Depth Estimation from Defocused Images in Camera Motions

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Abstract

A new approach is presented for estimating depths of defocused objects which are at distances by camera motions. An ordinary camera is used for obtaining defocused images in order to propose a coarse method with a potential. This method, therefore, requires only a few camera parameters, the amount of camera motions and defocused images that mean the sizes of defocused images in itself. We use the median filter as a fitting method for estimating depths of useful accuracy with relatively simple scheme. Experiments with real images show that depths of objects can be estimated concurrently although there are several objects in an image.

I. Introduction

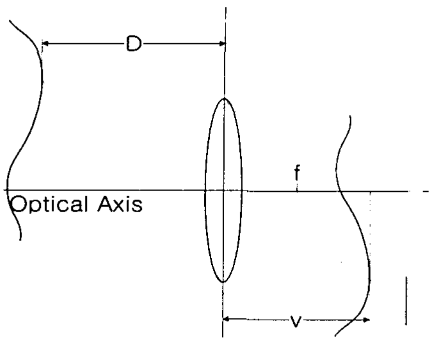
For years, many researches have been studied about extracting focus information from defocus since the work of Pentland was the first research in computer vision to test the use of defocus information as a depth cue [1]. The most common approaches of many other schemes for the computation of blur have been proposed are inverse filtering [1], depth recovery from edges [1],[2], and the S-transform [3-5]. These methods all include ways to estimate the amount of defocus, i.e., the amount of the blur. It is no exaggeration to say that those intended to find the amount of defocus. This paper, in contrast to them, presents the method to find the same result with the defocused images in-itself so that we may avoid the complicated method obtaining the amount of defocus and reduce possible errors from that. Besides, an ordinary camera is used for obtaining defocused images in order to propose a coarse method with a potential. Hence, the method presented in this paper requires only the amount of camera motions, the defocused images, and a few camera parameters which are two real distances between the lens and the position of the focused/defocused image. We use the median filter as a fitting method for estimating depths of useful accuracy with the relatively simple scheme. Several experiments with objects having their own different depths will be done in order to be estimated concurrently their depths.

II. Camera Model

A simple diagram of a camera system with variable camera parameters in defocus is shown in Fig. 1. The depth D of focused objects depends on the focal length f of the lens and the distance v between the lens and the position of the focused image. The relation between these three parameters is expressed by the well-known lens formula

$$\frac{1}{D} + \frac{1}{v} = \frac{1}{f}. \qquad (1)$$

The problem of focusing is to find and adjust the value of focal length f or the distance v or both sothat a specified object is focused. One way of



D	Depth
f	Focal Length
v	Focusing Distance

Fig. 1. Image formation in a convex lens.

focusing then is to vary f and/or v in steps until the observed image of the object is in the sharpest focus. Once the values of f and v which correspond to focusing the object are found, the depth of the object can be calculated using the lens formula. However, it is difficult to know the correct values of f and v in the use of a ordinary camera and there is in trouble to use them, although these are known, because this equation is ill-conditioned. Then a new approach by defocused images is described in this paper.

Ⅲ. Depth Estimation

From the geometry of Fig. 2, we obtain

$$I_d = \frac{v_0}{v} I_f + 2r(\frac{v_0 - v}{v}), \quad (2)$$

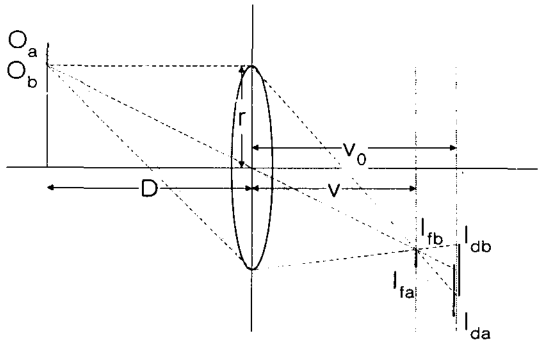
where I_d is the defocused image $\overline{I_{da}I_{db}}$ and I_f is the focused image $\overline{I_{fa}I_{fb}}$.

Because this method needs two defocused images at different distances, using the basic expression

$$\frac{I_f}{L_O} = \frac{v}{D}, \quad (3)$$

for two distances D_1 and D_2, we can obtain

$$D_2 = \frac{I_{d1} - C}{I_{d1} - I_{d2}} \times \Delta D, \quad (4)$$



D	Depth
r	Lens Radius
v	Focusing Distance
v_0	Defocusing Distance
$\overline{I_{fa}I_{fb}}$	The focused image
$\overline{I_{da}I_{db}}$	The defocused image

Fig. 2. The relation between camera parameters and focus/defocus.

$$\text{where } C = 2r(\frac{v_0 - v}{v}),$$

ΔD is the difference $D_2 - D_1$ between two images, practically by camera motions, and C is constant.

Therefore, depth of two defocused images can be calculated by the sizes of defocused images I_{d1} and I_{d2}, without knowing the amount of defocus. It is natural that the fitting process which is needed to obtain the correct values of the defocused images is proposed in this paper. An example about that the median filtering is accomplished recursively for fitting is shown in Fig. 3.

In such a case with more than one object, depth estimation can be done approximately for other objects which are not related to one object we handle. Original relation between two objects is

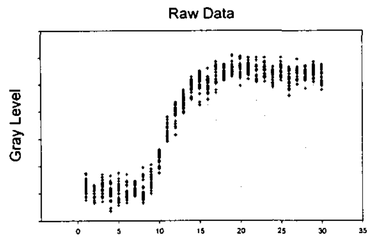
$$D_2 = D_1 \times \frac{I_{f1}}{I_{f2}} \times \frac{v_2}{v_1}. \quad (5)$$

By $I_f = I_d - \beta$ and $v_2 = v_1 - \alpha$, we obtain

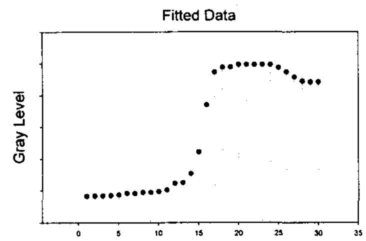
$$D_2 = D_1 \times \frac{I_{d1}}{I_{d2}}, \quad (6)$$

where $0 < \alpha, \beta_1, \beta_2 \ll 1$.

Hence, depths of all objects in an image can be estimated directly and coarsely.



(a)



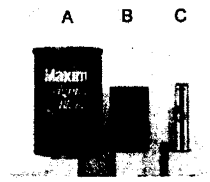
(b)

Fig. 3. Before and after median filtering recursively (a) raw data, (b) fitted data.

IV. Evaluation

As a ordinary camera, PENTAX with 50mm lens made in Japan is used for all experiments in this paper. An aluminum can (A), a radio speaker (B), and a CD case (C) are used as objects with their own different distances. First, for three objects the standard focused/defocused image should be known beforehand. Then all defocused images with the information of camera motions are checked for estimating each depth. Some defocused images from this experiment and the zoomed images which show defocus in detail are presented in Fig. 4. Estimated depths for three objects with distances (e.g., 700, 800, 900, 1000, and 1100mm) are shown in Table 1.

According to Table 1, the standard images are obtained at the standard distances (STD), such as 900mm and 1000mm and several tests are proceeded to objects at the various distances. By the algorithm, the depth of a specified object is obtained by Eq. (4) and then the standard distance can be calculated and *depths of other objects by Eq. (6)* as well. We see that most results are fine for estimating depths of objects with the useful accuracy. Moreover, depth



(a)

(b)

(c)

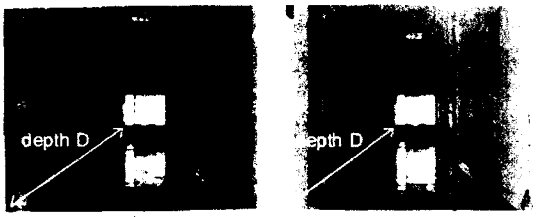
(d)

Fig. 4. Defocused Images and the zoomed parts (a) the standard image at 900mm, (b) the defocused image, (c) a part of Fig. 4. (a), (d) a part of Fig. 4. (b).

Table 1. Depths Estimation about objects at short distances

unit : mm (%)		STD (error)	object A (error)	object B (error)	object C (error)
Test 1	depth	900	800	700	1000
	by A	904 (0.45)	804 (0.45)	708 (1.10)	998 (0.17)
	by B	912 (1.28)	811 (1.42)	712 (1.64)	1007 (0.65)
	by C	952 (5.75)	847 (5.89)	745 (6.43)	1052 (5.17)
Test 2	depth	900	1000	800	1100
	by A	919 (2.08)	1019 (1.87)	819 (2.34)	1106 (0.52)
	by B	908 (0.91)	1006 (0.62)	808 (1.02)	1093 (0.63)
	by C	974 (8.23)	1079 (7.92)	868 (8.50)	1174 (6.73)
Test 3	depth	1000	700	900	800
	by A	998 (0.19)	698 (0.27)	905 (0.58)	806 (0.74)
	by B	1061 (6.11)	744 (6.29)	961 (6.79)	857 (7.10)
	by C	1032 (3.17)	723 (3.34)	936 (3.96)	832 (3.96)

estimation about objects at long distances, in contrast to the preceding tests, is proceeded simply and the result is shown in Table 2. This experiment at long distances is about just one object which is shown as a window in a hallway in Fig. 5. The infinite focal length is used for this situation because the distance between the object and the camera is enough far and it is meaningless whether the image is focused or not.



(a) (b)

Fig. 5. Two images with the infinite focal length for the second experiment (a) the standard image, (b) the image at an arbitrary distance.

Table 2. Depth Estimation about objects at long distances with the standard depth 36000mm.

Real depth [mm]	EST depth [mm]	error [%]
38000	36411	4.18
40000	38468	3.83
42000	40475	3.63
44000	44428	0.97
46000	46157	0.34

V. Conclusions

We have described a new approach to estimate depths from defocused images at short and/or long distances by camera motions without knowing the amount of defocus-in-itself. This method needs only some information which are the standard image, the camera parameters(such as the distances between the lens and the position of the focused/defocused image), and the size of the defocused image. In order to obtain the correct values of defocused images, median filtering was used as the fitting method. Several experiments with objects having their different depths have done in order to be estimated concurrently their depths having useful accuracy with the relatively simple scheme.

References

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