COMPROMETIDA COM A PROMOÇÃO DO DESENVOLVIMENTO DA ENGENHARIA E DAS CIÊNCIAS MECÂNICAS

CONEM 2010
VI Congresso Nacional de Engenharia Mecânica

VI CONGRESSO NACIONAL DE ENGENHARIA MECÂNICA
VI NATIONAL CONGRESS OF MECHANICAL ENGINEERING
18 a 21 de agosto de 2010 – Campina Grande – Paraíba - Brasil
August 18 – 21, 2010 – Campina Grande – Paraíba – Brazil

OMNIDIRECTIONAL VISION SYSTEM FOR AGRICULTURAL MOBILE ROBOT NAVIGATION

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Abstract: *Computer vision, when used in open and unstructured environments as in the inspection of crops, requires the use of specific vision systems acquiring algorithms prepared for such situations. These algorithms work mainly with images composed of complex objects, textures, shadows and brightness. The present project aims to apply an omnidirectional vision system for mobile robot navigation in agricultural area. Theses systems make the acquisition of image within a 360° field of view practicable. The arrangement of convex hyperbolic mirrors with lenses makes a computer vision system structure with larger vertical field of vision. Two methods of image correction were employed: Polar-to-Cartesian transformation and Direct hyperbolic transformation. Therefore, a panoramic image pre-processing module is deployed for edge detection, segmentation, and binary imaging algorithms, with artificial neural networks techniques, resulting in manageable images for space navigation and planting area.*

Keywords: *Omnidirectional Sensors, Catadioptric Systems, Computer Vision, Mobile Robots.*

1. INTRODUCTION

Computer vision, when used in open and unstructured environments as in the inspection of crops, requires the use of algorithms prepared for such situations. These algorithms work mainly with images composed of complex objects, textures, shadows and brightness. Several segmentation algorithms proposed in literature (Liu & Zhou, 2004, Chen et al., 2002; Hill, 2002) were designed to process images originally characterized by the above-mentioned items. Additionally, agricultural automation may take advantage of computer vision resources, which can be applied to a number of different tasks, such as inspection (Brosnan and Sun, 2002), classification of plants (Tang et al., 2003; Neto et al., 2003, Steward et al., 2004), estimated production (Annamalai et al., 2004), automated collection (Plebe & Grasso, 2001) and guidance of autonomous machines.

Bearing the afore-named in mind, the present project proposes a customized omnidirectional vision system with mathematical modeling and physical construction of the catadioptric sensory system unit for image acquisition and digital processing, applied into agricultural mobile robots navigation.

2. MATERIALS AND METHODS

2.1. Omnidirectional Vision System Modeling

Several previous works have described different kind of mirrors in catadioptric systems for omnidirectional vision acquisition. Typically, these systems consist in a convex mirror fixed in front of a camera that also remains fixed with its lens facing up.

Baker and Nayar (1998) describe a vision system set with a single center of projection, which generates any projected image on any defined and known plane. So it is possible to generate perspective or panoramic images without distortions. In more specific works, Nayar (1997) and Peri (1997), developed a vision system that uses an orthographic projection camera and a parabolic mirror, with simulation software that allows manual adjustment of perspective projection properties (vision virtual direction, field of view and camera magnitude). Chang and Hebert (1998) use

Nayar's omnidirectional system in an application of visual servo control of a mobile robot, thus avoiding that a pan/tilt mechanism point directly to the interest target.

Svoboda (1997) also develops a catadioptric system with single center of projection. This system is composed of a perspective projection camera and a hyperbolic mirror, which allows the acquisition of perspective and panoramic projections without distortion. The author also shows the epipolar curves/geometry for this type of system, which calculates distances based on stereo vision. The epipolar geometry between two images of the same scene, captured by similar cameras, is the intersection geometry of both image planes (I and I'), with the planes bundle that has the base line (line that connects both optical centers, O and O') as axis.

Among the above-mentioned works, this one aims to build a hyperbolic mirror similar to Svoboda (1997). The hyperbolic mirror with a perspective projection camera would allow image acquisition with single projection center in an omnidirectional system (panoramic or perspective images).

Omnidirectional computer vision systems make the acquisition of image within a 360° field of view practicable. The arrangement of convex hyperbolic mirrors with lenses makes a computer vision system structure with larger vertical field of vision (Gaspar *et* al, 2000 – Yagi, 1999).

The angle of elevation (φ) is the angle of incidence of light on the mirror surface, and the radial angle (ψ) corresponds to the angle of reflection of light into the image acquiring device. Thus, a pixel coordinate in perspective projection is related to a light-ray direction that reaches the camera sensor and forms a pixel in the polar image, as illustrated in Figure 1.

The above-named relation can therefore be determined by geometrical functions and exemplified by the following equations.

$$\tan\varphi = \frac{f_p sen\varphi_o + v_p \cos\varphi_0}{f_p \cos\varphi_0} \tag{1}$$

$$\tan\theta = \frac{(f_p \cos\varphi_0 - v_p sen\varphi_0) sen\theta_0 - u_p \cos\theta_0}{(f_p \cos\varphi_0 - v_p sen\varphi_0)\cos\theta + u_p sen\theta_0} \tag{2}$$

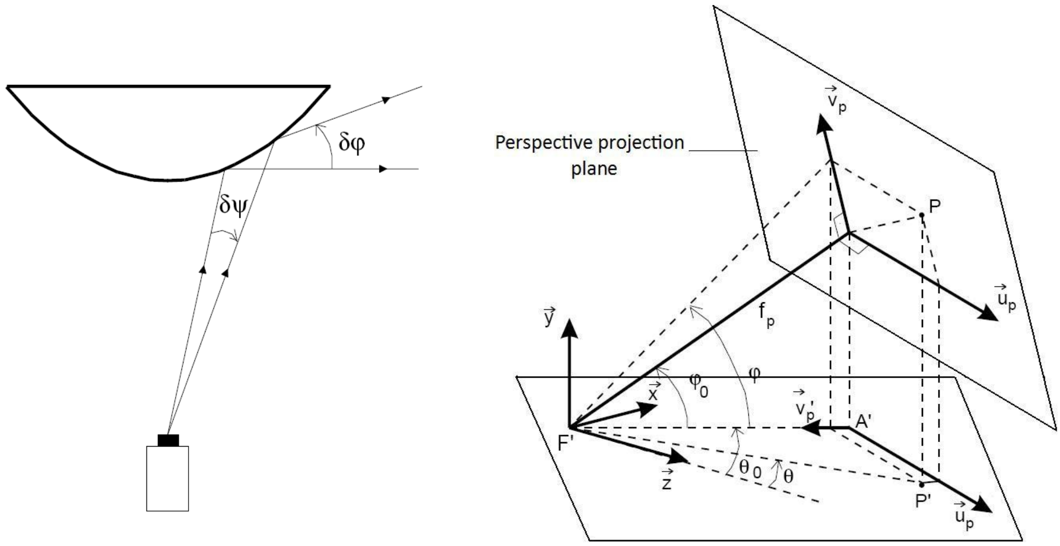

Figure 1. Vertical angular gain and geometric relations of the perspective images.

Two methods of image correction were employed, namely the direct transformation from Polar to Cartesian coordinates and the hyperbolic mirror equation in the rectification process.

2.2 Direct Transformation from Polar to Cartesian coordinates

This correction method is based on a Polar-to-Cartesian transformation (Grassi, 2002). The radius of the omnidirectional image acquired by the system is linearly mapped as the *y* coordinate and the angle in the same image are mapped in the omnidirectional *x* coordinate of the rectified image as shown in Figure 2. According to this method, if the center of the image is considered the origin (0,0) and all variables assume values between 0 and 1, Equation 3 is used to do the correction.

$$\begin{aligned} x_{in} &= y_{out}.\cos(2\pi x_{out}) \\ y_{in} &= y_{out}.sen(2\pi x_{out}) \end{aligned} \tag{3}$$

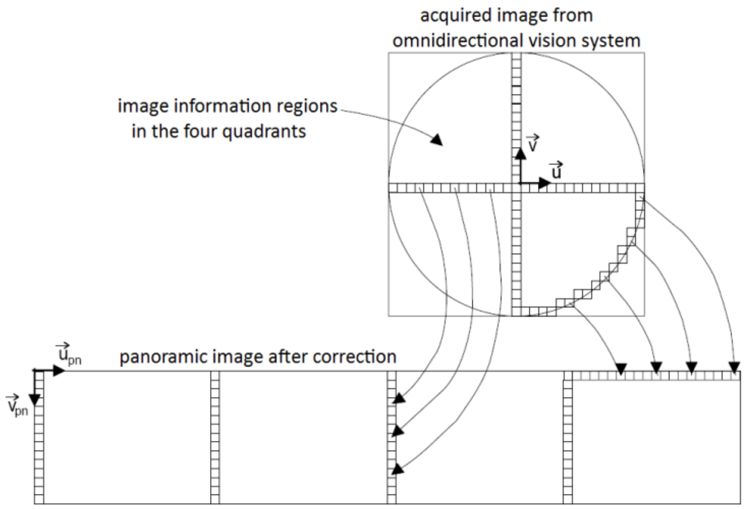

Figure 2. Correction method with direct Polar-to-Cartesian transformation.

A panoramic image acquisition in a 360° field of view is transformed from Polar to Cartesian coordinates. The azimuth angle, also known as meridian angle, which manifests itself by the incidence direction of the light-ray onto the angular compass in the coordinated original image, is mapped on the horizontal coordinate axis of the panoramic image, and the radial coordinate in original image is mapped on the vertical coordinate axis of the same image, with omnidirectional, panoramic and binary imaging view processes as illustrated in Figure 3.

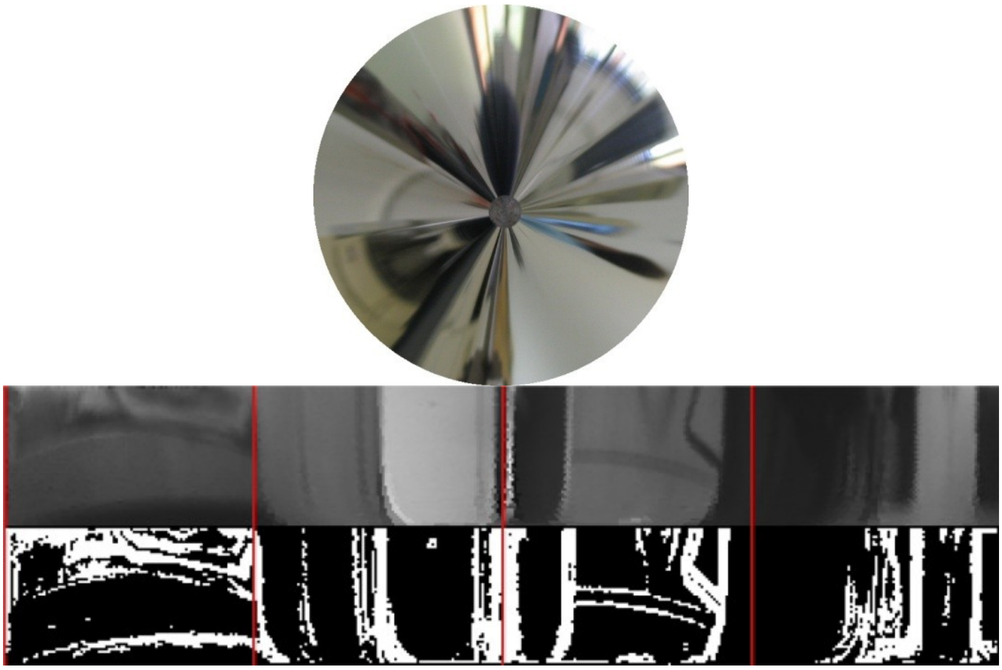

Figure 3. Omnidirectional, panoramic and binary images.

2.3 Hyperbolic Mirror Equation in Rectification Process

In this method, not only the hyperbolic mirror equation but also the single center of projection are calculated, which results in panoramic images without any distortions.

Reflected optical rays intersect themselves at a given point in the hyperbolic mirror (focus of a hyperbola), also known as center of projection. With this projection, one can reconstruct prospected images, projecting them onto a spacelike plane.

Figure 4 above shows how the ray of a pixel, an omnidirectional vision system image, is converted into a column matrix, given the hyperbolic geometry mirror, in a panoramic image obtained by a cylinder projection. Through some trigonometric manipulations made from the same figure's scheme above, we obtain the math relations expressed in Equation 4 and 5 used in the transformation process.

$$p_{in} = \frac{x.D.r_{pixel}.(2e + y_{up})}{p_{out} + x.y_{up} + D.2e.r_{up}} \tag{4}$$

$$y = \frac{x.p_{out}.y_{up}}{D.r_{up}} \tag{5}$$

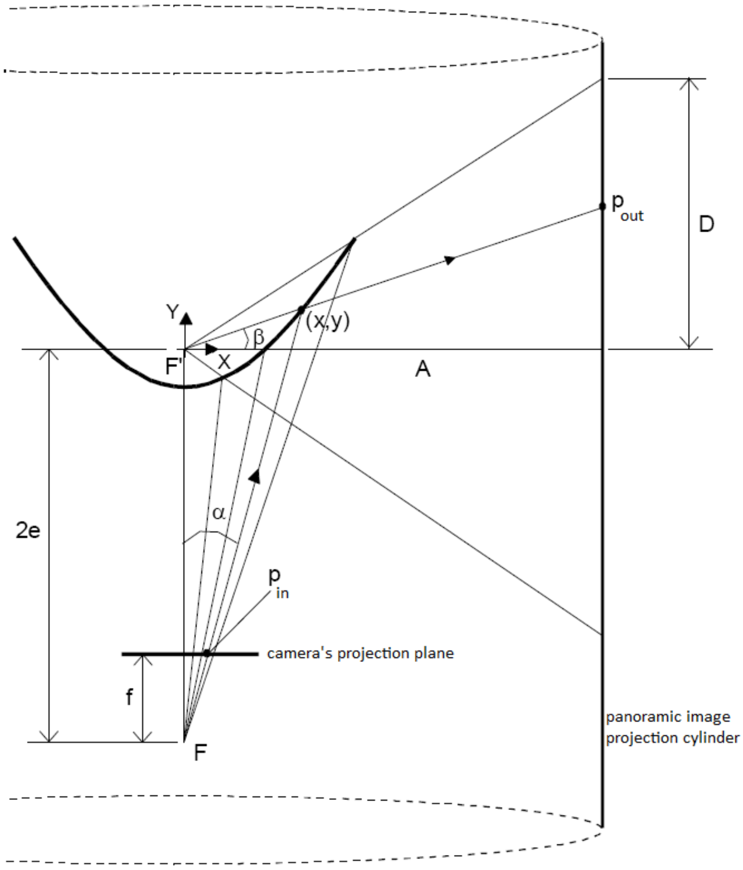

Figure 4. Hyperbolic geometry mirror.

In the equations above, p_{out} represents a column pixel in the rectified image, p_{in} represents a radius pixel of the plane's projection in the omnidirectional vision system, x and y are the axis coordinates of mirror surface, D is a given height in pixels, of rectified image, which extends from the pixels of mirror's edge mapping line ($x = r_{up}$), to the mapping line formed by corresponding pixels to y = 0. The other parameters, mirror eccentricity 2e, r_{pixel}, y_{up} and r_{up}, are known.

Equation 5 represents a straight line that crosses the focus of the hyperbola and p_{out}. The polynomial root is calculated by Newton numerical method (x value, where line and mirror are intersected). Substituting this x value in Equation 4, we obtain a matched p_{in} pixel value to a given p_{out} value.

An inverse mapping is done to this correction method, by means of which each pixel in the rectified image has its matching pixel of captured image. Such mapping is calculated in an extended math expression for the entire image.

$$\begin{aligned} x_{in} &= p_{in}.\cos(2\pi x_{out}) \\ y_{in} &= p_{in}.sen(2\pi x_{out}) \end{aligned} \tag{6}$$

x_{out} is a value from 0 to 1 representing the column in which the rectified image mapped; p_{in} is the value obtained by Equation 5 according to p_{out}; x_{in} and y_{in} represent the coordinate pixel of the captured image that corresponds to a given pixel in the rectified image.

3. PANORAMIC IMAGE PRE-PROCESSING MODULE

In this stage, the image is prepared for Artificial Neural Networks (ANN) analysis through edge detection and binary imaging processes. Problems with ANN often require that conventional processing techniques be used so as to simplify the image data for manageable network (Braga *et* al, 2000 – Cavani, 2004).

Edge detection algorithms identify edge discontinuities in an image, characterizing it as a border. Consequently, in order to present a simplified image to ANN, edge detection generates an image without interference from other features. It is calculated through the Sobel operator (magnitude formulated gradient equations for horizontal and vertical pixels) (Fairhurst, 1988 – Gonzales and Wintz, 1987). A threshold is determined by the average of the values of the Sobel operator, when applied to all pixels, resulting in a 3x3 window normalized to the 255-bit maximum value, avoiding noise transformation data. Magnitude and edge detection are represented in Equation 7 below.

$$G[f(x,y)] = \sqrt{(G_x^2 + G_y^2)} = \left|G_x\right| + \left|G_y\right| \tag{7}$$

4. CONCLUSIONS

In conclusion, this initial research project reached the majority mathematical principles for dynamical modeling and physical construction of the catadioptric system. Omnidirectional vision systems require complex calculus for lenses and cameras catadioptric set. Forthcoming tasks cover the real application of such system on an open environment, where agricultural scenes will be processed, segmented and classified based on ANN topologies, for reliable navigation.

5. ACKNOWLEDGMENT

The authors would like to thanks to CAPES for funding this initial research project.

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7. RESPONSIBILITY NOTICE