LINE SEGMENT EXTRACTION IN PANORAMIC IMAGES

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ABSTRACT

Omni-directional sensors are useful in obtaining a 360° field of view of a scene for telepresence, panoramic scene capture and machine vision. An approach to obtain a panoramic view is to utilize a radially-symmetric, non-planar mirror and a single image sensor. This catadioptric optical arrangement creates new challenges for feature extraction as that many of the benefits of a perspective projection are not present, specifically the detection of straight line edges. Our previous work addressing this need saw the development of a modified Hough transform to facilitate the detection of horizontal and vertical line feature edges. Algorithms tailored to utilize this Panoramic Hough transform to robustly extract horizontal and vertical line segments are presented. Specifically a robust method for using this Panoramic Hough transform to successively identify and remove clusters that appear in the parameter space is shown. Experimental results are presented to validate this model.

Keywords: Omni-directional, panoramic, feature extraction, line extraction, non-SVP, catadioptric

1 INTRODUCTION

Panoramic imaging is an alternative to conventional image capture devices such as most film, video and digital cameras that provide a view in one direction only. Image processing and computer vision can benefit from the full 360° seamless field of view a panoramic image sensor can provide. Suitable applications of panoramic imaging range from pan-tilt cameras with no moving parts to immersive telepresence to machine vision for mobile robotics. Panoramic image sensing can remove the need of the concept of a direction of gaze and issues with its management. A panoramic view can be obtained using a a catadioptric system where a curved mirror with a constant radial profile is viewed by a conventional camera. If such a camera and mirror arrangement is used for computer vision, feature extraction provides extra challenges not faced with conventional cameras. The model of a perspective pinhole projection and the benefits of an affine transform cannot be used for mirrors with other than parabolic or hyperbolic profiles [1]. Of principal importance, the preservation of straight lines is restricted from all lines in a perspective projection to only lines that are parallel to the main axis of the camera/mirror sensor. In this paper this axis is assumed to be vertical, and thus straight vertical lines project in the scene project to straight radial lines in the image. However all other lines project to a complex curved locus of points. Our work focuses on the extraction of horizontal and vertical lines, the motivation being applications in a man-made environment where the majority of features are straight horizontal or vertical lines.

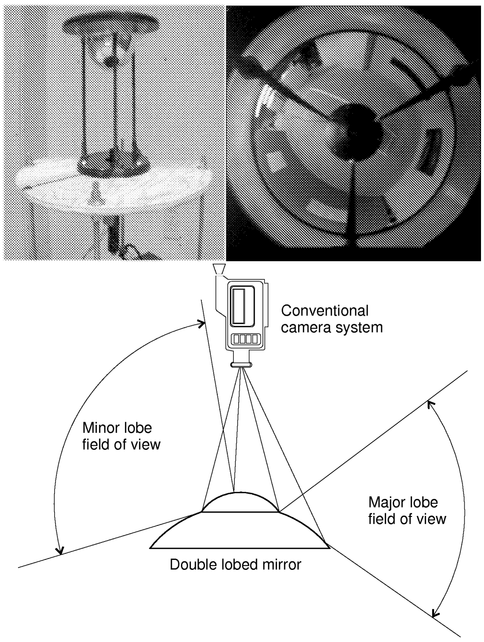

Figure 1: *(Top)A Panoramic Imaging system using Catadioptric optics (shown mounted on a mobile platform), and a sample panoramic image. (Bottom) Panoramic Stereo Image Sensor using a concentric double convex lobed mirror.*

The *Panoramic Hough Transform* (herein referred to as the PH transform) was developed to identify these horizontal lines [10]. Successful application of this tool to aid in feature extraction for panoramic computer requires further consideration of theoretical and practical issues.

Two further concepts are put forth: Creating PH spaces for different edge directions and the *Identify and Remove* method for cluster detection.

This theory finds specific application in our development of the panoramic stereo vision sensor [15] which uses a bi-lobed catadioptric optical system to provide panoramic stereo views with a single image sensor. The theory and procedures described would be performed twice in such a system, and matching performed on the located features to model the environment.

2 PROCESSING IMAGERY FROM PANORAMIC SENSORS

2.1 Panoramic Image Capture

Catadioptric imaging systems, those employing mirrors as well as lenses in the optical path, allow for the capture of a panoramic image. Bogner [5], Basu [4], Yagi [17] and others have demonstrated such systems. Many researchers have participated this research as evidenced by the number of researchers at a special forum at CVPR 2000 (Omnivis 2000) [12, 16, 6, 7, 14]. These systems are typically composed of a radially symmetric mirror, and a single perspective camera which together are capable of capturing light from all azimuth angles. The camera is positioned with it's main optical axis parallel with the central axis of the mirror. The reflection from the mirror of the scene is captured by the camera providing a panoramic view of this scene. A desired vertical viewing field of view can be readily accomplished with proper choice of mirror profile, camera-mirror distance and camera focal length.

Figure 1 depicts two systems used in our research, each consisting of a standard video camera and a radially symmetric mirror. The lower image shows using a bi-lobed mirror where scene points are imaged twice, allowing stereo reconstruction [3, 2, 15].

The paradigm motivating this research is that of reconstructing 3D scenes of man-made environments with panoramic imagery. Much of the objects in man-made environments, especially indoor ones, can be described in large part as polyhedral objects with horizontal and vertical edges. The theory and algorithms developed in [10] and this paper provide a way to extract features of horizontal and vertical line segments and planar regions bounded by such segments. Matching of these features and reconstruction is not performed in the work of this paper. Feature extraction is described for a single mirror lobe only below, but can be extended to the bi-lobed mirror [11], or used with multiple panoramic cameras as described in [13]'s longer baseline configurations.

2.2 Line Feature Extraction using Non-SVP Catadioptric Systems

Several radial profiles for the mirror of panoramic catadioptric systems have been explored in the literature such as circular profiles, parabolic, hyperbolic and others designed for equi-angular response ([1], [8], [9]). Parabolic and hyperbolic profiles have qualities that allow the creation of virtual perspective projection views and hence feature extraction can reduce to methods used in the large body of work directed towards conventional image sensors. This is due to the existence of a virtual point of convergence for all rays incident on the image plane, referred to as a *Single View-Point (SVP)* in the literature.

Other profiles such as circular for spherical mirrors don't have this property and hence detection of straight lined features is more difficult. Due to the easier manufacturing considerations of optically usable spherical mirrors, and desirable traits of other non-SVP profiles, investigation of possible extra or different processing stages for this profile family is justifiable. This work shows that a specially modified series of steps for line extraction can adapt to the nature of non-SVP panoramic images and allow for similar feature extraction results as previous computer vision work (for horizontal and vertical features).

A modified Hough transform was created to provide a way to automatically recognize the curved lines on the image plane that a horizontal line feature would map to. This *Panoramic Hough Transform* was described in [10] and provides a two-dimensional space in which clusters form in the presence of a horizontal straight line.

2.3 Panoramic Hough Transform

The extension of the basic *Hough Transform* concept to locate straight horizontal and vertical lines in the imagery provided by non-SVP catadioptric panoramic image sensors was presented in [10]. Assuming a vertical central camera/mirror axis of a radially symmetric mirror lobe and camera combination, straight vertical lines will project as straight radial lines and most horizontal lines will project to non-circular curved lines.

In [10], a one dimensional histogram method was used to identify vertical lines due to their projection to straight radial lines, and the *Panoramic Hough Trans-*

form proposed to identify horizontal lines. The latter is a transform that creates a two-dimensional parameter space image.

Horizontal feature lines whose height causes incident rays to the mirror to be horizontal before reflecting from the mirror form a special circular locus on the image place labelled herein as the *horizon line* (shown as a dotted line in the image and PH space images). Horizontal features at this height, or at great distance relative to the sensor dimensions will project onto this line. The projection of horizontal lines not at this height is a curved (but non-circular) locus of points that start and end on the *horizon line* and extend a maximum distance from this horizon line at an image point (θ_{main}, R_{main}) in polar coordinates. The angle of maximal deviation from the horizon line is equal to the azimuth angle θ_{main} of closest approach of this horizontal line to the vertical camera axis.

The two degrees of freedom for the projection of a horizontal line (θ_{main}, R_{main}) form the X and Y axis respectively of the PH transform image plots. A point in the transform image represents a set of points in the image space, and conversely a point in the source image could be belong to any of a set of line projections, each represented by a transform space point. This is analogous to the point-line duality of the classic Hough Transform as shown in Figure 2.

The forward and reverse transforms (Equations 1, 2) can be defined as functions, and are implemented in practice as lookup tables. $P(\theta, R)$ and $P^{-1}(\theta, R)$ are reciprocal functions of a radius and a angular distance from a central angle θ_{main}.

$$R_{ph} = P(\theta_s - \theta_{main}, R_s) \quad (1)$$
$$\theta_{ph} = \theta_s - \theta_{main}$$

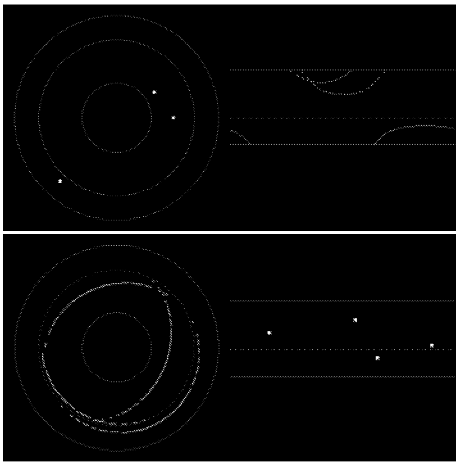

Figure 2: *Demonstration of point/line duality of the Panoramic Hough Transform. Mapping points from image space (left) to hough space (right) - a point in image space becomes a curved line in the PH space. Likewise mapping points backwards from hough space, a point in hough space corresponds to a curved line in image space. The right hand images are the transform space with θ_{main} as the X-axis and R_{main} as the Y axis.*

$$where(-\pi/2 < \theta_{main} < \pi/2)$$
$$R_s = P^{-1}(\theta_{ph} - \theta_{main}, R_{ph}) \quad (2)$$
$$\theta_s = \theta_{ph} - \theta_{main}$$
$$where(-\pi/2 < \theta_{ph} < \pi/2)$$
$$R = P(0, R) = P^{-1}(0, R) \quad (3)$$

[10] derives these equations for the general case, and specifically for a spherical mirror (circular profile). For practical systems, a lookup table was created for the forward and reverse transforms. Points were mapped from the image space to the PH Transform space, and clusters detected representing projections of horizontal lines.

The feature extraction for horizontal edges involves finding these cluster peaks, each of which provide the parameters of θ_{main} and R_{main}. Defining a segment requires two more parameters, θ_{begin}, θ_{end}

which are not found using the transform alone, which is addressed in the method presented below.

2.4 Handling Cluttered Scenes

Since the desired feature to extract in this approach is line features, the PH Transform is performed on an edge magnitude version of the input image. In [10], all points in this high-pass image (generated by the Sobel edge template pair) are projected onto a single PH parameter image, indiscriminate of edge direction. Points corresponding to vertical lines are projected along with those from horizontal lines, providing extra unnecessary calculations and noise. Also horizontal edges that represent the top or bottom of a lighter colored object are treated in the same transform.

2.5 Separate Transform Spaces For Different Edge Directions

This method of processing all edge points in one PH Transform space generated distinct cluster peaks in simple images, but automatic detection of these peaks became less robust in more cluttered scenes.

The first improvement to this method is to filter the edge pixels according to edge angle and send them to one of four algorithms, two for horizontal lines using the PH Transform, and two for vertical lines using one-dimensional histograms. One horizontal algorithm collects edge pixels that represent increases in image intensity as radius increases, the other represent intensity decreases. Likewise one vertical algorithm processes edge pixels that correspond to increasing intensity in a clockwise direction, the other for decreasing intensity.

2.6 Identify and Remove Cluster Location Algorithm for Horizontal Edges

Although the PH transform shows good grouping in parameter space, automatically isolating these cluster peaks successfully in cluttered scenes with noisy images is problematic. Improvements were needed for robust automatic detection.

Only processing potential horizontal edgels in one of two spaces according to edge polarity is one improvement, using a more sophisticated method for locating peaks would also help.

Due to the dynamic range of different peaks, a smaller cluster peak can be difficult to detect in the neighborhood of more prominent peaks.

The *Identify and Remove* cluster detection method modifies the problem from finding multiple peaks in one transform image to that of finding a single peak in multiple transform images. This method allows the effect of removing source image pixels without needing to full recalculate the PH transform. This involves creating special data structures when performing the initial transform so that once a peak is identified the projections of all source image points that lead to that peak can be removed and thus reveal other peaks.

This was done by iteratively selecting the cluster of maximal response and then identifying the source image pixels and removing their projections from this PH transform image. This is done successively until the maximum peak in the transform image falls below a given threshold.

The data structures used when creating the PH transform are shown in Figure 3. One linear list, one two-dimensional list and two linked lists provide a circular structure for associating points in both directions between the source image and the PH transform space.

Selected edge points from image A create an entry in linear array B. B is indexed by an arbitrary pixel number p_i and each entry contains the edge magnitude and pointer to the beginning of the linked list C that contains all the u, v locations in the PH parameter image D that the edge point maps to. The edge value is added to the PH parameter image D at each of the u, v locations. Each pixel in D has a pointer to the beginning of another linked list E that contains the pixel numbers p_i in list B for all source image pixels that project onto this PH image pixel. Thus when a cluster is identified, all it's contributing source pixels are identified, and their effect removed from the transform image. The clusters are identified and removed sequentially starting with the largest response.

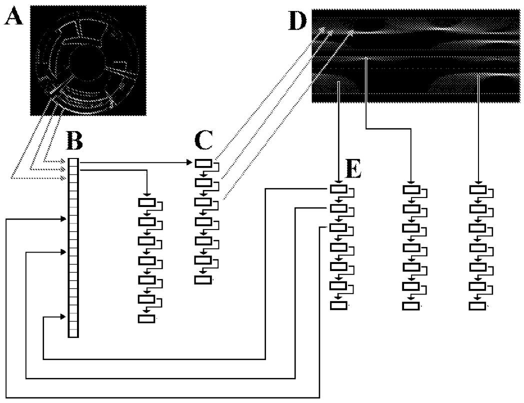

Figure 3: *Identify and Remove cluster peak detection method. The circular data structures allow identification of which source pixels transform to a point in PH parameter image D.*

Each cluster peak is found by the maximal value in the PH image. The extent of the cluster around the maximum value allow the determination of confidence in the existence and location of this edge. The clusters are typically more uncertain in their central azimuth angle θ_{main} than in R_{main} and so the clusters are typically wider in the θ direction (X-axis in the transform images). Also as expected, the clusters widen as R_{main} approached the horizon line as that the central angle becomes more indeterminate on the horizon.

A real image captured from a panoramic image sensor is shown in Figure 4. The horizontal PH transform image for the first four iterations of the *Identify and Remove* procedure for edge points with radially increasing intensity, is shown in Figures 2.6a-d. Note that the transform images are scaled to the value of the maximum peak and so lesser clusters get brighter as more dominant clusters are removed.

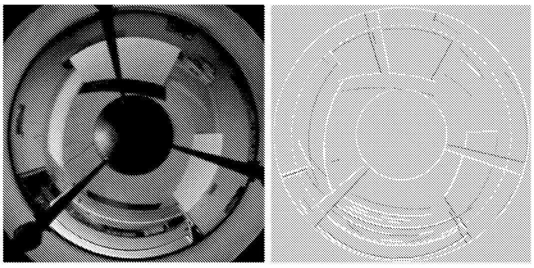

Figure 4: *(Left) Source image captured by a catadioptric single-lobed image sensor. Aspect ratio compensated image from a Sony 999 NTSC camera with a 15cm diameter spherical mirror. (Right) Automatically extracted line segments.*

The clusters detected using the *Identify and Remove* stage are written out to a database with each feature entry containing the line description θ_{main}, R_{main}, and the start,end points (θ_{begin}, θ_{end}) detected of segments along this line. The confidence and matching aid statistics of cluster spread (width of bounding box in PH space), number of pixels contributing to this edge and the total edge strength are also provided in this output feature list.

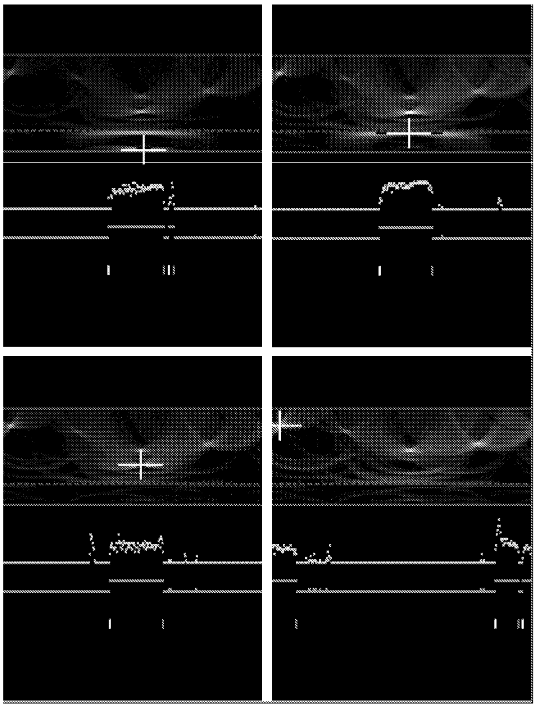

Figure 5: *First 4 successive stages of the Identify and Remove cluster detection algorithm (left-to-right, top-to-bottom). The cluster center is marked by the cross-hairs. Source image pixels are identified and their projections removed for the next iteration. Below the PH image is the raw and processed histogram of edge pixel frequency according to angular position to determine line segment start and end points.*

3 Discussion:Results of Horizontal and Vertical Line Feature Extraction

The results are quite robust given the noise and low resolution of the input image (from a NTSC greyscale video camera) and the lack of any intensive camera calibration. The three parameters of camera focal length, mirror radius and distance between the camera focal point and mirror center were measured very roughly but the vertical and horizontal line features were well detected. Current research using this method is employing a high resolution digital camera to provide a panoramic image of much larger resolution without the blurring of an NTSC signal and much finer features should be detectable.

4 Conclusions

The *Panoramic Hough* transform had shown to be a useful and robust method for detecting the projection of horizontal line edges for catadioptric panoramic image sensors with a non-SVP (Single View-Point) mirror profile. Many useful mirrors shapes, such as conical or spherical, are non-SVP and can benefit from this transform method. However the PH transform cannot provide reliable automatic detection alone, and needs to be combined with methods to help distinguish individual cluster peaks in the PH transform parameter space. Also the PH transform alone can only indicate the presence of horizontal edge lines and not locate the start and end points of segments.

The filtering of edge pixels into two different PH spaces allow the PH parameter spaces to be less cluttered and less noisy than if all edge pixels, horizontal and vertical, are put into one PH transform parameter space. Also closely spaced edges of increasing and decreasing intensity, as around a thin horizontal object, can be discriminated as that they are mapped into different spaces. The *Identify and Remove* method allow for closely spaced clusters in this parameter space to be separately identified and line segment information to be found to augment the line detection.

The methods proposed allow for robust feature extraction of horizontal and vertical line segments from panoramic images with non-SVP mirror profiles, enabling such panoramic catadioptric image sensors to be useful for modeling and machine vision tasks.

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