Usage of Shape From Focus Method For 3D Shape Recovery And Identification of 3D Object Position

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Abstract

Shape from focus is a method of 3D shape and depth estimation of an object from a sequence of pictures with changing focus settings. In this paper we propose a novel method of shape recovery, which was originally created for shape and position identification of glass pipette in medical hybrid robot. In the proposed algorithm, Sum of Modified Laplacian is used as a focus operator. Each step of the algorithm is tested in order to select operators with the best results. Reconstruction allows not only to determine the shape but also precisely define the position of the object. The results of proposed method, obtained on real objects, have shown the efficiency of this scheme.

Keywords: Shape From Focus, Image Processing, 3D Shape Recovery.

1. INTRODUCTION

Recovery of a three-dimensional shape from two-dimensional images has been actively studied for a long time. In the literature, there are many proposed techniques like Shape From Shading[1] or Shape From Motion[2]. One of them is also Shape From Focus (SFF)[3]. In this method, the shape of the objects is estimated from series of images of the same scene with changing focus level. In SFF, after image acquisition, a focus measure operator is applied to specify points with the best focus for every image. In the next step, every pixel is assigned to the frame where the best focus has been obtained. Thanks to that, it is possible to reconstruct the shape of the object[3]. In this paper, a novel Shape From Focus algorithm, which was originally developed for the shape and the position identification of a glass pipette in a medical hybrid robot, is presented. This element is hard to examine because of it's partial transparency, so the algorithm needs to be adapted to the type of a reconstructed object. The proposed algorithm reconstructs shape even when object is difficult to determine or is very complex. Different focus measure operators have been studied and the one with the best results has been chosen. After focus measure, obtained pictures have been filtered with a Butterworth first order filter in order to get rid of high frequencies, occurring on the reconstruction as picks. Method for elimination of noise and determination, not only the shape, but also the position of the object was developed. Every pixel was assigned to the height were it obtained the maximum focus measure. The beginning of the pipette was the critical area, which was crucial to defined in this experiment, this is why it was used as a threshold in the reconstruction process. According to this threshold, the decision was made if the focus value of the pixel is enough to be considered during the reconstruction. In the end, the shape was filtered with the average filter, in order to make edges smoother and also to eliminate remained noises.

2. PREVIOUS WORKS

There are numerous solutions of SFF method examined in the literature. Each of them deals with different aspects of this algorithm. Many of works consider focus measure operator used in the algorithm. Mostly common are : Modified Laplacian (ML), Sum of Modified Laplacian (SML), Tenenbaum gradient (TEN) and gray level variance (GLV)[3].

SML is based on Laplace filter. In this filter, second derivatives in x and y directions can cancel each other. This is why Modified Laplacian model has been proposed [3]. It is defined as:

$$ML(x,y) = \left|\frac{\partial^2 g(x,y)}{\partial x^2}\right| + \left|\frac{\partial^2 g(x,y)}{\partial y^2}\right|$$

,where g(x,y) is the gray value for the coordinates (x,y). To improve the results of reconstruction focus measure in coordinates x,y are presented as a sum of ML in local window.

$$SML(x_0,y_0) = \sum_{p(x,y)\in \mathrm{U}(x_0,y_0)} ML(x,y)$$

Tennenbaum method is based on Sobel gradient operator. This focus measure method uses sum of squares of horizontal and vertical Sobel masks, also summed in a local window[4].

$$TEN(x_o,y_o) = \sum_{p(x,y)\in \mathrm{U}(x_0,y_0)} [G_x(x,y)^2 + G_y(x,y)^2$$

The last one, GLV focus measure is based on variations in a gray level values. On sharp image this variation is bigger that on image that is blurred. We get information about focus of the object by detecting variations between gray level variance in local window[3].

$$GLV\left(x_{0,}y_0\right) = \frac{1}{N-1} \sum_{p(x,y)\in \mathrm{U}(x_0,y_0)} [g(x,y) - \mu_{\mathrm{U}(x_0,y_0)}]^2$$

where $\mu_{\mathrm{U}(x_0,y_0)}$ is an average gray level variance of neighborhood pixels $\mathrm{U}(x_0,y_0)$.

There are also some innovative methods of focus measure proposed in the literature. One of them measures focus with fast discrete curvelent transform – FDCT. [5] Another one uses Anisotropic Nonlinear Diffusion Filtering – ANDF [6].

Effectiveness of focus measure not only depends on used algorithm. Very important is also the type of window used in the calculations. In one of proposed algorithm instead of 2D, 3D window was used[7].

Some of works focus on the initial state of the algorithm which is acquisition of the pictures. An example is the algorithm based on combinatorial optimization[6]. This algorithm tries to find combination of frames for which the maximum focus level will be achieved. A similar problem is taken into consideration in the paper about the minimum number of images required to obtain sufficient shape reconstruction [8].

Another issue often analyzed in order to improve SFF is a method of approximation of edges after focus measure process. An examples of such improvement can be usage of Lorentzian-Cauchy function[9] or kernel regression [10].

3. PROPOSED ALGORITHM

In this chapter, a new approach for improvement of the SFF method, is shown. The proposed algorithm is stated below. Basic process contains steps like: image acquisition, normalization, focus measure, filtering, creating initial and final depth map, as shown in FIGURE 1.

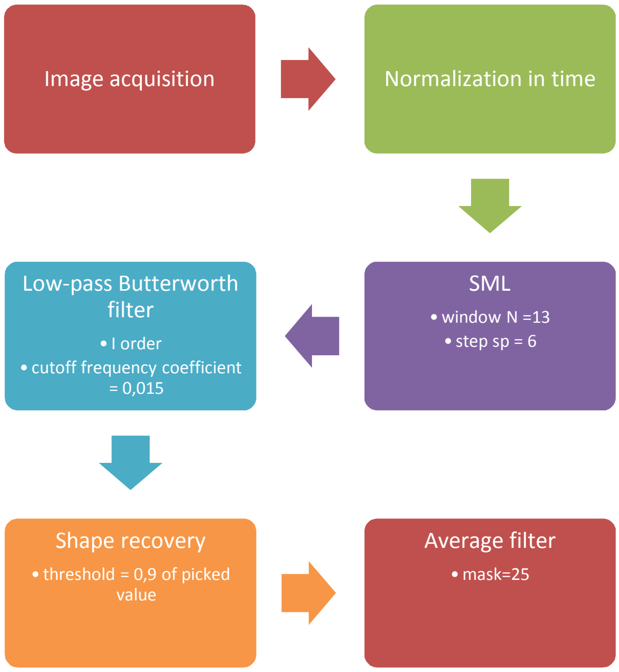


FIGURE 1: Proposed Algorithm.

After image acquisition, normalization process was performed. Every frame was divided by the maximum value of this frame. Thanks to that every frame was in range 0÷1.

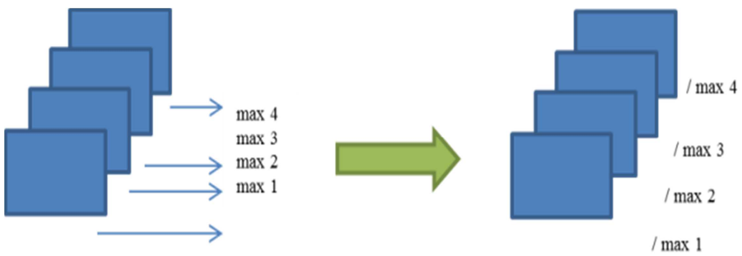


FIGURE 2: Normalization In Time.

In the second step, it was decided which focus operator should be used in the algorithm. Many operators have been proposed to measure the degree of focus level of the picture. The most commonly used are: Laplacian (Lap), Modified Laplacian (ML), Sum of Modified Laplacian (SML) and Tenenbaum gradient (TEN).[3] Focus measure values in this paper have been obtained by using the Sum of Modified Laplacian, because it gives the best results in experiments. Results of one of this experiments are shown below. In the FIGURE 3 one frame, from series that was taken into analysis, is presented. Focus measure values obtained with different focus operators for pixel marked in red are shown on FIGURE 4.Knowledge of the series, indicates that maximum focus measure should be obtained on the last – 18 frame.

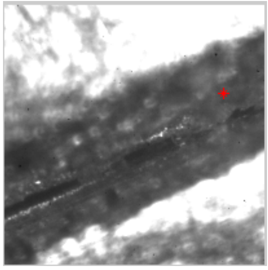


FIGURE 3: Frame from series that was taken into analysis.

As it can be seen only SML was able to detect the maximum focus correctly. ML found the maximum focus on 18th frame too, but it also detected high focus on 14th frame, what was incorrect. This is an example of experiments conducted to find the best focus measure operator. According to the results of those experiments SML will be operator used in this algorithm.

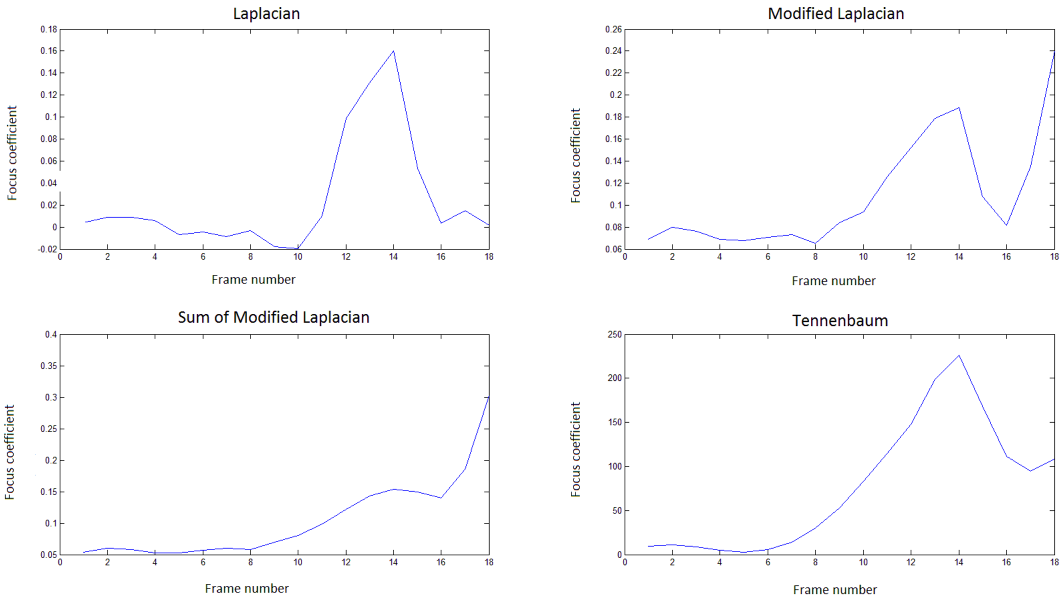


FIGURE 4: Focus measure obtained with different focus operators.

Afterwards, frames were filtered with low pass Butterworth filter. This allows to get rid of undesirable high frequencies, occurring on reconstructed image as a peaks. It is also the method of approximation of edges after focus measure process. Butterworth filter has flat frequency response, so it will smooth the edges without significant distortion. After experiments, first-order Butterworth filter with cutoff coefficient equal 0.015, shown in FIGURE 5, was used.

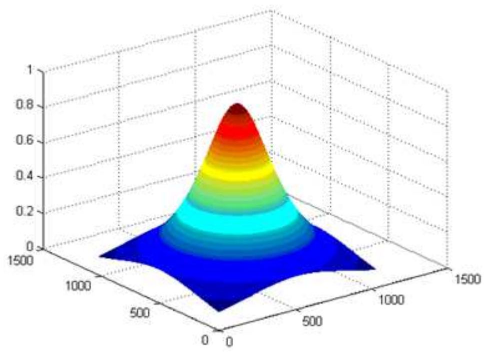


FIGURE 5: First-order Butterworth Filter.

Prepared images were ready for the shape recovery process. For every pixel, frame where the highest focus measure level was obtained, was found. Knowing picture number and high of that picture made possible to assign every pixel to high where it obtained maximum focus measure. It was necessary to set a threshold. It was a the minimal value of pixel focus measure that should be reached to allow the assignment process. To do this one point was picked, for this reconstruction, it was beginning of the pipette because correct estimation for this area was the most crucial. Experimentally, the threshold was set as a 90% of picked value. This process allowed to create initial depth map. To enhance results of reconstruction, average filtering was applied. Thanks to that final reconstructed shape was smoother and did not have a high frequency noises.

4. RESULTS

In this section we show the improved performance of proposed scheme by testing it on a various images. Experiments were conducted on four different types of objects shown on FIGURE 6 (a-d).

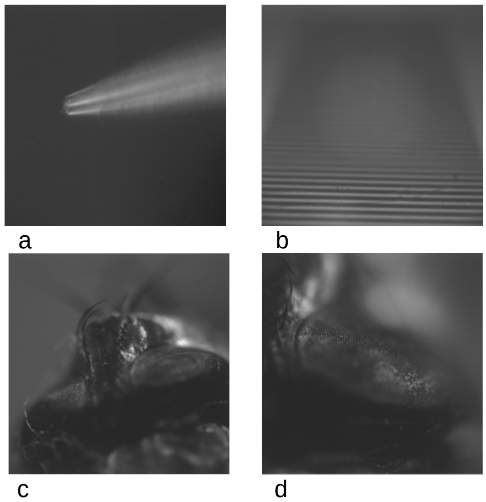


FIGURE 6: Objects on which experiments were proceeded (a-d).

All series of pictures have been made with specially designed optical system. It contains fully apochromatic zoom system, where zoom, iris diaphragm and focus are motorized. It provides high resolution images without chromatic distortions. The system also has objective LEICA PLAN APO 5x/0.5 LWD, what makes 95% of an area flat during the observation. In addition, system has illumination module that provides a coaxial illumination of the test object. First object was a partially transparent pipette (FIGURE 6a), for which this algorithm was originally dedicated. This object is highly difficult to reconstruct because of it’s transparent structure. The shape was reconstructed from a sequence of 22 pictures.

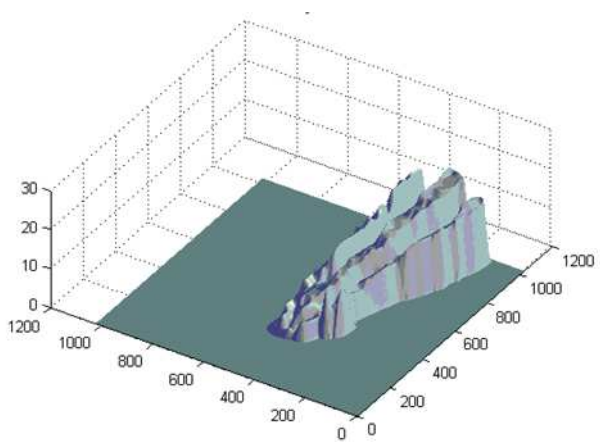


FIGURE 7: Reconstruction of the Pipette.

As it can be seen on FIGURE 7, there are areas for which reconstruction was impossible because of transparency of those places. However, the general shape was successfully reconstructed. Also the pick of pipette, which was crucial in this experiment was exactly detected.

Second object was *DOF 5-5 Depth of Field Target, Edumnd Optics* (FIGURE 6b). The shape was reconstructed from a sequence of 22 pictures. This experiment was mostly performed to show that it is possible not only to reconstruct shape but also keep proportions and exact depth map of the object. Depth of Field Target was placed so that it would be possible to observe the surface at an angle of 45 degrees. As it can be seen in the FIGURE 8 this angle was preserved while reconstruction process. Steps that are visible on reconstructed object are a result of established step of scanning and iris settings. To rectify this effect it is need to decrease the scanning step or change depth of filed by opening the iris. In this experiment it was important to verify the correct angle of the reconstructed surface, exact shape was not crucial, that is why big step has been used.

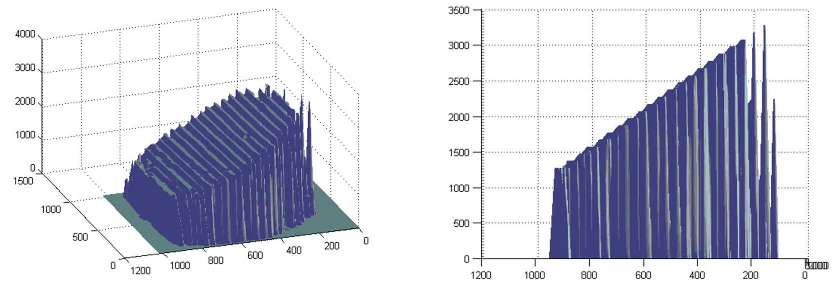


FIGURE 8: Reconstructions of DOF 5-5 Depth of Field Target, Edumnd Optics.

In the FIGURE 9, it is shown how the reconstruction changed when depth of field was higher. Algorithm with the same number of pictures was able to reconstruct shape properly.

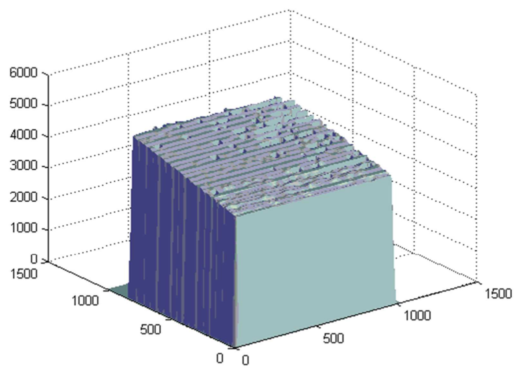


FIGURE 9: Reconstructions of DOF 5-5 Depth of Field Target, Edumnd Optics with high depth of field.

In third experiment a biological object was examined. A fly was used for this purpose (FIGURE 6c). This shape is very complicated so it was possible to fully prove the possibilities of the algorithm. Of course reconstruction was not exact, because only view from one perspective was available. However, object has been reconstructed accurately despite from it's high complexity.

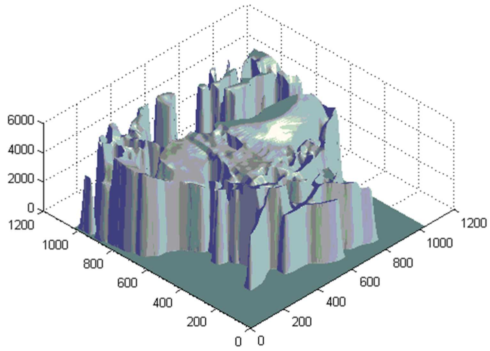


FIGURE 10: Fly's Head Reconstruction.

The last experiment was conducted also with the fly, but attention was focused on smaller part (FIGURE 6d). Only the eye of the fly was reconstructed. Pictures were made with six time zoom and iris open with 100%, what gives very small depth of field. Distance of 1275 um was scanned with step of 25 um, what gives 53 pictures. Those parameters were needed because of small size of the object and small variation of surface. Results of the experiment shown on FIGURE 11 are very satisfying.

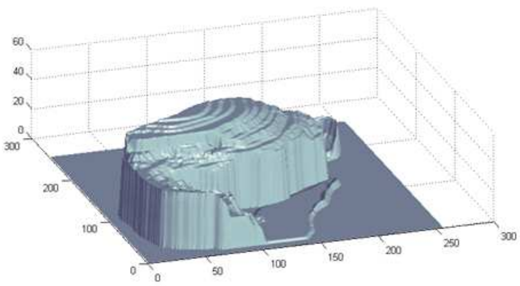
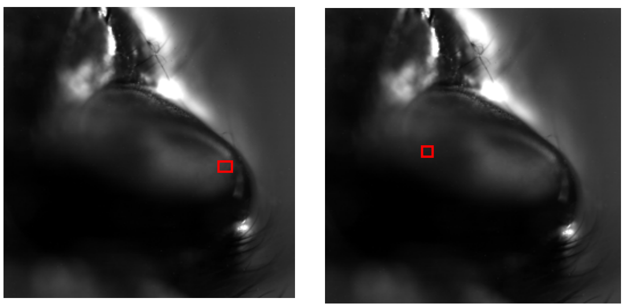


FIGURE 11: Fly's Eye Reconstruction.

Shape of the eye has been carefully restored, even small changes on the surface were detected by the algorithm.

One more experiment was proceed to shows possibilities of algorithm to define the position of the object and distance between two parts of reconstructed shape. Small areas on fly's eye were selected, what is shown of FIGURE 12 (a,b).



a B

FIGURE 12: Selected Areas (a,b).

In FIGURE 13, it is shown how value of focus measure depends on high in Z axis. Plot blue is for one selected area and plot green is for the other. As it can be seen, maximum focus measure for both is strictly defined, so it is possible to find the high of them and consequently distance between them. The results confirm that it is possible to obtain accurate information about individual elements, even when they are really small or complicated.

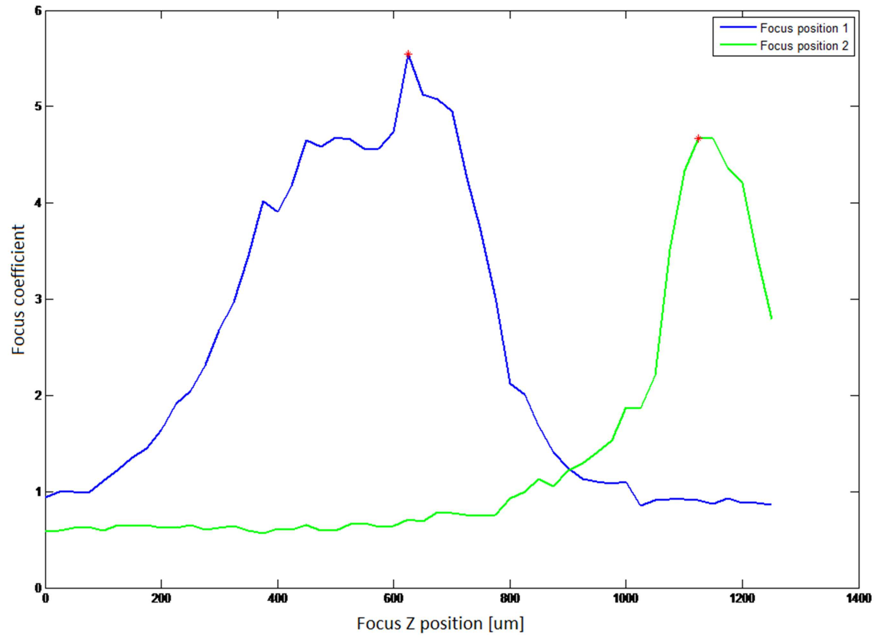


FIGURE 13: Value of focus measure depending on high in Z axis.

5. DISCUSSION

Proposed algorithm is a substantial improvement in the field of shape recovery methods. While creating the processing scheme, every aspect of reconstruction process was carefully analyzed and the most adequate method was selected. For each step the extensive literature background was checked, the best solutions were found, tested, and in the end, parameters for those methods were chosen to fulfill the requirements as close as it was possible[11][12][13]. The novel Shape from Focus method was able to reconstruct objects with high accuracy and preserve proportions even with a large complexity of the object. Also the height of a single point and the distance between two points were possible to obtain. Thr proposed methodology was dedicated for a glass pipette, which is difficult to reconstruct, but the algorithm managed to gain this goal. There is anxiety that the algorithm created for one specific case would not be efficient for different objects. To limit this problem, there are steps like normalization in time, or picking the threshold, which make the proposed method useful for diverse cases. In most of researched papers authors were focused on one aspect of the algorithm, like the image acquisition[6][8],the focus measure operator[5][6][14], the size of the window[7] or approximation methods [9][10]. In the proposed scheme all aspects of the algorithm were analyzed to create the most efficient solution. Comparative evaluation with other authors wasn't fully possible, because object that were used in other experiments were not available for tests. The algorithm proposed in this paper, in comparison to other works, was able to reconstruct even really complex and difficult to determine structures.

6. CONCLUSION

In this paper, a novel SFF method was presented for 3D Shape recovery and identification of a 3D object position. The algorithm was originally created for the shape and the position identification of a glass pipette in a medical hybrid robot. In the proposed algorithm, after image acquisition, there is a normalization process. In the next step Sum of Modified Laplacian is applied in order to find areas with the maximum focus. After this, images are filtered with a first order low-pass Butterworth filter. The initial depth map is obtained by assigning each pixel to the height, where it reached the maximum focus value. The threshold in the reconstruction process depends on the value of a pixel, for which proper reconstruction is the most important. In this case, it is beginning of a pipette. Thanks to that, it is sure that the most important area will be reconstructed correctly. In the end, average filtering is applied to smooth the edges of the reconstructed shape. The proposed scheme was tested on four different objects and reconstruction gave really good results. Moreover, the proposed algorithm is able to define the position of the object and distance between two selected areas.

7. Acknowledgements

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