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PJBS

ISSN 1028-8880

Pakistan Journal of Biological Sciences

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Pakistan Journal of Biological Sciences 9 (15): 2818-2822, 2006
ISSN 1028-8880
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3D Reconstruction of Ultrasonic Images Based on Matlab/Simulink

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Abstract: In this study we use Matlab/Simulink as a user friendly interface to examine three recent works on UT image processing; furthermore a new method based on morphological features is proposed. A series of simulated 2D UT images of two known cysts are processed by the 4 different methods. They will serve as the input for 3D surface reconstruction package. A novel comparison way related to 2D and 3D features of cysts is provided. The weakness, the advantages and the deficiencies of each method are explained for cyst 3D reconstruction. It is shown that our novel morphological based method has good performance for online reconstruction specially.

Key words: Index-Ultrasonic, Matlab, 3D reconstruction image processing

INTRODUCTION

Over the past decade, robots have been appearing in the operating rooms. With the robotic system assistance, operations have become less invasive. Robotic surgery requires the use of computer imaging to diagnose and perform the operation. A three dimensional (3D) shape, formed by stacking a contiguous series of 2-D images, can be used to visualize complex structures in 3D. The inherent flexibility of ultrasonic images, the low price and non hazardous properties are the reasons why researchers care 3D UT visualization. The problem of automatically detecting regions of interest in a UT image is of fundamental importance in 3D reconstruction systems. Segmentation algorithms require accurate edge maps for good performance, however the highly signal dependent nature of ultrasound speckle makes these difficult to obtain. Various filtering techniques have been developed to suppress speckle in order to improve the quality of images. Among them, the nonlinear filters have recently received an increasing interest, due to some of their important capabilities over linear filters. Also some introduced techniques for image enhancements can help to better edge detection. The large number of Image processing methods and their combinations make it difficult for the researchers to select the best among them.

The video and image processing blockset (VIPB) is a tool for processing images and video in the matlab/simulink environment. It is used for the rapid design, prototyping, graphical simulation and efficient code generation of video processing algorithms. With VIPB simulink we can reach to more realistic results by watching the models and gaining a better understanding of image processing methods. The substitution of each model by the other ones and changing the internal parameters are simple. In this study we present four models for automatic image processing, needed for 3D reconstruction. It consists of 3 recent researches on UT image processing methods besides a novel algorithm base on morphological filtering. In addition, a novel method for comparing the results base on 2D morphological features, execution time consumption and 3D rendered visualization sense with its mathematical features is introduced. Using a UT image simulator package makes it easy to extract object features and comparing them. The recent researches were focused on one image processing method without attention to 3D reconstruction goal and also without the combining the methods, we try to find the best composition of image processing methods are proper for ultrasonic images by a user friendly matlab/simulink package.

MATERIALS AND METHODS

B-mode UT simulator: The ultrasonic images were generated by Field II, a set of programs for simulating ultrasound transducer fields and ultrasound imaging using linear acoustics. It uses the Tupholme Stepanishen method (Jensen, 1996) for calculating pulsed ultrasound fields. The programs are capable of calculating the emitted and pulse-echo fields for both the pulsed and continuous wave case for a large number of different transducers.

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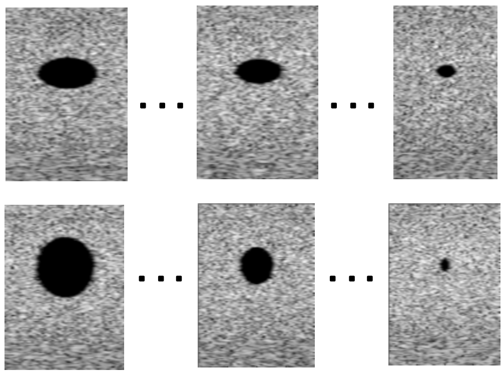

Fig. 1: Successive UT images of elipse and circle made by field II

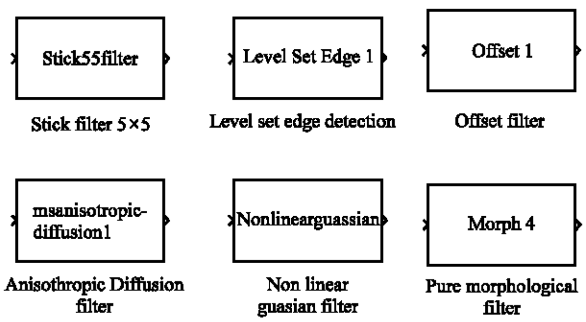

Fig. 2: Specific simulink library

Also any kind of linear imaging can be simulated as well as realistic images of human tissue. The images are all obtained by modeling the generation of an image of a phantom, using a scattering field of a 60° image sector, containing 100,000 point scatterers, randomly distributed within the field. The scattering strengths of the point scatterers are Gaussian distributed, with a mean zero and standard deviation one (Fig. 1). The model of the probe, used as system that generates the images, includes the central transducer, which has a 64-element phased array with a half wavelength inter-element spacing. The width of each element in the array is 0.29 mm and its height is 13 mm. The central frequency of transducers is 3.5 MHz.

Matlab/Simulink environment: Simulink is a software package for modeling, simulating and analyzing dynamic systems. The instant access to all of the analysis tools and visualize the results can be achieved easily. For modeling, simulink provides a Graphic User Interface (GUI) for building models as block diagrams, using click-and-drag mouse operations. Simulink allows the user to create models for dynamic systems simply by connecting blocks from available or user made libraries. The available libraries for image processing are useful but are not enough. We made some recent image processing methods as a user made simulink library (Fig. 2).

Filters description: The anisotropic diffusion filter can get rid of the major drawback of the conventional spatial filters and improve the image quality significantly while preserve the important boundary information (Perona and Malik, 1990). The power of the anisotropic smoothing scheme lies in its dealing with local estimates of the image structures. Smoothing is formulated as a diffusive process, suppressed or stopped at boundaries by selecting locally adaptive diffusion strengths. Hence, in this filter, the smoothing operation could be prevented from across edges, the discontinuities can be preserved and a weak slope remains nearly unchanged if the slope falls within the monotonically increasing part of the gradient values. According to Adam *et al.* (2006), the formulation of a nonlinear Gaussian filter is suggested to be:

$$G(\sigma_X,\sigma_Z,p) = f(p) + \frac{1}{N_p}\sum_{q\in p} g_x(\| p-q \|).g_Z(f(q) - f(p)).(f(p)-f(q)) \qquad (1)$$

Where

$$g_X(t) = \exp(\frac{-t^2}{2\sigma_X^2}); g_Z(t) = \exp(\frac{-t^2}{2\sigma_Z^2}) \text{ ; and}$$

$$N_P = \sum_{q\in P} g_X(\| p-q \|) g_Z(f(q)-f(p)).$$

The weight function $g_x(f)$ is responsible for image smoothing while the function $g_x(f)$ preserves edges within the image. In order to enhance the noise reduction, a parameter g was added to the nonlinear Gaussian filter:

$$G(\sigma_x,\sigma_y,p) = f(p) + \frac{n}{N_p}\sum_{q\in P} g_X(\| p-q \|). g_Z(f(q)-f(p)).(f(p)-f(q)). \qquad (2)$$

The parameter n should be in the range [1,1.5]. In general, the smoothing effect of a single nonlinear Gaussian filter may not be satisfactory (Aurich and Weule, 1995). Therefore, a filter chain was used, which comprises several filters in series, with different parameters σ_X and σ_Z. The first filter in the filter chain serves mainly for reducing the contrast of the fine details in the images. The next stages perform additional contrast reduction, but at the same time sharpen the edges of the coarser structures, which have been blurred by the first step. Formally, the filter chain may be written as:

$$I_N = G_N(\sigma_{X,N}, \sigma_{Z,N}) G_{N-1}(\sigma_{X,N-1}, \sigma_{Z,N-1}) ... G_1(\sigma_{X,1}, \sigma_{Z,1}) I_0$$

with $\sigma_{X,n} = 2\sigma_{X,n-1}$ and $\sigma_{Z,n} = \sigma_{Z,n-1}/2$.

An alternative approach to anisotropic diffusion filter was developed by Fischl and Schwartz (1999), whose nonlinear filter has excellent performance, comparable to nonlinear diffusion methods and whose theoretical basis includes the notation of offset filtering specifically, they introduced an offset term which displaces kernel centers away from presumed edge locations, thus enhancing the contrast between adjacent regions without blurring their boundary. By separating the estimation of an offset vector field from image filtering in itself, we obtain a simpler, more robust and faster class of algorithms. The stick, as a set of short line segments of variable orientation, is able to locally approximate the boundaries and to reduce speckles as well as improve the edge information in the ultrasound images (Chang *et al*., 2005).

It is a constant-length line segment of variable orientation, which we use at every point of the image to determine the strength of the most significant line passing through that point (if any). At each pixel, we project the image onto a family of sticks, differing in orientation, but always centered at and passing through the pixel under study. The greatest total projection of any stick is then plotted as the pixel intensity of the enhanced image at that point. In other words, at each point, we compute the sum of intensities of all the pixels that lie along a straight line segment through the original point and plot the greatest sum (Czerwinski *et al*., 1999).

The level set method is a numerical technique for computing and analyzing the front propagation. It offers a highly robust and accurate method for tracking interfaces moving under complex motions. Instead of propagating the front directly, it embeds the front as the zero level set of a higher order function called the level set function (Li *et al*., 2005). In a morphological filter, the value of each pixel in the output image is based on a comparison of the corresponding pixel in the input image with its neighbors. By choosing the size and shape of the neighborhood, we can construct a morphological operation that is sensitive to specific shapes in the input image. Because each UT image has one cyst and definite shape, the morphological structuring element can be created by disk-shaped and diamond-shaped for sphere and ellipse, respectively.

EXPERIMENTS

For comparison of 3D shapes we produced two types of cysts; the ellipsoidal and spherical shape with the following equation:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1 \qquad x^2 + y^2 + z^2 = a^2 \tag{3}$$

The diameters are 2a = 26 mm, 2b and 2c = 10 mm for ellipsoidal and 2a = 20 mm for sphere (Fig. 1). The 2D UT images are produced by Field II, through the solving of:

$$\frac{x^2}{a^2} + \frac{z^2}{c^2} = 1 - \frac{y^2}{b^2}$$

and $x^2 + z^2 = a^2 - y^2$ In fact, it means we put the UT probe on top of the objects and move it on y axis at the determined steps. The best quality for 3D reconstruction is acquired when the voxel dimensions are the same, it means the step distance on y axis should be equal to the pixel widths or heights. For satisfying the conditions the 20 and the 40 2D UT images are needed for ellipse and sphere, because of the symmetrical shape of objects half of the images are enough to be simulated by Field II (Fig. 1). The avi file we made from all successive 2D UT images is considered as input of simulink models for convenience. Actually we can apply different filtering techniques to implement cyst edge detection with using the simulink matlab, but the 4 methods which are suitable, cause of their performance comparison are focused; nonlinear Gaussian diffusion (NLG), anisotropic filter with level set (ANL), offset filters (OFS) without level set and pure morphological (PUM). At first, a non linear Gaussian filter applies to UT images. With a proper threshold the image changes to the binary format and our object is extracted by canny edge detection. In the second way, the original ultrasonic image is initially processed by the anisotropic diffusion filtering, stick method and thresholding method. After, we achieve a binary image and then combine it with the original image. Finally, we utilize the level set method to segment the cyst in the combined image. In OFS, we omit the level set; the anisotropic filter is substituted with a fast offset filter which gives the same result and the canny edge detector extracts the border. The last method applies the special morphological filters for selecting and smoothing the desire object which uses threshold and dilate. Figure 3

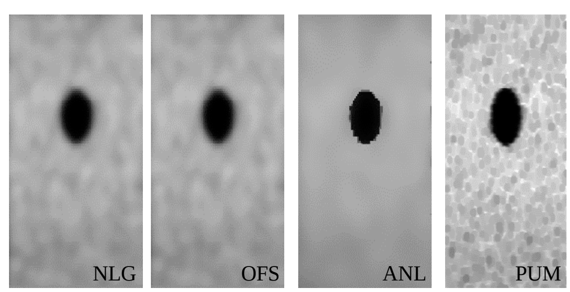

Fig. 3: Output images after 4 different filtering

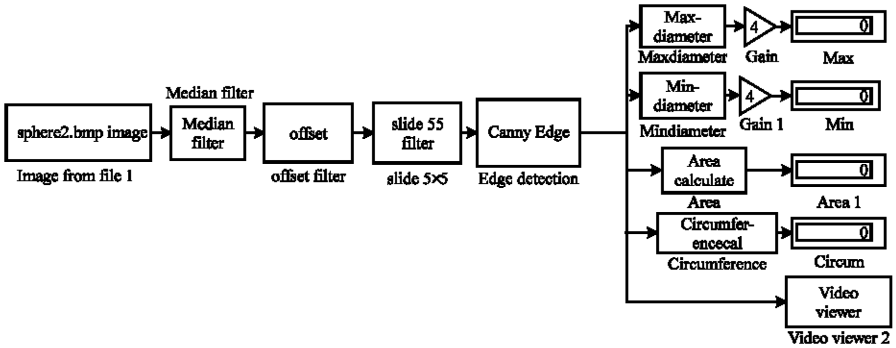

Fig. 4: Automatic 2D feature extractions in simulink model for offset and stick filtering

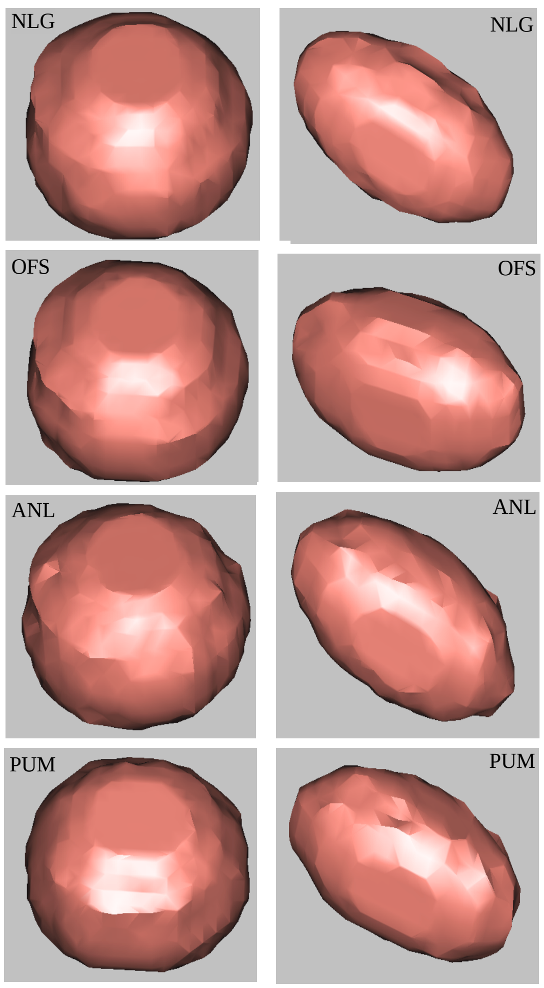

Fig. 5: 3D reconstruction of cysts based on 4 mentioned method

Table 1: Mean (%) error for calculation area and circumference of 2D successive UT images based on 4 mentioned methods

		Methods			
2D object	Analyze	NLG	OFS	ANL	PUM
Ellipses	Area	1.68	4.80	6.63	5.63
	Circumference	-0.33	0.99	1.75	1.89
Circles	Area	3.47	4.85	5.04	4.29
	Circumference	1.48	2.57	2.65	2.31
Average		1.58	3.30	4.02	3.53

Table 2: (%) Error in calculation of volume and surface in 3D shapes based on 4 mentioned methods

		Methods			
3D object	Analyze	NLG	OFS	ANL	PUM
Ellipsoid	Volume	3.39	7.54	7.83	6.78
	Surface	18.73	19.74	22.35	21.28
Sphere	Volume	4.20	5.59	12.98	5.15
	Surface	9.20	9.78	15.05	12.37
Average		8.88	10.66	14.55	11.39

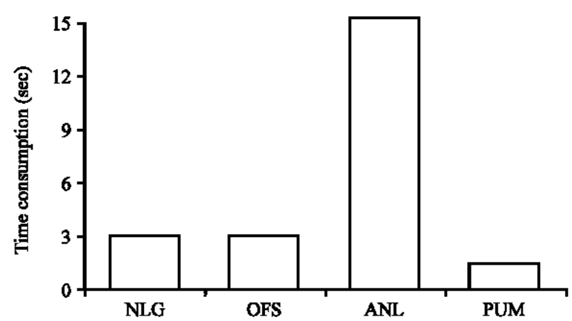

Fig. 6: Time consumption for image processing in 4 methods

shows the output images after the 4 algorithms. Into all models we designed a part for mathematical feature calculations of extracted object like diameter, area and circumference (Fig. 4). It becomes easy to compare the results of each method with the origin 2D UT image. Table 1 shows the mean error for acquired area and circumference of all objects in each method. The successive 2D UT images are used for 3D surface reconstruction, to keep the originality of visual sense any smoothing filters were ignored during the reconstruction (Fig. 5) (Zhang *et al*., 2004) . In addition to the visual appearance, the volume and surface of 3D objects are recorded in Table 2 to compare the accuracy. Time consumption, as an important factor in online 3D reconstruction in robotics-assisted surgery projects, was measured on P4, 2.94 MHz CPU and 1 Gbyte RAM (Fig. 6).

CONCLUSIONS

According to Table 1 the 2D average error of 4 methods are less than 5% which NLG, OFS and PUM are the first to the three. We expect to decrease the accuracy when we combine the 2D images for 3D reconstruction, the average error is increased to range of 10% but the NLG method also keeps its priority, then OFS and PUM come the next with small difference.

In point of time consumption PUM is about 2 times faster than NLG and 10 times faster than ANL. In visually comparison, it doesn't seem any big difference between the 4 3D shapes, although all methods can't show the cysts clearly but they appear equally.

Based on our referee's parameters NLG and PUM are the best image processing filters for 3D reconstruction, they can be selected due to our applications; briefly we suggest the NLG for offline 3D reconstruction and PUM for the online one.

This study used the matlab/simulink models for comparing various image processing filters. They accept one stream of UT Images as a movie file and make another movie of edge detected objects. They were checked by two types of cysts without necessity to change libraries parameters. Based on 4 parameters comparisons; 2D and 3D performance, time consumption and visual sense, It was found the non linear Gaussian (NLG) filter has the best quality and pure morphological (PUM) filter has the best time consumption. We are going to decrease NLG time execution by decreasing the chain numbers and programming through the faster algorithms for future. On the other hand we will try to enhance the PUM methods for increasing the quality.

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