THREE-DIMENSIONAL SHAPE RECOVERY FROM FOCUSED IMAGE SURFACE

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ABSTRACT

A new method for the three-dimensional shape recovery from image focus is proposed. The method is based on approximation of the Focussed Image Surface (FIS) by a piecewise curved surface which tracks the realistic FIS in image space. The piecewise curved surface is estimated by interpolation using the Lagrangian polynomial. The new method has been implemented on a prototype camera system. The experiments and their results are provided and discussed. The experimental results show that the new method gives more accurate results than the previous methods.

1. INTRODUCTION

Three dimensional shape recovery of object is very important in image processing and computer vision. Some copious methods of 3-D shape recovery have been proposed for the past few decades in the literature. Among these methods, Shape from Focus (SFF) method is challengeable because it has good properties in terms of the correspondence problem and camera calibration.

Traditionally, a focus measure at each pixel position is computed in a small window around the pixel over image frames sensed by planar image detector [1][2][3][4][5]. Once the best focused image frame is found from focus measure, the object distance can be computed by using the lens formula equation. The traditional methods do not consider the fact that an image of 3-D object is also three dimensional in image space. This means in order to increase an accuracy of shape recovery a focus measure should be computed over realistic focused image surface in image space rather than over planar image frames. In 1995, Subbarao and Choi proposed an accurate SFF method based on Focused Image Surface (FIS) [6]. The method called SFF.FIS used a piecewise planar approximation for the shape recovery of simulated and real objects. The SFF.FIS method yielded more accurate results than the traditional methods. In fact the SFF.FIS method gave some hints to extend our thought from 2-D plane to 3-D space. However, it still has some shortcomings in accuracy and computation. There are two main reasons for this. The first one is that the piecewise planar approximation causes misleading to determine the distance of the focused image from the lens plane because the actual FIS using the piecewise planar surface is not well approximated. The shape of a realistic FIS is arbitrarily curved rather than planar even in a small window around a target pixel. The second reason is that its computation cost is high because the whole cubic volume in image space is searched by each piecewise planar surface in order to compute focus measures.

In this paper, we propose a new method to improve the accuracy of depth estimation of a physical object surface. Our new method is based on approximation of the FIS by a piecewise curved surface which tracks the realistic FIS in image space. The contribution of this method is that the accuracy of depth estimation of a physical object surface is increased comparing to the prevision method SFF.FIS. The new method has been implemented on a prototype CCD camera system. A number of experiments were carried out to evaluate our method. The experiments and their results are provided and discussed. The experimental results show that the new method gives more accurate results than the previous methods.

2. SHAPE FROM FOCUS(SFF)

2.1 Focused Image Surface(FIS)

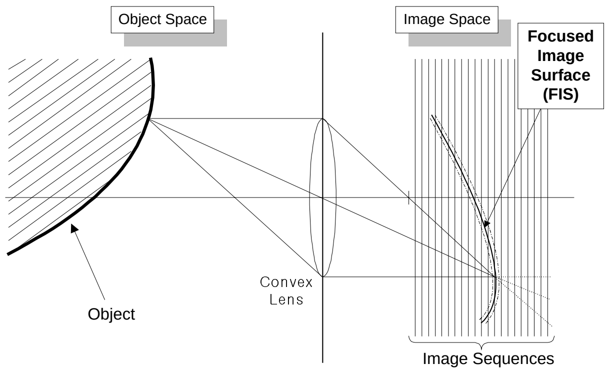

Figure 1. Focused Image Surface in Image Sequences.

The focused Image Surface (FIS) was defined in Subbarao and Choi's Paper [6]. According to paraxial-geometric optics, there is a one-to-one correspondence between the shape of an object and the shape of its FIS [6]. Fig**.** 1 shows a corresponding surface of the realistic object in image space. This surface is defined to be the FIS and the image position on where FIS and image detector meets is focused. The geometry (i.e., the shape) and the radiance distribution of the object surface are uniquely determined by the FIS and the focused image. Therefore, the problem of shape recovery can be posed as the problem of finding the accurate shape of FIS.

In practice, we estimate the continuous FIS from the discrete sequence of image frames. So the step size between an image frame and the next one should be small enough to find the best focused position. But small step size causes the increase of the number of images. It requires large memory space and computational costs. Note that this image step size problem is similar to the sampling theorem in signal processing.

2.2 Previous SFF Method (SFF.FIS)

The SFF.FIS method which was previously proposed is described briefly as follows.

1) The image detector is first moved to $z = z_0$. An image, $g_i(x, y)$, is recorded by moving the image detector to positions $z_i = z_0 + i * \delta$ where δ is a small displacement for $i = 0,1,2,\cdots, I-1$, $x = 0,1,2,\cdots, X-1$, and $y = 0,1,2,\cdots, Y-1$. Usually, $z_0 =$ focal length f, X and Y are the number of rows and columns respectively in each image frame, and I is the number of image frames

2) Compute the Laplacian image $L_i(x, y)$ at every point (x, y) on each image.

3) To get a rough estimation a traditional SFF method is used. In this method overlapping windows of size $(2N+1)\times(2N+1)$ (N is about 7) are used at intervals of $N/2$.

4) In the second phase of the algorithm, the initial estimate of FIS is refines as follows. In this phase, the entire original image sequence g_i containing I image frames is used. For every window in which the FIS was estimated in the first step, a small cubic volume (about the size of $(2N+1)^3$) image space is considered in the image sequence. The volume is centered at the initial estimate of FIS in that window. Now, in this volume, a search is made for a planar window which is the closest to the actual FIS by maximizing the focus measure computed over the planar search window. The initial estimates of position and orientation of the FIS are used as starting values during the search process. A simple gradient ascent search can be used for the search. In pervious SFF.FIS method, the actual FIS is estimates by using a piecewise planar surface. However, it is also possible to use a piecewise curved surface rather than a simple piecewise planar surface to improve the accuracy of depth estimation of the object.

3. NEW METHOD USING PIECEWISE CURVED SURFACE

In this section we will propose a new SFF method which is based on approximation of FIS by a piecewise curved window that tracks the realistic FIS in image space. The idea of the new SFF method came from FIS concept like as SFF.FIS, but piecewise curved windows are used to estimate FIS because the piecewise planar approximation does not fit for objects with complex geometry.

If we select nine points $(x+p, y+q, i_{x+p,y+q})$ where $p = -N,0,N$ and $q = -N,0,N$ obtained from rough depth estimation $i_{j,k}$ in considering window area centered (x, y) as shown in Fig. 2, we can interpolate a curved surface $S(p,q;x,y) = \{(x+p, y+q, i); F(p,q,i) = 0\}$. In this paper, we simply adapted Lagrangian polynomial equation [7] which passes through given points for the surface function $F(p,q,i) = 0$. Other surface function also can be used.

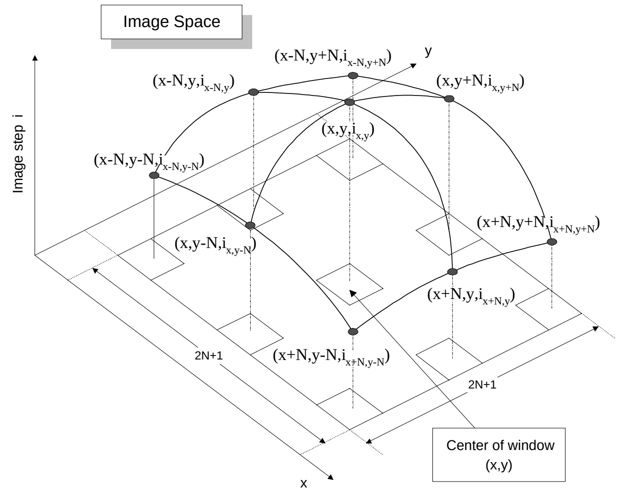

Figure 2. Nine Control Points in Image Space.

The algorithm which computes curved windows to calculate focus measure by using Lagrange polynomial [7] can be realized as below:

$p_{-1} = -N$, $p_0 = 0$, $p_1 = N$
$q_{-1} = -N$, $q_0 = 0$, $q_1 = N$
for $p = p_{-1}$ to p_1 do /* for x coordinate */
$P_{-1} = \{(p-p_0)\times(p-p_1)\}/\{(p_{-1}-p_0)\times(p_{-1}-p_1)\}$
$P_0 = \{(p-p_{-1})\times(p-p_1)\}/\{(p_0-p_{-1})\times(p_0-p_1)\}$
$P_1 = \{(p-p_{-1})\times(p-p_0)\}/\{(p_1-p_{-1})\times(p_1-p_0)\}$
$s_{-1} = P_{-1}\times i_{x+p_{-1},y+q_{-1}} + P_0\times i_{x+p_0,y+q_{-1}} + P_1\times i_{x+p_1,y+q_{-1}}$
$s_0 = P_{-1}\times i_{x+p_{-1},y+q_0} + P_0\times i_{x+p_0,y+q_0} + P_1\times i_{x+p_1,y+q_0}$
$s_1 = P_{-1}\times i_{x+p_{-1},y+q_1} + P_0\times i_{x+p_0,y+q_1} + P_1\times i_{x+p_1,y+q_1}$
for $q = q_{-1}$ to q_1 do /* for y coordinate */
$Q_{-1} = \{(q-q_0)\times(q-q_1)\}/\{(q_{-1}-q_0)\times(q_{-1}-q_1)\}$
$Q_0 = \{(q-q_{-1})\times(q-q_1)\}/\{(q_0-q_{-1})\times(q_0-q_1)\}$
$Q_1 = \{(q-q_{-1})\times(q-q_0)\}/\{(q_1-q_{-1})\times(q_1-q_0)\}$
/* piecewise curved window by Lagrange polynomial */
$S(p,q;x,y) = Q_{-1} * s_{-1} + Q_0 * s_0 + Q_1 * s_1$
end /* y loop */
end /* x loop */

Note that various curved shape windows can be made by changing $i_{x+p_\alpha,y+q_\beta}$.

The rough estimate of FIS from the traditional SFF method is used as the initial position of nine control points. By changing the initial position of nine control points about ±1 or ±2, curved windows for search of FIS are estimated. The focus measure is then computed by using Laplacian values on these curved windows. The center of curved window which gives the maximum focus measure is the accurate FIS position of each image point.

4. IMPLEMENTATION AND EXPERIMENTS

The proposed algorithm was implemented on a camera system called KACS (K-JIST Active Camera System). A block diagram of the system is shown in Fig. 3. The image frames taken by the frame grabber are processed in the PC-Pentium. The processed images are transferred to the SUN Ultra Sparc-1 for further processing. The image step numbered 0 to 96 is controlled through the motor interface by the program resides in the PC. Step number 0 corresponds to focusing an object at far distance and step number 96 corresponds to focusing a nearby object at a distance of about 1m from the principal plane of camera lens so that the whole FIS of the object lies in the image sequence. The camera settings with those objects were as follows: focal length=51mm, F-number=1.2. The image size used in the experiments was 256 by 256 in pixel.

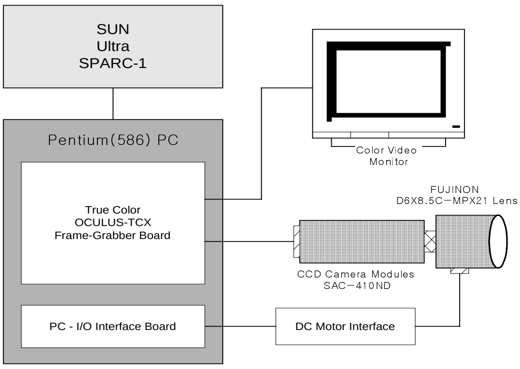

Figure 3. KACS: K-JIST Active Camera System.

For good experiments following factors should be considered:

- Sufficient edge information on image.
- Depth of field (DOF) of camera
- Image step interval

Two experiments were conducted for a simulated cone object and a real cone object. The simulated cone object is necessary to verify our new SFF algorithm. For the real cone object, the point of comparison is the tip op the cone. The sharper is the better, because the tip of the real cone is sharp. Here we present the results for the objects. Fig. 4 shows the ideal tip and surface of the simulated cone.

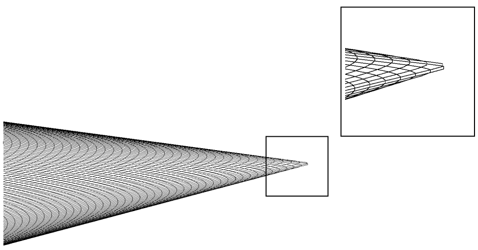

Figure 4. A simulated cone object.

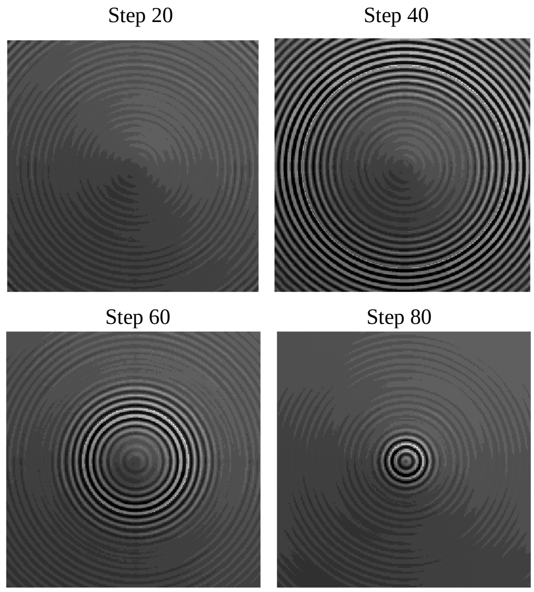

Figure 5. Simulated cone images.

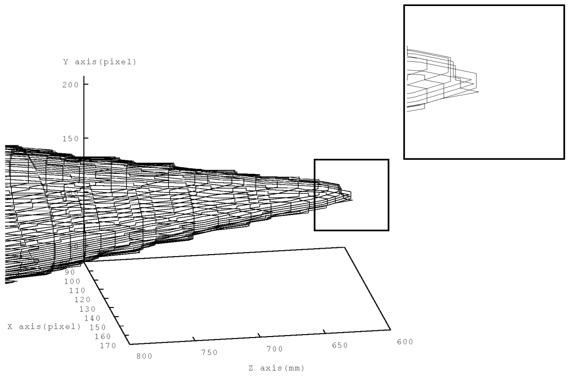

Figure 6-a. 3-D Depth map for a simulated cone object by the previous method. (SFF.FIS)

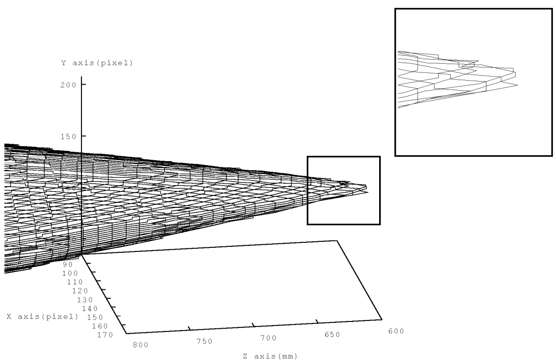

Figure 6-b. 3-D Depth map for a simulated cone object by the new method.

The images of simulated cone object at each step are shown in Fig. 5. Fig. 6-a and b show the results for a simulated cone object to compare our new method and the SFF.FIS method. As shown in Fig. 6-a and b, the tip of the cone is cone shaper and the surface of the cone is smoother in the case of our new SFF method comparing to the SFF.FIS method.

The real cone object of length 90cm and base diameter 14cm is made by hardboard. Black and white strips were drawn on it so that dense textures of ring patterns are viewed. Each picture of Fig. 7 was taken at different lens steps. As shown in the pictures, only a part of cone surface is in focus and elsewhere it is out of focus. The sharply focused area in the picture moves as the step changes forward or backward.

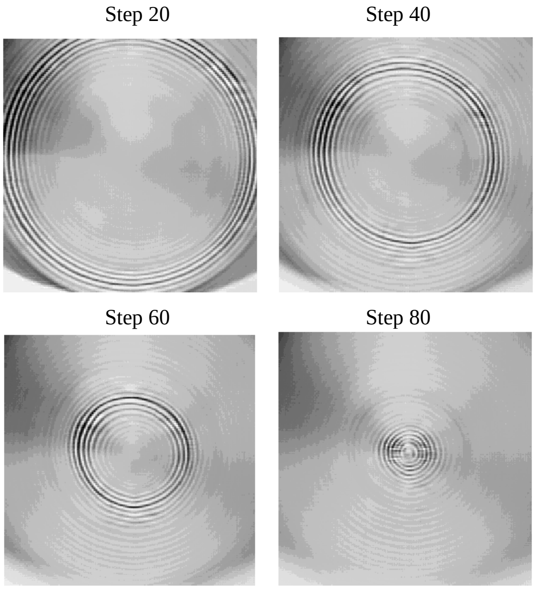

Figure 7. Real cone images.

Fig. 8-a and b show the results for the real cone object. Particularly, the tip of the cone is sharper and closer to the original shape of the object in the case of the new method as compared to the previous one.

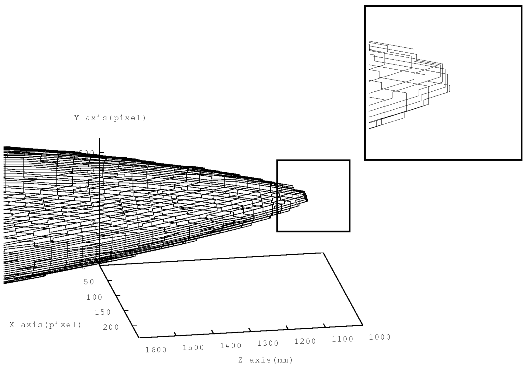

Figure 8-a. 3-D Depth map for a cone object by the previous method. (SFF.FIS)

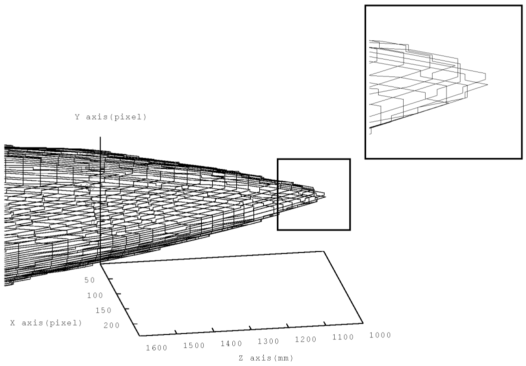

Figure 8-b. 3-D Depth map for a cone object by the new method.

5. CONCLUSIONS

A general form of search window for SFF method based on a piecewise curved surface has been proposed. Especially the Lagrangian Polynomial has been used to estimate the piecewise curved surface for finding a depth map of cone objects. The experimental results indicate that our new SFF method provides more accurate results than the previous one.

6. REFERENCES

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