등거리 스테레오 전방위 렌즈의 위치 측정 알고리듬을 위한 파라미터 측정에 관한 연구

Parameter Estimation for Range Finding Algorithm of Equidistance Stereo Catadioptric Mirrors

최 영 호* 강 민 구** 조 문 신***
Young-ho Choi Min-goo Kang Moon-shin Zo

요 약

전방위 렌즈(Catadioptric mirror)는 전방위 감시를 위해 널리 사용되고 있다. 대부분의 전방위 렌즈에서의 단점은 전방위 렌즈를 통하여 획득한 영상의 해상도가 위치에 따라 일정하지 않다는데 있다. 본 논문에서 사용한 등거리 전방위 렌즈는 이러한 문제를 해결할 수 있도록 설계된 렌즈이다. 실제 등거리 전방위 렌즈를 통한 거리 계산 시 오류의 원인으로는 카메라 영상 센서와 전방위 렌즈와의 축의 어긋남, 설계 시 가정한 focal length의 변화 등을 들 수 있는데 이 중 focal length의 변화는 기구의 정확한 제작으로 해결할 수 없는 문제이다. 본 논문에서는 이러한 focal length의 변화에 대처하기 위하여 focal length를 수정하는 방법을 제안한다. 영상 정합을 통해 임의로 선정된 두 개의 objects points에 대한 반대편 스테레오 영상에서 대응점을 찾은 후 이들 화소의 원점에서의 거리를 사용하여 경계에 해당하는 화소의 위치를 찾는다. 이렇게 측정된 경계의 위치가 미리 계산된 경계화소의 위치와 다를 경우 제안한 방법으로 focal length의 값을 수정한다. 제안한 방법은 매우 간단한 계산만으로 기존의 반복적 연산을 통해 수행한 focal length 수정 방법과 유사한 성능을 보인다.

Abstract

Catadioptric mirrors are widely used in automatic surveillance system. The major drawback of catadioptric mirror is its unequal image resolution. Equidistance catadioptric mirrir can be the solution to this problem. The exact axial alignment and the exact mount of mirror are the sources that can be avoided but the focal length variation is inevitable. In this paper, the effects of focal length variation on the computation of depth and height of object' point are explained and the effective and simple focal length finding algorithm is presented. First two object's points are selected, and the counterparts on the other stereo image are to be found using MSE criterion. Using four pixel distance from the image center, the assumed focal length is calculated. If the obtained focal length is different from the exact focal length, 24mm, the focal length value is modified by the proposed method. The method is very simple and gives the comparable results with the earlier sophisticated method.

☞ Keyword : Equidistance catadioptric mirror, range finding algorithm, stereo images, 등거리 전방위 렌즈, 거리 및 위치 추정 알고리듬, 스테레오 영상

1. Introduction

A catadioptric sensor is a sensor that contains mirrors (catoptrics) and lenses (dioptrics). In spite of the advantage of full viewing angle, the lack of uniformity of resolution of common traditional catadioptric sensors, which results in the distorted image, leads to the additional image processing endeavor. In two projection schemes, orthographic and perspective, they derived the equiresolution catadioptric lens's profiles and the former works of

* 종신회원 : 호남대학교 정보통신학과교수
cyh@honam..ac.kr
** 종신회원 : 한신대학교 정보통신학과교수
kangmg@hs.ac.kr
*** 정 회 원 : 카사테크(주) 대표이사
casa911@hanmail.net
[2006/09/01 투고 - 2006/09/18 심사 - 2007/01/10 심사완료]

Chahl and Srinivasan [2], Conroy and Moore [3] and Ollis et al.[4] are compared using their unified approaches on lens's resolution.

From that result, the equiresolution lens with perspective projection can be said to provide the more superior panorama image with the minimal additional efforts especially in the automatic surveillance applications. But as noted in [1], their equiresolution catadioptric lens with perspective projection scheme confronted with the errors in determination of structure. The sources of errors in that case can be stated as followings: the axial misalignment of camera with lens, the mismatch of the axial distance from the camera to the mirror and the mismatch of the distance from the camera nodal point to the image sensor with the predetermined values in the design process.

Some of the above can be avoided but the latter problem, the mismatch of the distance from the camera nodal point to the image sensor with the predefined values in the design process, can not be avoided even the sophisticated endeavors.

This mismatch results from the inherent focusing process of the conventional camera. To cope with this problem, the range finding algorithm has to take account of the variation of camera nodal point. In this paper, the novel range finding algorithm that exploits the effect of camera nodal point's variation on the depth calculation is presented

2. Characteristics of Stereo Equidistance Catadioptric Lens

As shown in Fig. 1, the symmetry axis of the rotationally symmetric panoramic mirror coincides with the optical axis of the camera and the nodal point of the camera lens lies at the origin of the coordinate system. The incident ray with a zenith angle δ is reflected by the panoramic mirror M and enters the camera lens with a zenith angle θ. Scenes from full 360^o directions are captured in the image sensor I in a ring shape and this image can be subsequently unwrapped to give viewer-friendly full 360^o panorama scene.

2.1 Range Finding Algorithm.

In case of known correspondence, the distance and the height of an object point can be determined using Eq.(1) and Eq.(2) as in [5].

$$H=\frac{(z_1\cot\delta_2-z_2\cot\delta_1)+(\rho_2-\rho_1)\cot\delta_2\cot\delta_1}{\cot\delta_2-\cot\delta_1} \quad (1)$$

$$D=\frac{(\rho_2\cot\delta_2-\rho_1\cot\delta_1)-(z_2-z_1)}{\cot\delta_2-\cot\delta_1} \quad (2)$$

The zenith angle for the reflected ray is given as

$$\theta=\tan^{-1}\left(\frac{\xi}{f}\right) \quad (3)$$

By measuring the two corresponding distance $\xi_1$and ξ_2 for a common object point in the image sensor, the position of the object point can be determined using the above mentioned equations. The image sensor is square in shape with one side measuring 15mm and containing 2048*2048 pixels. The distance from the camera nodal point to the image sensor is assumed the same as the camera focal length. From the pixel position ξ, the reflection angle is calculated as

$$\theta=\tan^{-1}\left(\frac{15}{2f}\frac{\xi-1024}{1024}\right) \quad (4)$$

From the calculated θ, the zenith angle δ for the incident ray can be given by

$$\delta=2\cot^{-1}\left(\frac{dz}{d\rho}\right)-\theta \quad (5)$$

Using the following relation, δ can be calculated.

$$\frac{dz}{d\rho}=\begin{cases}(3.4231-0.1396\rho+0.00132\rho^2)\\(-0.775-0.003328\rho+0.000528\rho^2)\end{cases} \quad (6)$$

2.2 Errors in finding the depth

2.2.1 Focal Length Variation

The Fig.2 shows the effects of focal length variation on the calculation of degree theta. Although the location of mirror that relates to the exact z value could be adjusted, the focal length variation is inevitable. This inevitably results in the focal length variation in conventional perspective camera system. In Fig.2, a is the boundary between the inner and outer image and b is too. The pixel distances estimated based on the wrong focal length, i.e. $f-\Delta$, results in the wrong estimation of the pixel distances.

2.2.2 Focal Length Modification Method

Fig.2 illustrates the schematic diagram for the proposed range finding algorithm. There are two possible approaches to find out the exact f value. The size of the actual diameter of the acquired image can be used to find the exact focal length. The other method is explained as follows. In Fig. 2, the correspondences of two object points are determined using the line matching algorithm.

There are two possible approaches to find out the exact f value. The method presented in [7] is explained as follows. The correspondences of two object points are determined using the line matching algorithm.

ξ_{i1} represents the pixel location of object P_i on the inner image plane. ξ_{i2} represents

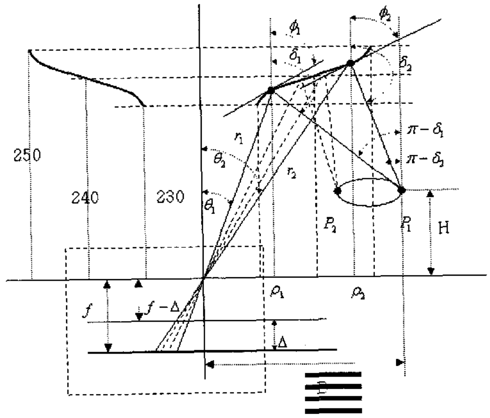


Fig. 1 A proposed range finding algorithm

the pixel location object P_i on the outer image plane. ξ_{i1} and $\xi_{i2}$are the correspondence of object P_i. The pixel distance from ξ_{21} to ξ_{11} correspond to the range of the incident ray originated from object 1 to the incident ray originated from object 2. Except the special case, the pixel distance from ξ_{21} to ξ_{11} is not equal to the pixel distance ξ_{22} to ξ_{12}. Fig. 2 shows the detailed view of the image plane and the estimated object points. Given four object points, ξ_{21}, ξ_{11}, ξ_{22} and ξ_{12}, one of the two image planes with focal length f and $f+\Delta f$ can be chosen to the more correct image plane using the object's view angle criteria. Object's view angle in the inner[outer] image plane is defined as Eq.(7)- Eq.(11)

$$VA^f_{inner} = \left[\theta^1_{inner}, \theta^2_{inner}\right] \tag{7}$$

$$VA^f_{outter} = \left[\theta^1_{outter}, \theta^2_{outter}\right] \tag{8}$$

$$VA = VA^f_{inner} \cap VA^f_{outter} \tag{9}$$

$$VA_{norm} = \frac{Nm(VA)}{\left(\frac{Nm(VA^f_{inner}) + Nm(VA^f_{outter})}{2}\right)} \tag{10}$$

$$Nm(VA) \cong fabs(\theta^1 - \theta^2) \qquad (11)$$

In [7], the final focal length value that gives the greatest VA_{norm} value for the given two object points has been used to calculate D and H values

In this paper, the simplified focal length modification method is presented.

2.2.3 New Focal Length Modification Method

Fig. 2 shows the positions of object point p_1 and p_2 on the focal plane of focal length f and $f+\Delta f$. Under the ideal configuration, the ray at the $\rho = 40mm$ on the mirror reaches at the pixel point a of the focal length 24mm. This pixel location is calculated as follows.

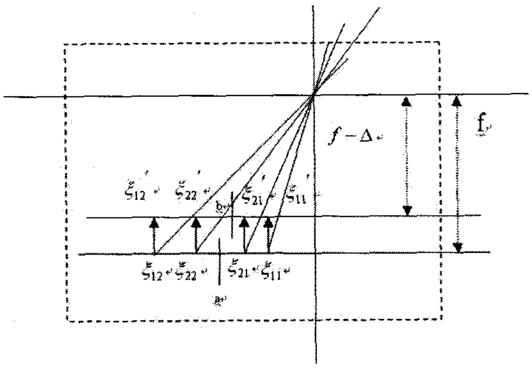


Fig. 2 The detailed view of Fig.1

Using $f=24$ and $\xi=4$, $\theta = \tan^{-1}\left(\frac{\xi}{f}\right)$ gives the value $\theta = 0.165149$ at the boundary between the inner and outter mirror. The following relationship gives the pixel position at the image plane.

$$\theta = \tan^{-1}\left(\frac{15}{2f}\frac{\xi - 1024}{1024}\right) \qquad (12)$$

The ideal boundary pixels are 546 pixels apart from the center of image. If the boundary pixel positions differ from the above ideal value, the lens is said to be misplaced. With the assumption that the other parameters except the focal length are to be set up correctly, we can modify the focal length to cope with the above mentioned mismatch as follows.

1. From the estimated object points ξ_{21}, ξ_{11}, ξ_{22} and ξ_{12}, calculate the boundary pixel distance from the image center using the following equation

$$\frac{\xi_{21} + \xi_{21} + \xi_{21} + \xi_{21}}{4} \qquad (13)$$

2. If the value is not equal 546, then calculate the image censor location with the following relation.

$$\xi_{est} = 15\frac{estimated\ boundary\ location\ value}{2 \times 1024} \qquad (14)$$

3. The modified focal length is obtained as follows.

$$f_n = \frac{24 \times \xi_{est}}{4} \qquad (15)$$

3. Experiments and Results

3.1 The Results of Image acquisition

The equidistance catadioptric mirror's focal length is 24mm. Fig. 3 is a captured image using the camera and Fig. 4 is the panorama image after the unwrapping.

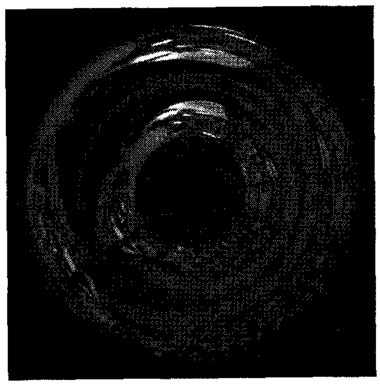


Fig. 3 Captured image

Fig. 4 Stereo equidistance images

3.2 Line Matching

Fig. 5 shows the correspondence process. Two arbitrary object's points are chosen manually. Fig. 6 shows the matching result. The pixel distances of four points form the image center are 741, 713, 426 and 441 respectively.

The range finding starts from these four estimated pixel distances. So the accurate pixel location determination is very important and this depends on the correct image center localization. The center of image is located manually.

The used matching criterion is MSE. For a given pixel point, 10-pixel angular neighborhood and 5-pixel radius neighborhood pixels are used in calculating MSE criterion on the every search area pixel location. The search area has been chosen as 1-pixel angular width and 40-pixel radius width.

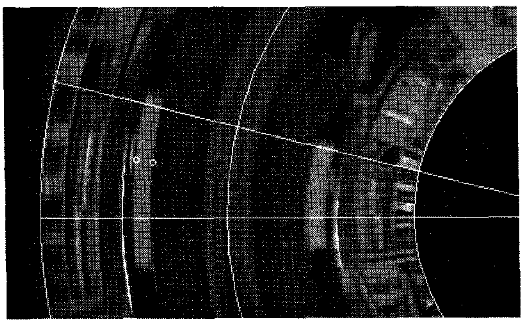


Fig. 5 Two image-points used in line matching

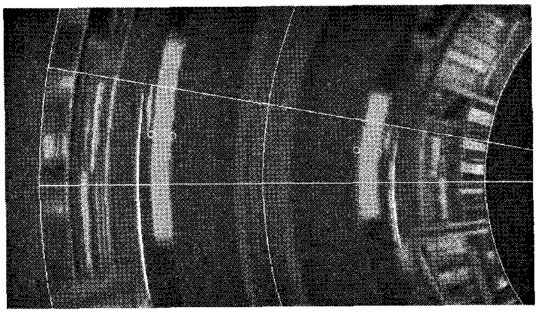


Fig. 6 Matching result

3.3 Focal length modifying & range finding

The experiment has been carried out using the same configurations as in [5]. The used value of focal length is 24.0mm.

$$\frac{\xi_{21}+\xi_{21}+\xi_{21}+\xi_{21}}{4} = \frac{741+713+426+441}{4} = 580.3 \tag{16}$$

$$\xi_{est} = 15\frac{580.3}{2\times 1024} = 4.25mm \tag{17}$$

$$f_n = \frac{24\times 4.25}{4} = 25.4 \tag{18}$$

In [7], the maximum normalized VA value of 25.1 gives the reasonable D and H values. The correct focal length value can be obtained easily. The real D and H values of the object's point were 150mm and 300mm. In this paper, the proposed method gives 25.4 focal length. The variation of D and H values according to the different focal length values is shown in Fig. 8. and Fig. 9.

The proposed method gives the slightly different or wrong focal length values from the earlier focal length modification method. But the deviations from the earlier method are negligible. As the proposed method does not use iterative calculation, the computational cost is very low.

The study on the range finding algorithm presented in this paper has been started with the design of catadioptric double-panoramic lens[5]. In [5], the focal length value has been chosen to be 24mm and the errors in the determination of depth and height are considered to be from the axial mismatch and the inexact mount. So the proposed range finding algorithm is the simple and effective formalized range finding algorithm considering the focal length problem.

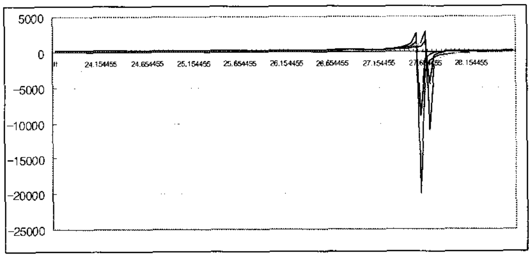


Fig. 8 The variation of D and H values according to focal length values

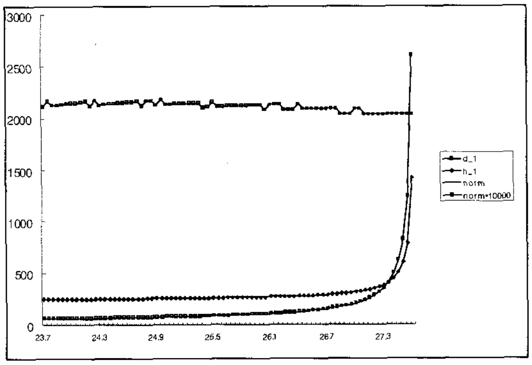


Fig.9 Detailed view of Fig. 8

4. Conclusion

The proposed double panoramic equiresolution catadioptric lens with the wide vertical field of view of 110 degrees can determine 3-D location of the objects when the correspondence has been determined. In this paper, the simple and cost effective focal length modification algorithm using the characteristics of the object's view angles and the boundary position has been presented. The proposed algorithm provides the comparable results with the original focal length modified range finding algorithm in [5].

From the experiments, we have concluded that the mirror profile was not manufactured correctly. So the estimated D and H values do not coincide with the real D and H. The validity of the proposed focal length modification method has been tested using the relative distance of two object's point. And the result has been compared with the original focal length modified range finding algorithm.

Furthermore, the single view point mirrors can be easily applied to many computer vision applications with their concise epipolar geometric structure. The major problem of the equidistance double-panoramic lens in successful range finding is the poor image resolution. To increase the image resolution, the large equidistance double-panoramic len is to be designed.

This Work is Supported by Hanshin University Research Grants in 2007.

References

[1] [Baker98] S. Baker and S. Nayar, "A theory of catadioptric image formation", Proc. International conference on computer vision, 35-42 (1998)

[2] [Chahl97] J.S. Chahl and M. V. Srinivasan, "Reflective surfaces for panoramic imaging", Applied Optics, 36:8275-8285(1997)

[3] [Conroy99] T. Conroy and J. Moore, "Resolution invariant surfaces for panoramic vision systems",

Proc. International conference on computer vision, 392-397 (1999)

[4] [Ollis99] M. Ollis, H, Herman, Sanjiv Singh, "Analysis and design of panoramic stereo vision using equiangular pixel cameras", Technical Report, The Robotics Institute, Carnegie Mellon University, 5000 Forbes Avenue Pittsburgh, PA 15213 (1999)

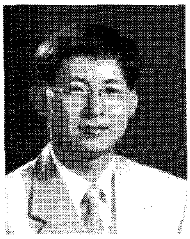
[5] [Kweon04] G. Kweon, K. Kim, Y. Choi, G. Kim, H, Kim, S, Yang, "A catadioptric double-panoramic lens with the equidistance projection for a rangefinder application" Proc. SPIE, 5613, 29-41 (2004)"

[6] Young-ho Choi etal, "Performance Enhancement of Range finding Algorithms for Equidistance Stereo Catadioptric Mirrors", APIC-IST 2006, pp213-218 May 2006

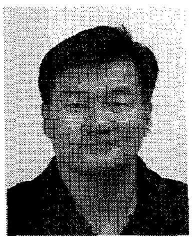
[7] Young-ho Choi, "등거리 스테레오 전방위 렌즈 영상에 대한 위치 측정 알고리즘", Jour. of Korean Society for Internet Information, pp149-162 Vol.6, No.6, Dec., 2005

◐ 저 자 소 개 ◑

최 영 호(Young-ho, Choi)
1988년 연세대학교 전자공학과(공학사)
1991년 연세대학교 대학원 전자공학과(공학석사)
1998년 연세대학교 대학원 전자공학과(공학박사)
1999~현재 호남대학교 정보통신학과 교수
관심분야 : 컴퓨터비전, 영상처리시스템 etc.
E-mail : cyh@honam.ac.kr



강 민 구(Min-goo, Kang)
1986년 연세대학교 전자공학과(공학사)
1989년 연세대학교 대학원 전자공학과(공학석사)
1994년 연세대학교 대학원 전자공학과(공학박사)
2000~현재 한신대학교 정보통신학과 교수
관심분야 : 정보통신시스템 etc.
E-mail : kangmg@hs.ac.kr



조 문 신(Moon-shin, Zo)
1987년 연세대학교 물리학과(이학사)
1989년 연세대학교 대학원 물리학과(이학석사)
2001~현재 영남대학교 센서및시스템공학과(박사과정수료)
1991~2000 SKC(주) 시스템개발팀(선임연구원)
2000~현재 카사테크(주) 대표이사
관심분야 : 영상검출, 영상정보시스템, AOI, etc.
E-mail : casa911@hanmail.net