Focus Measure of Light Field image using Modified-Laplacian and Weighted Harmonic Variance

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***Abstract*—A light field image generates a set of focusing images at different depth levels. When we reconstruct an all-focused image, we have to identify in-focused regions of the stack images. To address this problem, we propose a method to detect in-focused image regions. We employ sum-modified-laplacian and weight harmonic variance algorithms to solve the problem. The proposed method provides a focus measurement to select suitable in-focused areas of the stack images. Therefore, only regions with a sharp focus will have high responses. Finally, the process can detect the in-focused image regions. In addition, we also acquire an all-focused image by this algorithm. Experiment results demonstrate that the proposed approach can provide better performance in comparison to traditional methods.**

***Keywords*—light field image; all-focused image; in-focused regions; sum-modified-laplacian; weighted harmonic variance.**

I. Introduction

A light field camera, also called a plenoptic camera, has recently shown to be very effective in applications such as digital refocusing and 3D reconstruction. It is fabricated with internal microlens arrays to capture light field information in a manner that one can refocus the image after acquisition. This is a unique capability of the light field camera.

In object detection, object recognition, surveillance systems, image quality assessment and depth estimation systems, in-focused image region detection is an important application. Because such regions usually indicate meaningful objects. Generally, digital images can precisely focus at only one distance at a time. An area within a depth of field appears sharp, while the areas beyond the depth of field appear blurred. Therefore, the use of all-focused images, containing a series of images captured at different focal planes which provide the sharpest pixels, can overcome the problem of focus in the images.

A light field image generates a set of images focused at different depth levels, which suggests that one can determine the object, foreground, or background region. When we reconstruct an all-focused image, we should identify in-focused regions of the stack images. Until now, several prior methods have been proposed that measure in-focused regions. Aydin et. al. [1], proposed a focus measure operator to recover a dense depth map of the scene. De et. al. [2], introduced an energy of morphologic gradients algorithm for focus measure. While Zhang et. al. [3], presented a focus detection based multi-focus image fusion algorithm. Nomnob et. al. [4], suggested an adaptive window size based on sum of modified laplacian for focus measurement. Almost all of the prior methods apply with two source images, while the proposed method can be implemented with several different focal view images.

A. Focus measure operators

A wide variety of algorithms and operators have been proposed in the literature to measure the degree of focus of either a whole image or a single image pixel for different applications, such as all-focused images and autofocusing. The focus measure operators [5], have been grouped into six broad families according to their working principle. A brief description of each family is presented in this section. The six families of focus operators are:

1) Gradient-based operators (GRA)

This family groups focus measure operators based on the gradient or the first derivative of the image. These algorithms follow the assumption that focused images present sharper edges than blurred ones. Thus, the gradient is used to measure the degree of focus.

2) Laplacian-based operators (LAP)

Similar to the previous family, the goal of these operators is to measure the amount of edges present in images, through either the second derivative or laplacian.

3) Wavelet-based operators (WAV)

The focus measure operators within this family take advantage of discrete wavelet transform coefficients capability to describe the frequency and spatial content of images. Therefore, these coefficients can be utilized for measuring the focus level.

4) Statistics-based operators (STA)

The focus measure operators within this family take advantage of several image statistics as texture descriptors in order to compute the focus level.

5) Discrete cosine transform-based operators (DCT)

Similar to the wavelet-based operators, this family takes advantage of the discrete cosine transform (DCT) coefficients in order to compute the focus level of an image from its frequency contents.

6) Miscellaneous operators (MIS)

This family groups operators which do not belong to any of the previous five groups.

This paper proposes a method to detect in-focused regions of a light field image. We utilize sum-modified-laplacian (SML) for focal stack images because SML is a powerful method for extracting proper features for detecting a region. Moreover, laplacian has some desirable properties such as simplicity, rotational symmetry, elimination of unnecessary information, and retaining of necessary information. Next, we compute the image's response with respect to in-focused components. We apply weighted harmonic mean of variance (WHV) for decomposing in-focused regions. Out-of-focus blurs will be ignored. Therefore, only regions with sharp focus will have high responses. Finally, the in-focus regions of images will be provided and then an all-focused image can be reconstructed with a sharp display and shows the depth of field can be extended greatly.

II. Proposed Method

Focus measure operator is used to measure the focus quality of an image region. The operator should produce high response to high frequency variations of the image intensity, since the better focused image has higher frequency components. It should produce a maximal response to the perfectly focused image regions.

The following techniques are involved in the proposed method's implementation.

A. Focal stack images

In this paper, we use the lytro light field camera [6] as a device to get the light field image. We split the raw light field file to different focal depth layers as JPG images by the light field picture splitter [7]. This process is done in a manner that each image displays a same position view in which an image becomes in-focused image of the different focus plane as shown in Fig. 1.

B. Sum-modified-laplacian (SML)

We have chosen SML [8] as the first part of the focus measurement criteria in the proposed method. Huang et. al. [9], addressed that SML can provide better performance than other focus measurement criterion.

Modified laplacian takes the absolute values of the second derivatives in the laplacian, in order to avoid the cancellation of second derivatives in the horizontal and vertical directions that have opposite signs.

Fig. 1. The different focal depth layers as JPGs by the LFP splitter

In the case of the laplacian, the second derivatives in the x and y directions can have opposite signs and might tend to cancel each other. The modified laplacian (ML) is expressed as:

$$\nabla^2_{ML} I = \left|\frac{\partial^2 I}{\partial x^2}\right| + \left|\frac{\partial^2 I}{\partial y^2}\right| \quad (1)$$

Finally, the focus measure at the point *(x, y)* is computed as the sum of modified laplacian values, in a small window around *(x, y)*, that are greater than a threshold value:

$$\mathrm{F(x,y)} = \sum_{i=x-N}^{i=x+N} \sum_{j=y-N}^{j=y+N} \nabla^2_{ML} I(i,j) \qquad for\ \nabla^2_{ML} I(i,j) \geq T \quad (2)$$

The parameter N determines the window size used to compute the focus measure.

C. Weighted Harmonic Mean of Variance (WHV)

We use a sliding window to compute the mean (μ_m) and variance (σ_m^2) within each patch with respect to each SML result of the stack images. We use weighted harmonic mean of variance to measure the overall variance over SML image result within the window size to ensure reliable focus measurements.

$$\mathrm{H(x,y)} = \frac{\sum_{m=1}^{M} w_m}{\sum_{m=1}^{M} \frac{w_m}{\sigma_m^2(x,y)}} \quad (3)$$

Where w_m is the associated weight of variance (μ_m).

We use *H(x, y)* as the focus measure at pixel *(x, y)*. Under the equation 3, only when the responses are high, the weighted harmonic variance *H(x, y)* will be high. Any small σ_m^2 will result in low *H*. Therefore, this equation ensures that only local windows preserving all high responses would be deemed as in-focused regions.

Harmonic mean has two advantages. First, an arithmetic mean estimate can be distorted significantly by the large variances σ_m^2 of the blurred patches, while the harmonic mean is robust. Second, the harmonic mean considers reciprocals, hence it favors the small σ_m^2 and increases their influence in the overall estimation.

D. *All-focused image*

An all-focused image is generated by acquiring the pixels that possess high WHV values when it is sharply focused.

For a set of N light field stack images $\{I_i, i = 1, 2, \ldots, N\}$, the WHV values $\{H_i, i = 1, 2, \ldots, N\}$ are obtained first. The in-focused setting (f) for each pixel (x, y) of the final all-focused image (I_{AF}) is simply selected as:

$$f(x, y) = \underset{i}{\operatorname{argmax}}\{H_i(x, y)\}$$

$$I_{AF}(x, y) = I_{f(x,y)} \tag{4}$$

Where $i = 1, \ldots, N$ and N is the number of light field stack images. $H_i(x, y)$ is the WHV value of the i^{th} stack images. Then the final I_{AF} will contain all in-focused regions of the images.

III. Experiment Results

In this section, we show the experiment results of the proposed method on different image samples. The experiments are performed to examine the focus measurement. The algorithm is implemented on a PC with an Intel® Core i7TM-3930K 3.20 GHz CPU, 16.0 GB RAM and Windows 8.1 operating system. We conducted experiments on 360 × 360 pixel sample images.

The all-focused images are used to compare the proposed method. To evaluate the performance of the proposed method, we introduce some objective criteria such as mutual information (MI), root mean square error (RMSE). MI measures the amount of information transferred to the all-focused image from the source images. The higher the MI value, the better the focus measure performance. While RMSE measures the differences between the reference image and computed image. Therefore, if RMSE is smaller, the quality of the considered focus measure operation is higher.

A. *Mutual information (MI)*

Mutual information is expressed as:

$$\mathrm{MI}(\mathrm{R}; \mathrm{I}) = \sum_{r,i} p(r, i) log \frac{p(r, i)}{p(r)p(i)} \tag{5}$$

Where $p(r, i)$ is the joint probability distribution function of the reference image (R) and computed image (I) respectively. And $p(r)$ and $p(i)$ are the marginal probability distribution function of R and I respectively.

B. *Root mean square error (RMSE)*

Root mean square error is expressed as:

$$\mathrm{RMSE} = \sqrt{\frac{\sum_x \sum_y [R(x, y) - I(x, y)]^2}{M \times N}} \tag{6}$$

Where R and I are the reference image and computed image respectively, with the image size is $M \times N$ pixels.

We experiment with three image datasets. Fig. 2(Left) and Fig. 2(Center) are taken by the lytro light field camera, while Fig. 2(Right) which is common-used multi-focus image offered by [10].

Fig. 2. Experiment sample images

Fig. 3. The in-focused image regions of the stack images by Fig. 2(Left)

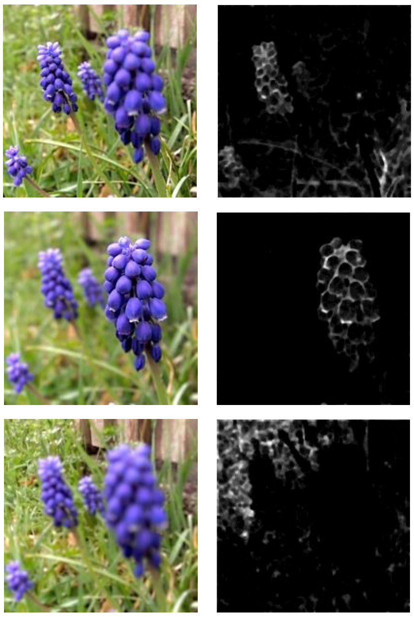

Fig. 4. The in-focused image regions of the stack images by Fig. 2(Center)

Fig. 3 and 4 demonstrate a focus measure of in-focused image regions of the stack images. The results display only sharply focused parts. Therefore, only regions with a sharp focus will have high response displays.

Fig. 5 and 6 show the results of all-focused image using different focus measure. Fig. 5-6(Left) illustrate the all-focused reference images, while Fig. 5-6(Center) are the fusion results using SML and Fig. 5-6(Right) are the proposed method's result images. Another result is presented in Fig 7.

Fig. 5. (Left) Ref. image, (Center) SML method, (Right) proposed method

Fig. 6. (Left) Ref. image, (Center) SML method, (Right) proposed method

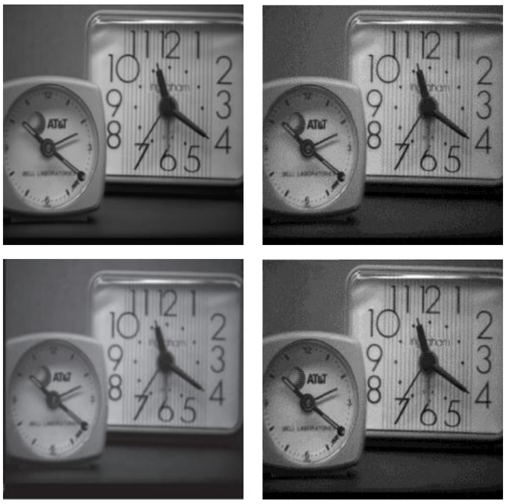

Fig. 7. (Top left) Ref. image, (Top right) SML method, (Bottom left) Nomnob's method [4], (Bottom right) proposed method of all-focused image

From the objective criteria shown in Table I and Table II, our algorithm has the outstanding objective criteria. The higher MI means that useful information converted into the all-focused result. The lower RMSE means that the reconstructed image is close to the actual reference image. These results indicate that the proposed method outperforms other comparative methods.

IV. CONCLUSIONS

In this paper, we proposed a focus measure of light field image for different focal image fusion. We apply sum-modified-laplacian and weighted harmonic mean of variance algorithms. SML is a process to select the proper feature for region detection. While WHV algorithm decomposes in-focused regions, then defocused and blurred parts will be omitted. Eventually, an all-focused image can be reconstructed. Based on the experiment results, we can analyze that the proposed method has more efficiently than other comparative methods. Furthermore, a comparison with the objective criteria confirms that the proposed method is superior to the conventional methods.

TABLE I. PERFORMANCE OF DIFFERENT FOCUS MEASURE BY DIFFERENT CRITERION (FIG. 5 AND 6)

Image	Criteria	SML	Proposed method
Cup	RMSE	2.532	**2.496**
	MI	6.832	**7.005**
Flower	RMSE	8.512	**8.378**
	MI	4.658	**4.874**

TABLE II. EVALUATION OF DIFFERENT FOCUS MEASURES BY RMSE (FIG. 7)

Image	SML	Nomnob's method [4]	Proposed method
Clock	5.654	5.628	**4.589**

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