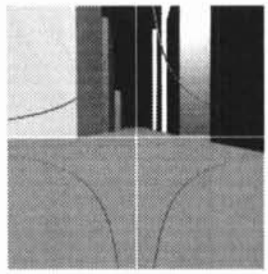

Figure 2: Hyperbolic Slit $xy = c$

From the above analysis, we can first use a hyperbolic slit to transform the images taken by a moving camera into a two dimensional spatiotemporal image and then by line extraction acquire the 3D information about the straight lines parallel to the Y axis in the global space.

If we use the equation (4) instead of equation (2) for the hyperbolic slit we will get equation (5) instead of equation (3), where a is a constant. We can see from equation (5) that just like using equation (2), a line parallel to the Y axis in the original coordinate becomes a straight line on the $y - t$ plane. Thus we can still acquire the 3D information by extracting the lines from the spatiotemporal image. The introduction a makes it possible to adjust position of the hyperbolic position in the $o - xy$ plane.

$$x(y + a) = c \tag{4}$$

$$y = \frac{-vc}{Xf}t + \frac{cZ}{Xf} - a \tag{5}$$

In the same way, we can acquire the 3D information about lines parallel to the X axis by extracting lines from the $x - t$ spatiotemporal images created with a hyperbolic slit.

From equation (3) we can see that lines parallel to the Z axis in the global space are projected on the spatiotemporal image as straight lines parallel to the t axis. If we get the coordinates of an intersection point, the lines parallel to Z axis and Y axis, then the X and Y coordinate of the line parallel to the Z axis is determined.

2.3 Creating Plane Spatiotemporal Image

Now we discuss how to set a slit in an $o - xy$ plane to create a PSI. First we can set the $xy = c$ slit in each image as shown in Figure 2, where c is a constant. We can set four hyperbolas, two for positive values of c and two for negative values of c. But they are not closed. Then arrange the pixels in time sequence on the slit to create spatiotemporal image.

In such settings, the position of slit $xy = c$ in a static image is determined only by the parameter c. Only its distance from the origin varies with the value of c in the image. Because the four slit lines are not

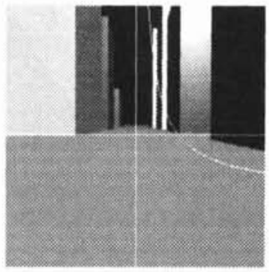

Figure 3: Hyperbolic Slit $x(y+a) = c$

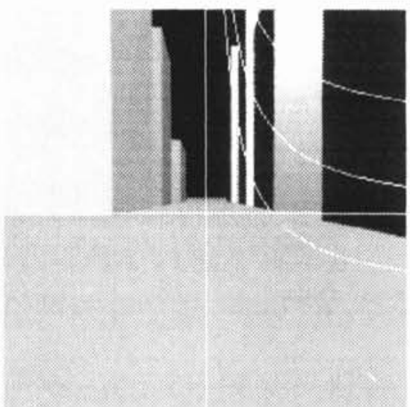

Figure 4: Position Change of Slit $x(y+a) = c$ Caused by a

closed, there should be some objects in the global space that are not covered by the slits. There is also the case that some objects in the moving environment far from the camera will cross the slits in the image, even these objects are covered by the slits. These objects are not clear in the spatiotemporal image. For those reasons, we use slit $x(y+a) = c$ and $y(x+a) = c$ to create the TSI. Then we can adjust the values of a and c so that the slit can be in an appropriate position. Figure 3 is an $x(y+a) = c$ slit and Figure 4 shows slit positions adjusted by the parameter a.

2.4 Features of plane spatiotemporal image

The following summarizes the characteristics of the plane spatiotemporal image created with hyperbolic slits.

1. 3D spatiotemporal image data are greatly compressed while keeping 3D information of objects.

2. Straight lines parallel to axes in the global space are projected to straight lines in the plane spatiotemporal image created with a hyperbolic slit and the 3D information of these lines in the global space can be obtained by extracting straight tracks of those lines in the plane spatiotemporal image.

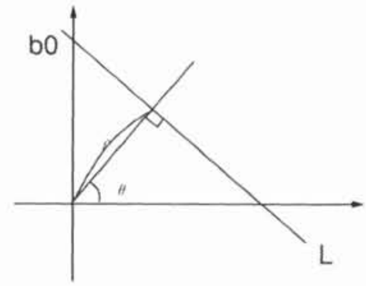

Figure 5: A Line in A Plane

3. The position of an object in the plane spatiotemporal image can be adjusted by changing the value a and c of the hyperbolic slit.

3 3D Information Acquisition

From the discussion of the previous sections, we can see that to obtain the 3D information we need to extract the projection of straight line edges of real world objects from the spatiotemporal image created from moving camera pictures. Many approaches have been proposed to extract straight lines from a two dimensional image We use the Hough approach and describe a straight line L with equation (6).

In the equation, θ and ρ are variables that, as shown in Figure 5, represent angle and distance respectively. They are finite in an image.

$$\rho = xcos\theta + ysin\theta \quad 0 \leq \theta < \pi \tag{6}$$

Based on the discussion up till now, we can see that in the created $y-t$ spatiotemporal image, the projection of vertical edges of objects are straight lines.

The inclination of the straight line $\frac{-cv}{Xf}$ is positive or negative depending on whether c is positive or negative and on whether the object is on the left or right side of the camera. The range of the inclination of the line can also be approximately determined by the vertical distance of the object. We further use Hough approach to determine the line from the plane to acquire the 3D information.

4 Selection of Slit

There are errors in the process of line extraction from two dimensional images. In this section we discuss slit selection with respect to these errors. As an example, we discuss the case of X coordinate acquisition.

Let θ and ρ be Hough transformation variables. As discussed previously, the inclinations of lines are used to obtain 3D information of objects. From equation (5) and (6) we have:

$$cot(\theta) = \frac{vc}{Xf} \tag{7}$$

Assume that the error in line extraction is $\Delta\theta$. The following gives a theoretical analysis.

The error of X caused by the error $\Delta\theta$, From equation (7), we have:

$$X = \frac{vc}{f} * tan(\theta) \tag{8}$$

$$\Delta X = \frac{vc\Delta\theta}{f} * \frac{1}{cos^2(\theta)} \tag{9}$$

From equation (7), we can also derive:

$$\frac{1}{cos^2(\theta)} = 1 + tan^2(\theta) = 1 + \frac{X^2 f^2}{v^2 c^2} \tag{10}$$

From equation (9) and (10) we can obtain :

$$\Delta X = \frac{vc\Delta\theta}{f}(1 + \frac{X^2 f^2}{v^2 c^2}) = \frac{vc\Delta\theta}{f} + \frac{\Delta\theta X^2 f}{vc} \tag{11}$$

Then we can calculate the minimum value of ΔX.

$$\frac{d(\Delta X)}{d(c)} = \Delta\theta(\frac{v}{f} - \frac{X^2 f}{vc^2}) = 0 \tag{12}$$

When

$$c = \frac{fX}{v}(or - \frac{fX}{v}) \tag{13}$$

ΔX is minimum :

$$\Delta X = 2\Delta\theta X \tag{14}$$

And at this time :

$$\theta = \frac{\pi}{4} \tag{15}$$

From the above equation we can see that when c equals $\frac{fX}{v}$ the error of X caused by the error $\Delta\theta$ is minimum. Because X is unknown we need to estimate it from the approximate position of objects when we select hyperbolic slit. if we decided the c, then we can adjust the slit's position via parameter a in the image to set the slit.

5 Simulation

In our simulation experiment, we first created images of road as shown in Figure 3. There are many buildings of different heights along the road. Our purpose is to try to obtain the 3D information about those buildings. A hyperbolic slit is set as shown in Figure 3. Then we created an TSI as shown in Figure 6. From the image straight lines are extracted as shown in Figure 7. From the information about these straight lines we have been able to obtain the information about the buildings beside the road.

6 Conclusion

In this paper, we proposed a method to acquire 3D information from a two dimensional spatiotemporal image created from images taken with moving camera, using a hyperbolic slit. This method greatly decreased the quantity of data while keeping the 3D information. It enables us to acquire 3D information by only extracting straight lines from two dimensional images.

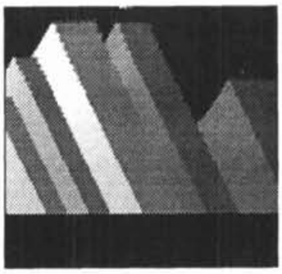

Figure 6: Spatiotemporal Image

Figure 7: Lines Extracted from TSI

We also discussed the selection of hyperbolic slit for the spatiotemporal images.

As future work, we will investigate other kinds of camera motions such as rotation and corresponding slit section methods for spatiotemporal image creation for 3D information acquisition.

References

[1] R.C.Bolles,H.H
Baker and D.H.Marimont. "Epipolar-Plane Image Analysis :An Approach to Determining Structure from Motion,"International Journal of Computer Vision,1.pp.7-55,1987.

[2] T.Yasuno and T.Hamano. "3D Structure from motion using homocentric spherical spatiotemporal image analysis ". *Proceedings of IAPR Workshop on Machine Vision Applications*, pp. 371-374,Tokyo,Novmber 1990.

[3] J.Y.Zheng and S.Tuji,"From Anorthoscope Perception to Dynamic Vision", Proc.IEEE Int.Conf.Robotics and Automation 1990.

[4] Duda,R.O.and Hart,P.E.:"Use of the Hough Transformation to Detect Lines and Curves in Pictures", Comm.AVM,vol.15,No.1,pp11-15 1972.