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Study of Shape from Focus Algorithm

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Abstract

Computer vision incorporates various three-dimensional (3D) vision techniques which mainly aim at reconstructing a scene from a set of two-dimensional (2D) images. Passive 3D vision techniques such as stereo vision require disparity between the images of the same scene taken from multiple views. Shape from focus (SFF) is a technique which recovers 3D geometry of the scene based on focus which is an accommodation cue. Multiple images of the scene are taken using a single camera with varying focus levels thus avoiding complex and expensive vision systems for reconstruction. However, one of the main drawbacks of this technique is that it requires the imaged scene to have texture variation for effective reconstruction. In this paper a SFF system has been developed and working of SFF algorithm for synthetic images has been studied.

Keywords: computer vision, accommodation cue, texture variation, surface mount devices

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INTRODUCTION

Acquiring well focused images is an important task in most of the image related applications such as PCB inspection, robot manipulation, etc. One such algorithm based on focus is shape from focus, which estimates depth of a scene from a sequence of images taken at different focus settings. This variation of focus levels in the image stack is used as a depth cue. An operator called focus measure is applied to the image stack to determine the degree of sharpness of a pixel. It takes the local neighborhood and calculates the sharpness of the center pixel.

The focus measure operator is considered as effective if it satisfies the following conditions. First, it should be monotonic with respect to image blurriness. Second, it should be able to discriminate between the focused regions and defocused regions. Finally, it should be invariant to noises in the image. Once the focus levels are obtained for all the images in the stack, three-dimensional (3D) reconstruction of the scene is performed.

A widely used method for 3D reconstruction that uses focus information was proposed by Nayar [1] under the assumption of Gaussian model of defocus. The images are taken either by translating the camera or by translating the object towards the camera. Most follow up works concentrated on new focus measures. Focus measures based on curvature and mean was used by Helmi [2] to reconstruct 3D models of microscopic objects. These focus measures used least square approximation and ratio between mean gray value and center gray value to find the sharpest regions in the image. Yap and Raveendran introduced a focus measure based on Chebyshev moments, which is more robust against illumination variation. [3]

The influence of the image content on the performance of Shape from focus (SFF) has been analyzed in the literature. The presence of texture content in the focus sequence was found to be critical by M.T. Mahmood. [4] The focus measure operators fail to detect changes in focus for low-textured scenes, thus making the estimation of depth unreliable. This paper will focus on developing a shape from focus system which uses a translating camera mechanism instead of stage displacement mechanism proposed in earlier works.

SHAPE FROM FOCUS

In order to generate the depth map of a scene using SFF technique it is necessary that information about the distance of each and every point from the camera be available, which is given by the thin lens camera model. Figure 1 illustrates the effect of defocusing using the thin lens model.

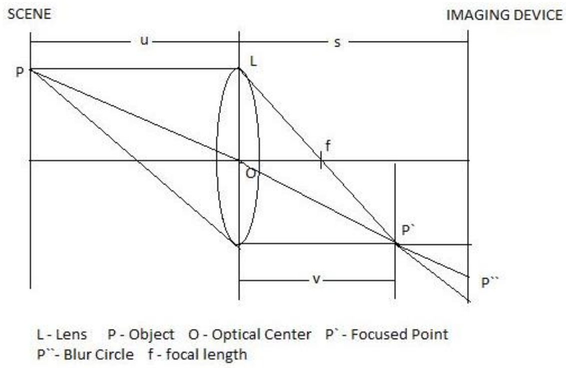

Fig. 1: *Thin Lens Model.*

According to the thin lens camera model, a camera focuses by providing a variation in the distance, v, between the lens and the sensing device. Points at a certain distance u will be in focus for a given focus setting which is governed by the lens focal length, f. The thin lens equation gives the relationship between the above mentioned variables. Since there is one to one correspondence between the object distance u and the focal plane location v, the maximum focus will be achieved at a specific object distance. If the sensor plane does not coincide with the image plane and is displaced from it by a distance, the energy received from the object by the lens is distributed over a circular patch which is often termed as circle of confusion. Its diameter C is given by

$$C = D * v * \left(\frac{1}{f} - \frac{1}{u} - \frac{1}{v}\right) \qquad \text{Eq. (1)}$$

where D is the aperture diameter of the lens. It can be observed that depth dependent term 1/u approaches zero when u takes a larger value, while the other terms stay constant, resulting in a small change of the blur radius for objects at larger distance u. Thus the real aperture methods is applicable only for close range scenarios, where two different depth value result in a measurable change of C. The intensity within the circle of confusion is considered to be constant, according to the laws of optics but due to undesirable effects that occur during image acquisition it is replaced by two-dimensional (2D) Gaussian models.

$$h(x, y) = \frac{1}{2\pi\sigma^2} e^{\frac{-1}{2}\frac{x^2+y^2}{\sigma^2}} \qquad \text{Eq. (2)}$$

where σ is a spread parameter such that σ =k.d for k > 0. In SFF input is a sequence of images taken at different focal levels which are obtained by either moving the camera towards the object or moving the object towards the camera. Once the focal levels are obtained, they are combined together to form a focal stack. Gausian interpolation is used for interpolating the focal stack as they resemble the two dimensional Gausian curve as shown in Figure 2.

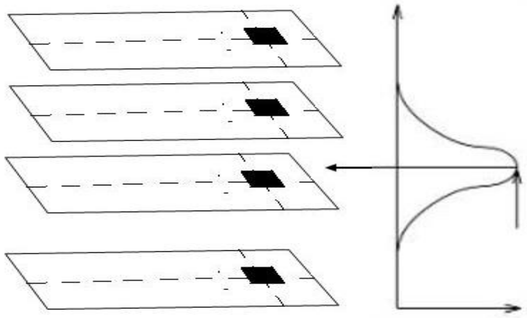

Fig. 2: *Gausian Interpolation of Focal Stack.*

METHODOLOGY

This section describes about the image acquisition setup, focus measure and reconstruction method used.

Image Acquisition Setup

The SFF technique demands relative motion between the camera and the object. Figure 3 shows the image acquisition setup where a tele-centric lens defines a plane of fine focus named as 'focused plane' which coincides with the top most surface of the object. The work described in this paper adopts a moving camera. The displacement of the camera is in the form of discrete steps given by Δd, and is always known. The distance between the reference plane and the focused plane d_f depends on the lens used and is also known. At every step an image of the scene is taken so that a stack of images at different focal levels for different regions in the scene is obtained. The distance between initial position of the camera and basement is d. We can compute the height of the focused region h at a particular instant as;

$$h = d - (d_f + n * \Delta d) \qquad \text{Eq. (3)}$$

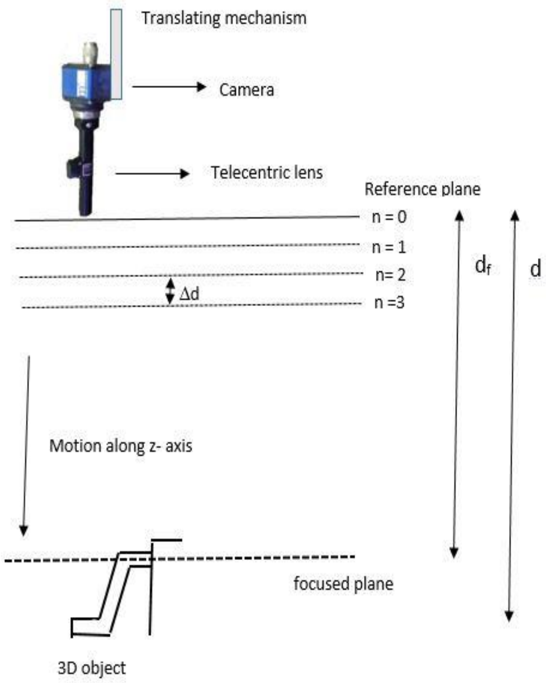

Fig. 3: *Schematic of Image Acquisition Setup.*

It is possible to obtain the entire shape of the object if focused image of every surface element is available along with the above mentioned parameters. To find well focused regions in the image an operator called focus measure is applied.

Focus Measure

The focus measure is a quantity to evaluate the sharpness of a pixel locally. The success of any focus measure depends on how accurately it can measure the sharpness of a pixel in the image locally. Hence, algorithms and techniques used for calculating edges and sharpness in the image can be used for the selection of focus measure. A lot of literature has been done by several authors in the field of focus measure operators. The evaluation of robustness of focus measure operators was carried out by Said Pertuz. [5] According to the author Laplacian-based operators were found to have best overall performance at normal imaging conditions. Since the work described in this paper was carried out in normal imaging conditions Laplacian operator was used in the work.

The Laplacian operator, being an edge detection algorithm can be used for sharpness estimation. The Laplacian focus measure is obtained by adding second derivatives of the image g (x, y) in x and y directions.

$$\text{Laplacian} = \frac{\partial^2 g(x,y)}{\partial x^2} + \frac{\partial^2 g(x,y)}{\partial y^2} \qquad \text{Eq. (4)}$$

In case of textured images, x and y components of Laplacian operator may cancel out ($g_{xx} = -g_{yy}$) and yield no response. Therefore, Modified Laplacian is computed by adding squared second derivatives.

$$\textit{Modified Laplacian} = \left(\frac{\partial^2 g(x,y)}{\partial x^2}\right)^2 + \left(\frac{\partial^2 g(x,y)}{\partial y^2}\right)^2 \qquad \text{Eq. (5)}$$

If the imaged scene has weak textured object, then Sum of modified Laplacian operator (SML) proposed by Nayar can be used.

$$\text{SML} = \sum_{p(x,\,y)\,\epsilon U(x_0,y} \left(\frac{\partial^2 g(x,y)}{\partial x^2}\right)^2 + \left(\frac{\partial^2 g(x,y)}{\partial y^2}\right)^2 \qquad \text{Eq. (6)}$$

where g (x, y) is the input image frame and p (x, y) is the pixel in the neighborhood $U(x_0, y_0)$ of pixel (x_0, y_0). Several other focus measures have been proposed in literature whose performance is robust; one such focus measure is based on statistical properties of the discrete wavelet transform (DWT) coefficients. This focus measure operator was used in autofocus applications in order to measure the focus level of a whole image. It has been modified for SFF application by Said Pertuz. [5–8] Since the work described in this paper focuses on developing a SFF system, Sum of modified Laplacian operator was used to find the focused regions in the image.

Scene Reconstruction

Once a sequence of images is acquired at different focal positions and the relative degree of focus is measured for all the pixels using the focus measure operator, a focal stack has to be formed to which a reconstruction scheme has to be applied to estimate the depth of every point of the scene. One such algorithm developed by Nayar in [1] looks for the displacement value that maximizes the focus measure and assigns the value to represent the depth of the surface point. This simple algorithm was used to estimate rough depth estimates. The performance of the algorithm is dependent on the selection of the step size Δd. Another algorithm proposed by Nayar used Gaussian distribution to model the focus measure function and was based on Gaussian interpolation. One approach is to fit all computed focus measures values to the Gaussian model. The focus measure may be expressed using the Gaussian model as;

$$F = F_{peak} \exp\left\{ \frac{-1}{2} \left(\frac{d - \bar{d}}{\sigma_F} \right)^2 \right\} \qquad \text{Eq. (7)}$$

where $\bar{d}$ and σ_F are the mean and standard deviation of the Gaussian distribution.

If F_{peak} is large and σ_F is small, the focus measure function has a strong peak, indicating high surface texture content in the vicinity of the image point.

RECONSTRUCTION

Experimental Setup

The Image acquisition setup for SFF requires a precise translating mechanism and a stable system which eliminates noise occurring due to vibrations and angular deflections. A mechanical setup was created using extruded aluminum channel as shown in Figure 4 to provide stability and manual adjustment of the translating mechanism.

Fig. 4: *Mechanical Setup.*

The translating mechanism consists of high precision worm and pinion gear mechanism supporting a timing belt driven slider. The motion of the translating mechanism is controlled using a microcontroller. The camera used is blue cougar-x125aG from matrix vision with an inline tele-centric lens. Figure 5 shows the internal construction of the translating mechanism.

A set of synthetic image sequence is used currently to implement the SFF algorithm. A set of around 40 synthetic images are used for reconstruction. Figure 6 shows the synthetic cone sequence used for implementing the SFF algorithm.

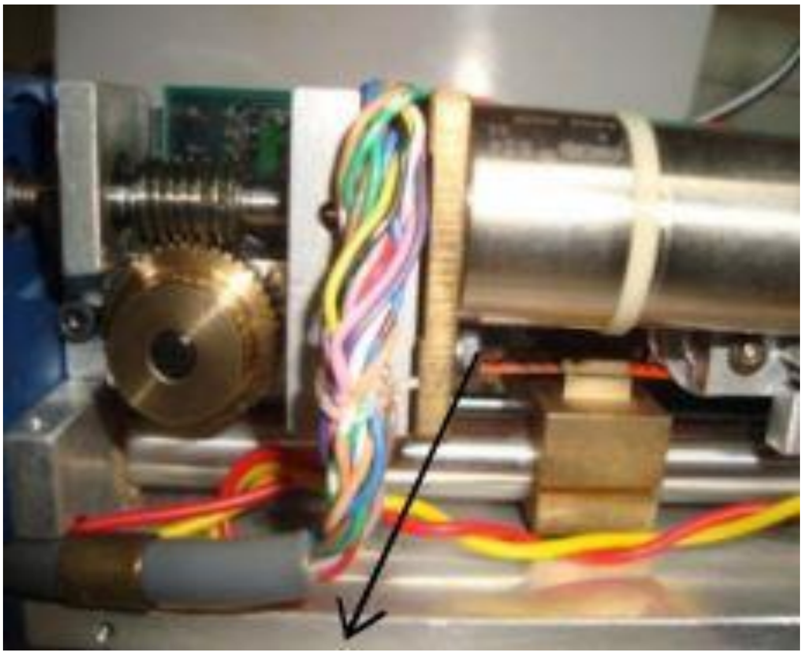

Fig. 5: *Geared DC Motor.*

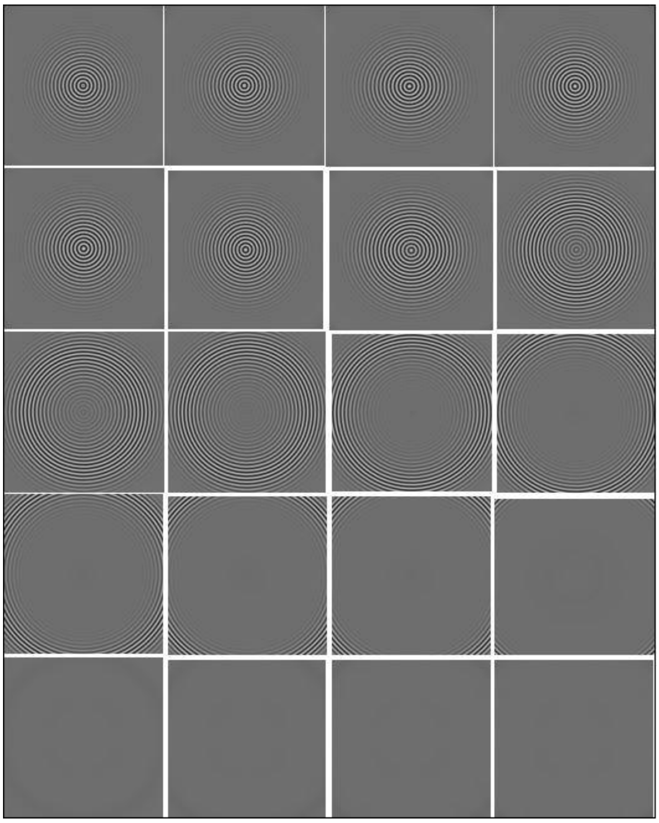

Fig. 6: *Synthetic Cone Sequence.*

Applying Focus Measure

As stated earlier Sum of Modified Laplacian operator was used for estimating the sharpness of the pixel locally. The SML operator looks for sharp intensity variations in the image, which correspond to high frequency content or focused region in the image. The effect of applying SML focus measure to one of the synthetic image sequence is shown in Figure 7.

Fig. 7: *Focus Measure Applied Image.*

It is clear from the image shown above that only sharp pixels in the image are extracted after applying the focus measure operator. The regions of the scene that are defocused are removed from the image.

Estimation of Depth

The Focus Measure Operator is applied to all the images to form a focal stack. The depth can be estimated by applying Gaussian interpolation. The result of applying Gaussian interpolation to the synthetic image sequence is shown in Figure 8.

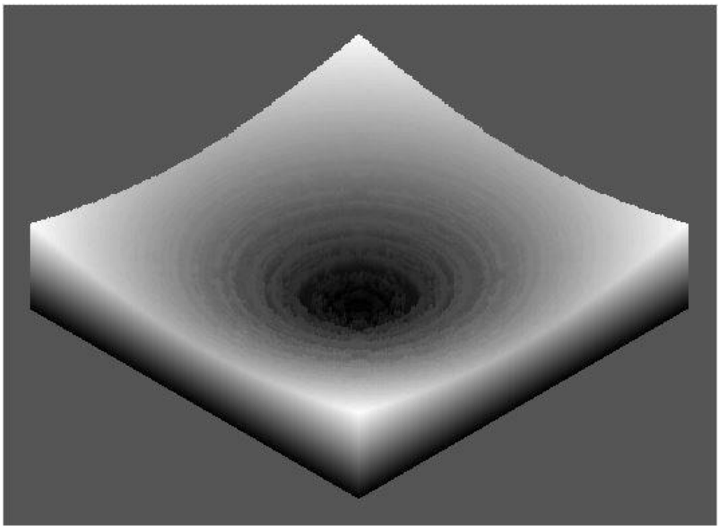

Fig. 8: *3D Plot of Simulated Cone Sequence.*

CONCLUSION

In this paper, we have discussed the SFF algorithm and we have designed the mechanical setup required to carry out the SFF technique. A set of simulated sequences was used to verify the working of the algorithm. Real object such as surface mount devices has to be inspected for solder joint defects and effect of texture variation on the performance of the algorithm has to be analyzed in future.

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