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Automatic Control of Horizontal-moving Stereoscopic Camera by Disparity Compensation

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Horizontally-moving method (HMM) stereoscopic camera has a linear relationship between vergence and focus control. We introduced the automatic control method for a stereoscopic camera system that uses the relationship between vergence and focus of an HMM stereoscopic camera. the Automatic control method uses disparity compensation of the acquired image pair from the stereoscopic camera. For faster extraction of disparity information, the proposed binocular disparity estimation method by the one-dimensional cepstral filter algorithm would be investigated. The suggested system in this study substantially reduced the controlling time and error-ratio so as to make it possible to achieve natural and clear images.

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I. INTRODUCTION

In recent researches, one of the major concerns in the area of stereoscopic camera systems is the development of a human-like vision system. When people look at an object, vergence control ensures that the reflected light is placed in the middle of retina, and simultaneously, focus control for clear image achieved by adjusting the thickness of the lenses. The basic requirements for a human-like vision system are smooth pursuit and vergence control for the key object [1,2].

There are two types of stereoscopic cameras designed to control vergence. They are the toed-in method (TIM) and HMM stereoscopic cameras. In comparison with TIM stereoscopic cameras, HMM stereoscopic cameras have less image distortion. Furthermore since they have a linear relationship between vergence and focus, they are able to acquire natural and clear stereoscopic images and are advantageous in automation study [4-6].

Currently, the emphasis on stereoscopic images is not on the observation of stereoscopic images but on object tracking using two CCD sensors and on compression of images using disparity information [3-5].

In this paper, we introduced an automatic vergence and focus control method for a parallel stereoscopic camera by binocular disparity compensation. In addition, we proposed a one-dimensional cepstral filter for the estimation of binocular disparity used for vertical projection information of stereo image pair. This method achieves better and more rapid control of the parallel stereoscopic camera.

This study describes automatic control of a stereoscopic camera for acquiring natural and clear real-time stereoscopic images. In the second chapter, after analyzing the geometric structure of the HMM stereoscopic camera, we attempt to derive an approximated proportional relation between the amount of vergence control and the amount of focus control. Then we describe is the embodiment of HMM stereoscopic camera system applying the proportional relation. In the third chapter, we describe the suggested disparity extraction algorithm and the automatic stereoscopic camera control method. The fourth chapter describes the result of an experiment on embodied HMM stereoscopic cameras, and evaluates the performance of the suggested disparity information extraction algorithm.

II. VERGENCE AND FOCUS CONTROL CHARACTER OF HMM STEREOSCOPIC CAMERA

A HMM stereoscopic camera can verge on an object by shifting its lens in the horizontal direction to the CCD plane of the camera and it can control focus by moving lenses forward and backward [1,2]. Therefore, unlike images acquired by a toed-in stereoscopic camera, it removes distortion by vergence control such as keystone distortion and depth plane curvature [3]. The geometry of the HMM stereoscopic camera is shown in Fig. 1.

Vergence control moves lenses and CCD planes to put an object in the middle of two CCDs so that it provides the sense of depth. In Fig. 1, binocular disparity $l - r$ from the coordinate the object O is calculated as

$$l - r = 2h - it/p \quad (1)$$

where p is the object distance, t means distance between lenses, h is the amount of movement of lens to vergence control, i is the distance between CCD and lens, and f is the focal length. In order to have natural stereoscopic images, CCD sensors should be moved so that the value of disparity value to the key object becomes zero. In other words, the central coordinates of two images on CCD sensors of the object placed at the same position should satisfy equation (2).

$$h = it/2p \quad (2)$$

And it should satisfy the lens equation to acquire a clear image. If the distance between lens and CCD i in the equation is replaced with i in the lens equation, h can be expressed as

$$h = it/2p = (pf/(p - f))t/2p = fs/2p \quad (3)$$

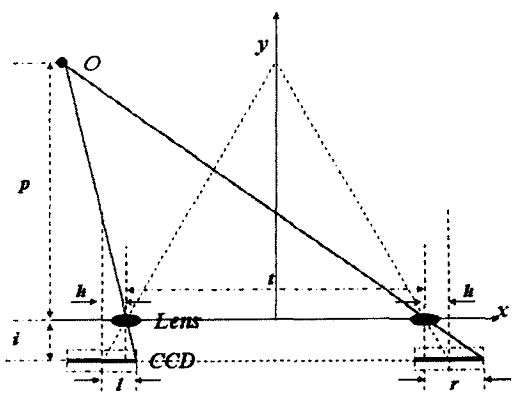

FIG. 1. Geometry of HMM stereoscopic camera.

where s is the distance between the two centers of the CCD sensors. If we say di is the amount of distance change between lenses and CCD sensors for focus control and df is the amount of horizontal movement of CCD sensors for vergence control, the relation between di and dh can be expressed as

$$dh/di = s(p - f)^2/2fp^2 \quad (4)$$

Generally the focal length of the normal lens f is much smaller than the object distance p, because we can ignore the focal length f. Therefore, equation (4) can be simplified to the following form:

$$\text{if } (p \gg f) \;\; dh/di \cong s/2f \quad (5)$$

This gradient shows the relationship of two directional shifts. As the focal length of the camera lens and the distance between the two centers of the lenses are constant, the gradient di/dh is constant. This mean that if we control either of the two factors (focus or vergence) and have a mechanism in which the other factor is automatically controlled based on the proportion relation, we can have clear and natural stereoscopic images.

Adopting proportional relation between vergence and focus by equation (5), we made a stereoscopic camera. It is designed such that moving CCD sensors to be wider and narrower control the vergence, and the focus is simultaneously controlled by automatically adjusting the distance between CCD sensors and lenses. Fig. 2 shows the camera as built.

III. AUTOMATIC CONTROL OF STEREOSCOPIC CAMERA

1. Extraction of Binocular disparity information one-dimensional cepstral filter

Since CCD sensors are moving horizontally, the parallel stereoscopic camera always has zero vertical binocular disparity. Therefore, what we need to do for vergence control is to make the horizontal binocular disparity near to zero. In order to extract the value of horizontal binocular disparity dh quickly and precisely from binocular image pair, we used a one-dimensional

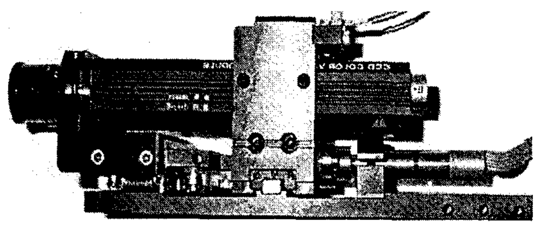

FIG. 2. Horizontally-moving method stereoscopic camera.

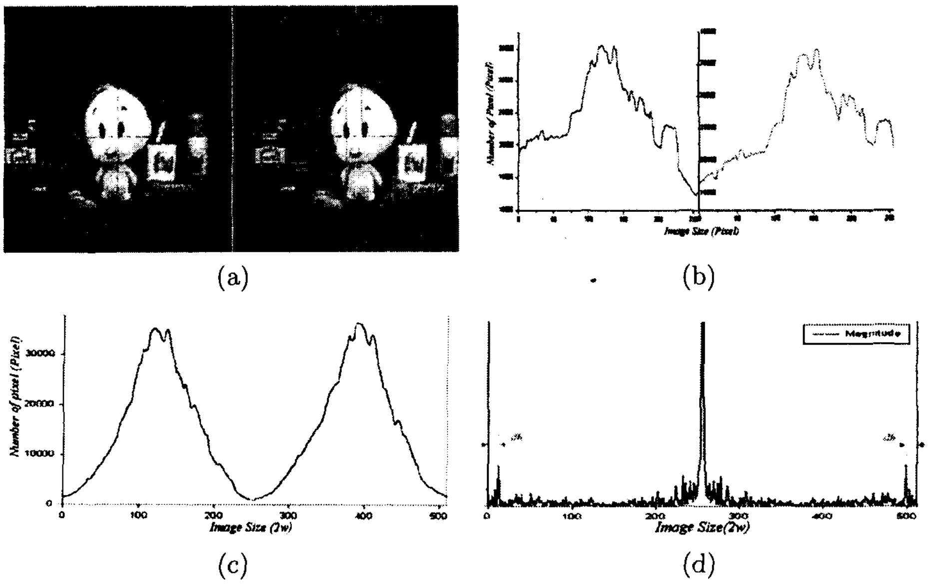

FIG. 3. Process of disparity extraction in binocular image pairs. (a) Stereo image pair. (b) Vertical projection data of left and right image. (c) Result graph of hamming windowing. (d) Output of cepstral filer.

cepstral filter with input of vertical projection data of the left and right image. Before being filtered, the binocular images are windowed with hamming functions [7] and concatenated to create a single vertical projection data. The disparity between key objects in a binocular scene is estimated from the positions of the correlation peak in the filtered data. That is expressed by the highest symmetric coordinate.

The cepstrum [8,9] is the Fourier transform of the logarithm of the power spectrum for a signal and can be expressed as

$$C_p = F^{-1}[\log|X(f)|]^2 \quad (6)$$

where $|X(f)|^2$ is power spectrum of data $x(t)$, and data $x(t)$is synthesized by signal $q(t)$ and delayed signal $x(t-\tau)$. The logarithm has the effect of reducing the contribution of the narrowband signals which are generally poor correlation targets, while leaving the broadband ones relatively unaltered.

The binocular disparity is the repeating factor of right image against left image. It is possible to extract disparity value via cepstral filter. If data $s(x)$ is vertical projection data of one image and if data $f(x)$ is synthesized by vertical projection data of left image $l(x)$ and right image $r(x)$, the data $f(x)$ can be expressed as follows. (The $*$ operator represents convolution.)

$$\begin{aligned} f(x) &= l(x) * \delta(x) + r(x) * \delta(x-W) \\ &\cong s(x) * (\delta(x) + \delta(x-(W+dh)) \end{aligned} \quad (7)$$

where W is the width of one image and dh is the horizontal disparity value. We need to apply equation (6) to equation (7) to search for the horizontal disparity value. Fig. 3 shows the process of disparity extraction in the stereo image pair. Fig. 3(a) shows left and right images achieved by the stereoscopic camera. We can note that the achieved right image moved by horizontal disparity value (dh) from the center of the left image. Fig. 3(b) is the result of vertical projection of each of left and right images. Fig. 3(c) is the result of Hamming windowing for accentuating the center of the image. And Fig. 3(d) shows the result of applying the cepstrum function to preprocess and link left and right projection data. Briefly, disparity information is expressed by the highest symmetric pixel coordinate.

2. Implementation

The block diagram in Fig. 4 shows the automatic vergence and focus control method by disparity information. For automatic vergence and focus control of a HMM stereoscopic camera, it is required to define the critical value of disparity that is ignorable. Next, we extract the disparity value through suggested disparity extraction algorithm. If the disparity value is higher than the critical value, the motor for vergence and focus control is activated so that the disparity value is kept below the critical value. With reiteration of this process, vergence and focus are controlled such that it is possible to have clear and natural stereoscopic images.

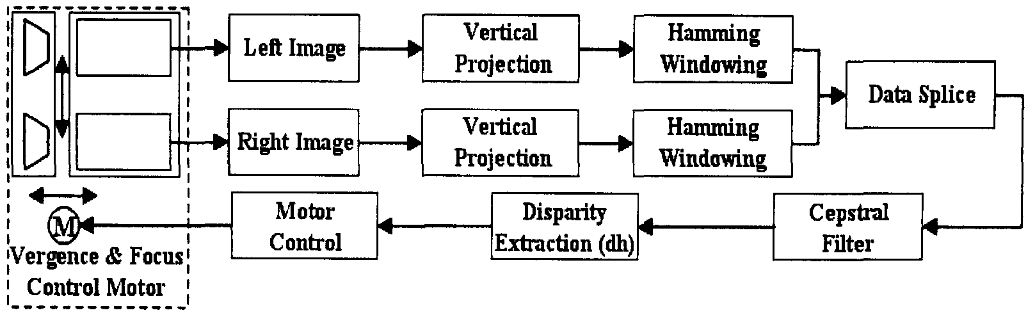

FIG. 4. Block diagram of HMM stereoscopic camera automatic control.

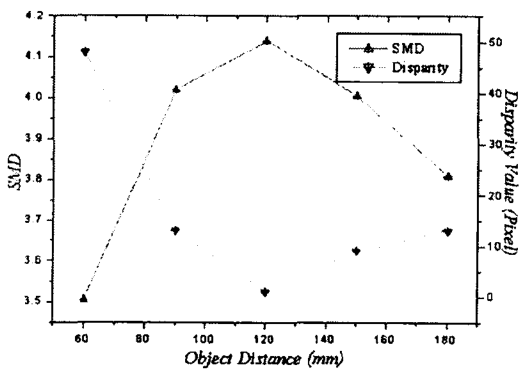

FIG. 5. Graph of characteristics of the relation between vergence and focus control.

IV. EXPERIMENTS AND RESULT

This chapter describes the experiment on the relation between vergence and focus control of the HMM stereoscopic camera; the evaluation of the binocular disparity information extraction algorithm; and the result of an experiment on embodiment of simultaneous control of vergence and focus control.

For the experiment on the relation between vergence and focus control of the HMM stereoscopic camera, the convergence distance of the camera was fixed to 1200 mm. Left and right images of an object were acquired every 300 mm interval, from 600 mm to 1800 mm. Disparity pixel value and amount of focus were measured. When vergence was controlled, disparity pixel value showed the lowest value; the amount of focus showed the highest value [10].

The graph in Fig. 5 shows the characteristics of the relation between vergence and focus control for the HMM stereoscopic camera. When convergence distance and object distance are equal (1200 mm), it shows the lowest disparity pixel value and the highest amount of focus.

In this experiment, we can confirm the fact that, when a factor of the both vergence and focus of HMM stereoscopic camera is controlled, the other factor is simultaneously controlled.

In the next step, we evaluated the performance of the disparity extraction algorithm by adopting the one-dimensional cepstral filter suggested in this paper. For evaluation, we compared two algorithms, one of which adopted the existing cepstral filter and the other adopted the one-dimensional cepstral filter suggested in the paper. The disparity information extraction algorithm adopting the exiting cepstral filter by Taylor, Olson and Coombs applied the cepstral filter to the left and right images. Since it takes too much time, we extracted disparity information by applying to down-sampled left and right images [4,5].

Table 1 shows the comparison of the two algorithms in terms of time requirement and accuracy.

TABLE 1. Comparison of disparity extraction time and error rate (Pentium 266MHz PC).

Disparity Extraction Method		Processing Time [ms]	Error Range [Pixel]
1D Cepstral Filter [512 Pixel]		0.0038	0
2D Cepstral Filter [Pixel Size]	512×256	2,746	0
	[256 × 128]	641	2
	[128 × 64]	141	4
	existing algorithm [64 × 32]	0.4	8
	[32 × 16]	0.031	16

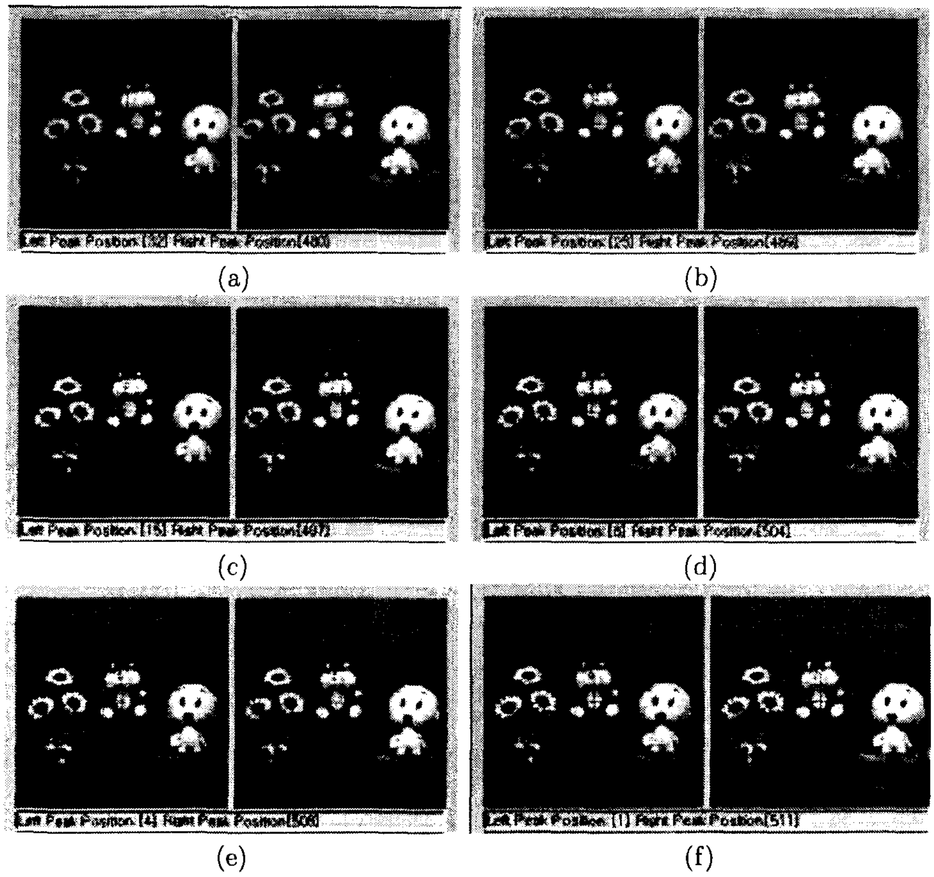

FIG. 6. Images of results in automatic vergence and focus control experiments. (Left peak position and right peak position perform horizontal disparity value in cepstral filter result). (a) Frame: 0. (b) Frame: 30. (c) Frame: 60. (d) Frame: 90. (e) Frame: 120. (f) Frame: 150.

We adopted the range of disparity pixel values by down sampling of images as the error range. We found that the suggested algorithm is 100 times faster than the existing algorithm [4,5,8].

Lastly, we applied the algorithm to the produced HMM stereoscopic camera and examined whether, when the backgrounds of left and right images are complicated, the camera performs simultaneous vergence and focus properly. Fig. 6 shows the change of disparity pixel value of images acquired by frame, when automatic vergence and focus control algorithm was applied to the produced camera. We could determine that, when the number of frames of acquired images increases, the disparity pixel value approaches zero and a clearer image is acquired.

V. CONCLUSION

This study illustrated the linear relation between the amount of vergence control and focus control of HMM stereoscopic camera, and described automatic vergence and focus control by disparity compensation. Firstly, the geometric structure of the HMM stereoscopic camera was adopted to display the relation between the amount of vergence and focus control. Subsequently, we applied the relation equation to the design of HMM stereoscopic camera and produced a stereoscopic camera that controls vergence based on extracted binocular disparity from left and right images and simultaneously controls focus depending on the vergence control. For faster and more accurate binocular disparity value extraction, a one-dimensional cepstral filter was suggested and applied for the automation of the camera.

We conducted three experiments analyzing: the relation between the amount of vergence and that of focus control; the performance comparison of binocular disparity information extraction algorithms using one-dimensional cepstral filter and existing two-dimensional cepstral filter; and the performance of the embodied stereoscopic camera. From the results of these experiments, we could realize the superiority of the HMM stereoscopic camera suggested in this study. The suggested algorithm is far superior than the existing two-dimensional cepstral filter used by Taylor, Olson and Coombs in terms of extraction time requirement. Further to our experiment, even in the case of images with complicate a background, the embodied camera could rapidly and accurately control vergence and focus.

In conclusion, the camera designed and produced for this study controls vergence only, from which the focus can be automatically adjusted so that it provides simplicity of operation. Since the camera adopted a one-dimensional cepstral filter, it greatly reduces the extraction time requirement and error so as to offer spontaneous control and greater real-time realism to acquire high quality stereoscopic images.

In continuation of this study, the automation of stereoscopic camera with a zoom function is required and improvement in hardware technology for the high-speed image processing will be explored.

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