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A Unified Framework for Correcting Panoramic Image Distortions

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Abstract: - This paper presents a unified framework for the correction of non-linear distortions in panoramic images. Several techniques are combined to make the system robust, scalable and adaptable to real-time operation. Constructive neural networks are applied where appropriate to achieve robustness. Interactive curve sketching techniques based on polynomial interpolation are used in situations where quick, reliable and practical results are desired. The effectiveness of the system is demonstrated by applying it to the correction of non-linear distortions in the generation of perspective-corrected views from panoramic images acquired using catadioptric systems for use in virtual tours of remote locations.

Key-Words: - Unified framework, Panoramic image, Neural network, Curve sketching, Polynomial interpolation, Distortion correction, Perspective-corrected view, Catadioptric system, Virtual tour

1 Introduction

The recent proliferation of affordable and powerful personal computing devices in the form of the ubiquitous personal computer and associated hardware and software, personal imaging devices in the form of digital still image and video cameras and associated tools and techniques, and accessible personal communications in the form of the Internet and related platforms has generated strong and growing interest in the creation and use of virtual tours. A virtual tour is typically an environment containing representations of remote locations and permitting one or more users to interact with the environment in a manner that gives the user the perception of being right there (immersed) within the remote location. The representations could contain still images, video, audio, navigational databases or any other type of data that is required to facilitate meaningful user interaction. Virtual tours have found significant applications in areas such as medicine, remote surveillance, telepresence, forensics, defense, flight simulators, navigation support systems, tourism and personal websites. A very important component of the data comprising a virtual tour is visual information in the form of still images, video or computer-generated renderings.

When creating environment maps for use in virtual tours, it is desirable to utilize a system that encodes as much visual information as possible in a single image frame and that preferably does so cost-effectively and without any moving parts. The limited field of view offered by conventional cameras and lenses makes them unsuitable for this task. Consequently, panoramic imaging systems [1] capable of much wider fields of view are used to create environment maps for use in virtual tours. Panoramic imaging systems, however, are generally characterized by various types of distortions that need to be corrected before the environment maps generated using them could be viewed comfortably by a human observer. Additionally, a unique effective viewpoint is required for the generation of arbitrary perspective-corrected views from panoramic images.

Several methods for creating and manipulating panoramas exhibiting varied drawbacks and strengths have been reported in the literature. Earlier attempts at solving the problem involved the use of rotating cameras to build panorama mosaics [2], [3] in systems that could operate effectively only in static environments. Orientation sensing devices [4] were later incorporated in an attempt to remedy the constraints of these early systems. The use of fish-eye lenses [5] and dodecahedral mirror systems [6] remedied some of the constraints of earlier systems but introduced other constraints of their own such as the strong non-linear distortions and the need for laborious, error-prone stitching associated with fish-eye images. Catadioptric systems comprising reflecting and/or refracting elements [7] represent a more robust solution to the problem. The authors have applied neural networks to the construction of arbitrary perspective-corrected views from panoramic images [8].

In a related paper [9], the authors introduced a novel approach to the correction of panoramic image distortions using constructive neural networks.

This paper presents a unified framework for the correction of panoramic image distortions that combines the robustness of the neural network approach with the speed and easy implementation of an interactive curve sketching technique based on polynomial interpolation. Selection of a specific method is based on the complexity of the panoramic imaging system involved. This paper focuses on the use of an interactive curve sketching technique based on polynomial interpolation for the correction of panoramic image distortions.

The remainder of this paper is organized as follows: Section 2 discusses the objectives, basic model and application of the unified distortion correction system. The interactive curve sketching technique based on polynomial interpolation is described in Section 3. Experimental results are highlighted in Section 4 while Section 5 concludes this paper.

2 Unified Framework

2.1 Objectives

The main goal of this research effort is to provide a unified framework for constructing distortion-free perspective-corrected views from panoramic images acquired using an arbitrary panoramic imaging system. By utilizing a combination of constructive neural networks and interactive curve sketching based on polynomial interpolation, the system presented in this paper eliminates the need to derive compact equations for the characteristics of the imaging system, removes the need to impose constraints on the imaging system and lends itself to quick and easy implementation. The system corrects all non-linear distortions including, but not limited to, radial distortions, tangential (de-centering) distortions as well as distortions caused by the misalignment of the components of the panoramic imaging system. This increases the scope of applications of the system.

2.2 Model

Formation of a distorted 2D image from the undistorted 3D real world scene by a panoramic imaging system is modeled as an input-output mapping between an undistorted 2D image plane and the distorted 2D image plane.

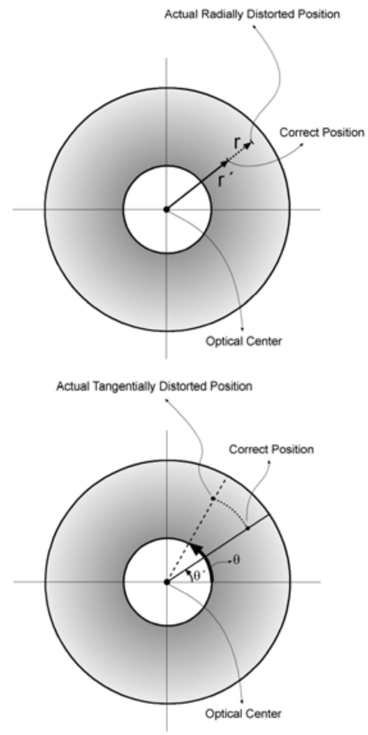

Fig. 1. Simplified model of radial and tangential distortions of a panoramic imaging system. r' represents the radius of the correct position, r the radius of the distorted position. Similarly, θ' represents the correct lateral angle, θ the distorted lateral angle.

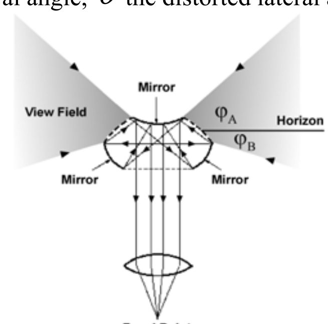

Fig. 2. Nature of a catadioptric system.

In the case of panoramic imaging systems that exhibit complex distortion patterns, a neural network of sufficient complexity to learn the characteristic distortion of the panoramic imaging system is constructed, trained on sample data and then the trained neural network is used to correct all or selected portions of any panoramic image acquired using the panoramic imaging system. Alternatively, for panoramic imaging systems that do not exhibit complex distortion patterns, an interactive curve sketching technique based on polynomial interpolation is used to define a distortion curve for the panoramic imaging system. The distortion curve is then stored to be used later to correct all or selected portions of any panoramic image acquired using the panoramic imaging system. Figure 1 shows a simplified model of the radial and tangential distortions of a panoramic imaging system. Most catadioptric systems are characterized by significant radial distortion and negligible tangential distortion. In an earlier paper [9], the authors relied on the general approximating ability of a multi-layer neural network consisting of perceptron processing units to correct radial and tangential distortions as well as any other non-linear distortions represented by the sample data. This paper extends the method of the previous paper by presenting a unified framework that permits the use of interactive curve fitting to correct distortions in panoramic images. Distortion correction based on interactive curve sketching is elaborated in the remainder of this paper.

2.3 Application to catadioptric systems

Application to catadioptric systems is used to demonstrate the effectiveness of the system. Figure 2 illustrates the nature a catadioptric system. The lateral field of view of a catadioptric system is the entire 360-degree range. The maximum angle above the horizon is denoted by φ_A (less than 90 degrees in most practical cases) while the minimum angle below the horizon is denoted by φ_B. Both φ_A and φ_B usually have values less than 90 degrees in practical catadioptric systems. For convenience in calculations, a positive value is assigned to φ_A while a negative value is assigned to φ_B. Points in the real world object space seen at the same vertical angles above or below the horizon correspond to concentric circles in the panoramic image. Similarly, points on lines in the real world object space parallel to the optical axis of the catadioptric system are projected onto radial lines in the panoramic image. Figure 3 illustrates an arrangement for the capture of a panoramic image using a catadioptric system placed at the center of the arrangement. The point X is represented by its polar coordinates θ_X (lateral angle) and φ_X (vertical angle). In Fig. 4, the projection of the point X (in Fig. 3) with coordinates θ_X and φ_X in real world space onto the point X' (in Fig. 4) with coordinates θ'_x (lateral angle) and r_X (radius) -- (between the inner radius, r and the outer radius, R) on the distorted panoramic image captured by the catadioptric system is shown.

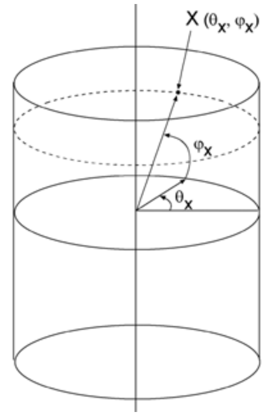

Fig. 3. Capturing a panoramic image with a catadioptric system.

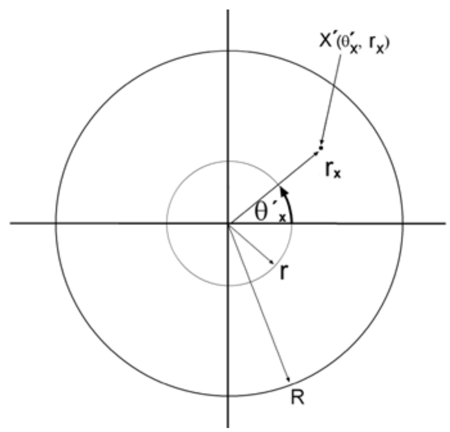

Fig. 4. Outline of donut-shaped panoramic image of the setup of Fig. 3 generated by the catadioptric system.

Since the interior of the panoramic image contains no useful image data, it is often necessary (for example, for transmission over bandwidth-limited media like the Internet) to extract the useful 360-degree panorama from the panoramic image using a polar to rectilinear coordinate transformation. For example, for the with rectilinear coordinates x and y on the 360-degree panorama, the corresponding point with rectilinear coordinates x' and y' on the source panoramic image can be obtained by first calculating the corresponding polar coordinates θ' and r' and then using polar to rectilinear coordinate transformation to calculate the x' and y' coordinates as illustrated in Fig. 5, Fig. 6 and by Eqs. (1)-(4).,

$$\theta' = \frac{2\pi}{P_W}x \qquad (1)$$

$$r' = R - \left(\frac{R-r}{P_H}\right)y \qquad (2)$$

$$x' = x_{center} + r'\cos\theta' \qquad (3)$$

$$y' = y_{center} + r'\sin\theta' \qquad (4)$$

where P_W is the width and P_H is the height, respectively, of the 360-degree panorama, and x_{center} and y_{center} are the rectilinear coordinates of the center of the source panoramic image as shown in Fig. 5.

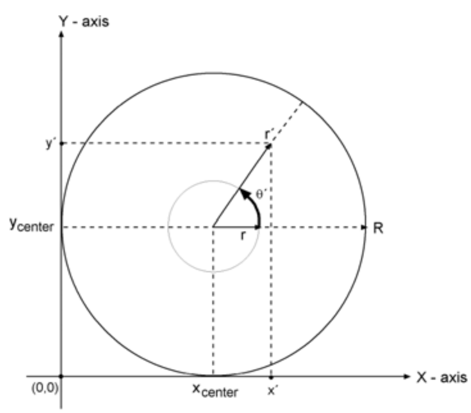

Fig. 5. Point on panoramic image expressed in both polar and rectilinear coordinates for the purpose of conversion into a 360-degree panorama.

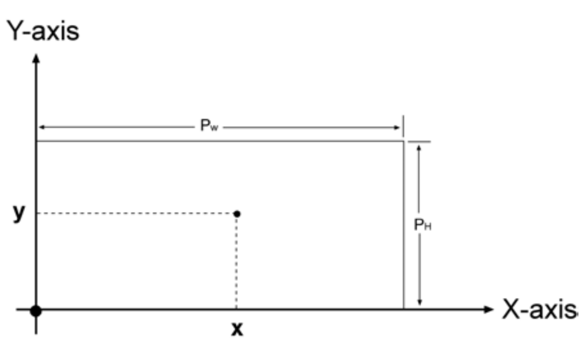

Fig. 6. 360-degree panorama generated from panoramic image. The point with coordinates x and y on the 360-degree panorama corresponds to the point with coordinates x' and y' on the source panoramic image as illustrated in Fig. 5.

3 Interactive Distortion Curve Sketching

For any given set of corresponding points in the undistorted and distorted panoramic images, the relationship between the polar coordinates can be expressed by Eqs. (5)-(6).,

$$\theta' = f^1(\theta) \qquad (5)$$

$$r' = f^2(r) \qquad (6)$$

where f^1 and f^2 are unknown distortion functions.

For most practical catadioptric systems with negligible tangential distortion, f^1 can be set to unity, resulting in the following relationship between the distorted and undistorted coordinates:

$$\theta' = \theta \qquad (7)$$

The goal now is to interactively define the radial distortion curve, f^2.

3.1 Initialization

The radial distortion curve, f^2, is initialized to a simple linear relationship between the distorted and undistorted coordinates for the set of usable angular coordinates between φ_A and φ_B. For simplicity, the angular range is normalized and set between 0 (for φ_B) and 1 (for φ_A).

Although any suitable function approximation technique could be used to obtain f^2, cubic spline interpolation is used because it has been found to give reasonably accurate results and to permit real-time operation.

3.2 Interactive modification of control points

Starting with an initial linear distortion curve as shown in Fig.7 and Fig. 8, control points are added and/or moved to sketch the actual distortion curve. The positions of the control points are used to build a cubic spline in real-time that is then used to generate an undistorted 360-degree panorama and a set of perspective-corrected views from the panorama. The panorama and perspective-corrected views so generated as used as feedback for the interactive modification of the distortion curve. The nature of the distortion present in the panorama and perspective-corrected views could be used to infer the modifications that must be made to the distortion curve. Interactive modification of the distortion curve could proceed until satisfactory results are obtained.

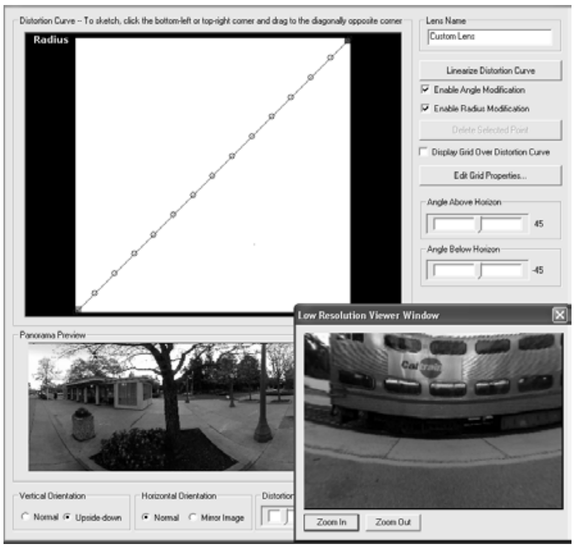

Fig. 7. Initial linear distortion curve. Note the distortion at the bottom of the perspective-corrected view to the bottom-right of the figure.

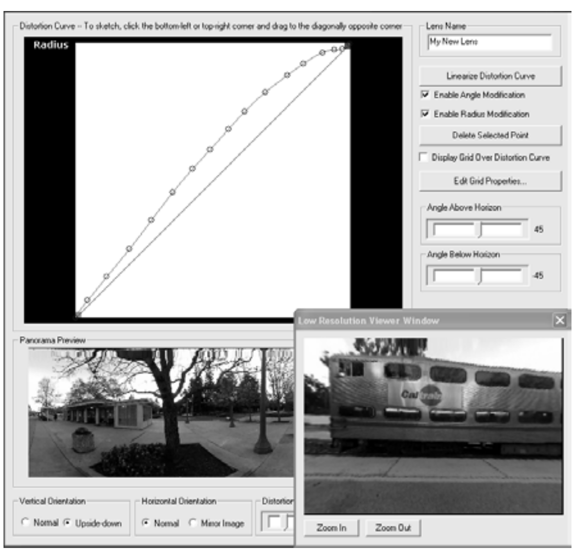

Fig. 8. More accurate non-linear distortion curve. Note that the distortion present in Fig. 7 has been corrected.

4 Experimental Results

Figures 9-10 show sample results. In Fig. 9, a portion of a 360-degree panorama with visible distortion around near the top of a wall is shown. Fig. 10 shows the same portion of the panorama of Fig. 9 with the distortions corrected using the methods described in this paper.

The accuracy of the system is tested by calculating the average precision with which vertical and horizontal lines are reproduced in the perspective-corrected views.

Fig. 9. Part of a 360-degree panorama showing distortion near the top of a wall.

Fig. 10. Distortion-free perspective-corrected view of the panorama of Fig. 9 obtained by using the methods described in this paper.

Several images each with a set of about 5 vertical and horizontal lines were captured. The lengths of the lines and their distances from the catadioptric system were measured. Next, the expected length l, in pixels, of these lines were calculated using the formula:

$$l = \frac{fL}{Dp} \qquad (8)$$

, where f is the effective focal length of the catadioptric system, L is the length of the line in the real world, D is the distance of the line from the catadioptric system in the real world, and p is the pixel width (width in metric units per pixel) for horizontal lines or the pixel height (height in metric units per pixel) for vertical lines for the camera with which the images were acquired. Finally, the actual lengths of the lines, in pixels, in the perspective-corrected views were measured and these measurements were then compared with the expected values. Eq. (9) gives the accuracy ζ (in percentage points), of reproduction of a line in the perspective-corrected view. The lengths of the lines and their distances from the catadioptric system were measured

$$\zeta = \left(1 - \frac{|l - l_0|}{l}\right) \times 100 \qquad (9)$$

, where l is the expected length, in pixels, of the line as determined by Eq. (8), and l_0 is the actual length, in pixels, of the line in the perspective-corrected view.

Accuracies of about 97% and 95% were obtained for horizontal and vertical lines, respectively, using about 20 control points. These results are slightly better than those obtained by the authors in a previous paper [9] in which constructive neural networks and an order of magnitude higher sample points were used.

5 Conclusions

This paper presented a unified framework for the correction of non-linear distortions in panoramic images. A model of the distortions in a panoramic image that could be applied to different techniques for distortion correction including constructive neural networks and interactive curve sketching techniques based on polynomial interpolation was developed. The use of constructive neural networks provides robustness while the use interactive curve sketching techniques based on polynomial interpolation makes the system easy to implement and easily adaptable to real-time operation. The distortion correction methods presented in this paper could be applied in the construction of distortion-free perspective-corrected views for use in virtual tours for interactive immersive television, surveillance, tourism, robot control and other virtual reality applications.

References:

[1] R. Benosman, Panoramic imaging from 1767 to the present, *International Conference on Advanced Robotics, Workshop*, Vol.1, 2001, pp. 9-10.

[2] R. Szeliski, Video mosaics for virtual environments, *Computer Graphics and Applications, Workshop*, Vol.16, No. 3, 1996, pp. 23-30.

[3] H. Sawhney, S. Hsu and R. Kumar, Robust video mosaicing through topology inference and local to global alignment, *5th European Conference on Computer Vision,* Vol.2, 1998, pp. 103-119.

[4] T. Boult, Remote reality demonstration, *IEEE Conference on Computer Vision and Pattern Recognition*, 1998, pp. 966-967.

[5] S. Shah and J. Aggarwal, Intrinsic parameter calibration procedure for a high-distortion fish-eye lens camera with distortion model and accuracy estimation, *Pattern Recognition,* Vol.29, No.11, 1996, pp. 1775-1788.

[6] R. Raskar, G. Welch, M. Cutts, A. Lake, L. Stesin, and H. Fouch, The Office of the future: a unified approach to image-based modeling and spatially immersive displays, *ACM SIGGRAPH*, 1998, pp. 179-188.

[7] P. Greguss, PAL-optic based instruments for space research and robotics*, Laser and Optoelektronik*, Vol.28, 1996, pp. 43-49.

[8] F. Ekpar, H. Hase and M. Yoneda, Constructing arbitrary perspective-corrected views from panoramic images using neural networks, *7thinternational Conference on Neural Information Processing*, Vol.1, 2000, pp. 156-160.

[9] F. Ekpar, M. Yoneda, and H. Hase, Correcting distortions in panoramic images using constructive neural networks, *International Journal of Neural Systems*, Vol.13, No.4, 2003, pp. 239-250. [8] R. Szeliski, Video mosaics for virtual environments, *Computer Graphics and Applications*, Vol.16, No.3, 1996, pp. 23-30.