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AN ULTRA-SOUND AND DOPPLER MEDICAL IMAGE ANALYSIS FRAMEWORK

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Abstract: Ultrasound imaging is widely used in medical investigations especially because of the two major advantages it offers: first, it is a non-invasive technique and second, it can provide real-time anatomic images. However, the clinical interpretations of the results are not straightforward, and sometimes visual inspection of the medical personnel must be completed with image analysis techniques. This paper presents some image processing algorithms implemented in the frame of **Angiodopp**, financed by VIASAN Romanian National Research&Developpment program, and this project has the purpose to assist specialized medical personnel in analyzing ultrasound endovaginal digital images. The algorithms involved in the application should be: robust, fast, and allow user interaction (to quickly and easily determine the regions of interest and segmentation thresholds) by the means of a user-friendly interface.

Key words: ultrasound imaging, image analysis

1. INTRODUCTION

Ultrasound (US) imaging is an important diagnostic tool in several major clinic disciplines, and its significance is still growing fast. Depending of the set-up of the ultrasound scanners, it can produce real-time topographic images of ultrasound scattering, real-time images of blood and tissue motion, elasticity and tissue flow (perfusion). All these images are built up line by line by sending ultrasound pulses into the tissue and recording the reflected radiofrequency signal. These reflected signals provide the necessary information to derive various ultrasound image types [1] with reasonable gray scale contrast. The tissue images can be combined with a dynamic color overlay that quantifies and localizes fluid flow and shows the flow direction. Another important advantage is that there are no known harmful effects of repeated ultrasound examinations, provided the guidelines for the setting of the ultrasound emitted energy are followed.

However, clinical interpretation of the results is not straightforward. Measuring velocity with color Doppler is possible, but the methods are still under development and have not been standardized across different brands of ultrasound equipment. Regional quantitative analysis is required to detect subtle motion abnormalities that cannot be evaluated by visual analysis [5]. There are two ways to quantify ultrasound data: work within the scanner with the raw data (this requires special software from the manufacturer, and some begin to offer such packages) or processing video outputs.

In this paper we investigate and employ some algorithms for extracting and processing the information comprised in still color images and also within gray-level video sequences – according to the needs of the medical staff – obtained in digital format after grabbing them to a PC from an US Doppler echograph from the Echography Department at Medical 3 Clinic, Cluj-Napoca.

The main information provided as a result of image analysis and processing are color quantification, velocity estimation, and mean intensity time plot in video-sequences, extracted from a manual defined region of interest (ROI).

These results are obtained by applying fast color image segmentation and video sequence processing algorithms, following the next steps:

1. Image acquisition
2. Image preprocessing (noise reduction, artifact removal)
3. Definition of ROI
4. Color decoding to extract the velocity values from color images; gray-scale processing to retrieve the mean gray intensity within a ROI
5. Quantitative analysis.

2. ULTRASOUND AND DOPPLER ECHOGRAPHY PRINCIPLES

2.1. Doppler echography

The Doppler principle states *that the frequency of reflected ultrasound is altered by a moving target, such as red blood cells.* The magnitude of this Doppler shift relates to the velocity of the blood cells, whereas the polarity of the shift reflects the direction of blood flow toward (positive) or away (negative) from the transducer. The Doppler equation:

$$\Delta F = \frac{V \times 2F_0 \times \cos\theta}{c} \tag{1}$$

shows that the Doppler shift (ΔF) is directly proportional to the velocity (V) of the moving target (i.e., blood cells), the transducer frequency (Fo), and the cosine of the angle of incidence (θ) and is inversely proportional to the velocity of sound in tissue (c =1540 m/s). The Doppler equation can be solved for blood flow velocity as follows:

$$V = \frac{\Delta F \times c}{2F_0 \times \cos\theta} \tag{2}$$

Doppler echography is used to evaluate blood flow velocity with red blood cells as the moving target. Current ultrasound systems can also apply the Doppler principle to assess velocity within tissue [2].

Currently, Doppler echography consists of 3 modalities: pulsed wave (**PW**) Doppler, continuous wave (**CW**) Doppler, and **color** Doppler imaging [1,2]. PW Doppler measures flow velocity within a specific site (or sample volume) but is limited

by the aliasing phenomenon that prevents it from measuring velocities beyond a given threshold (called the Nyquist limit). CW Doppler, on the other hand, can record very high blood flow velocities but cannot localize the site of origin of these velocities along the pathway of the sound beam. Color flow Doppler uses PW Doppler technology but with the addition of multiple gates or regions of interest within the path of the sound beam. In each of these regions, a flow velocity estimate is superimposed on the 2-dimensional (2D) image with a color scale based on flow direction, mean velocity, and sometimes velocity variance.

2.2. Wash-in Wash-out techniques using contrast agents

Although US is widely used in clinical practice, there are still fundamental limitations in imaging diseased tissues that have acoustic properties similar to those of normal surrounding parenchyma, as well as in the Doppler assessment of low-velocity blood flows and low volume flow rates. With the current limits on performance, there is clearly a need for ultrasound contrast agents [3].

The ideal ultrasound contrast agent should be safe, stable enough in the vascular system to survive pulmonary capillary circulation, and be capable of modifying the acoustic properties of the tissues of interest [3]. The objective of US imaging when using contrast agents is to increase the ratio between the signal provided by the contrast agent and the signal emitted by tissues.

Contrast agents are traditionally administered as bolus injections. This provides a typical **wash-in wash-out** enhancement profile [4], which is characterized by a rapid Doppler signal increase followed by a gradual decrease over a few minutes.

There are several concepts in ultrasound echography [7], concerning the use of the contrast agents:

1. Phase inversion principle – with linear acoustic response, the received echoes are similar to the transmitted ones; the sum of the two signals is close to 0.
   – with non-linear acoustic response, the shapes of the received echoes are different and their sum differs from 0. In this way, identification of the non-linear part of the acoustic signal is possible without filtering.
2. Amplitude modulation – the differential non-linearity between a high and a low state is detected.
3. Pulse inversion technique – the amount of fundamental component removal is limited by tissue motion

The wash-in wash-out curve parameters (like peak value, rise time, fall time, and slope) provide valuable information about the type of the tumors (malignant, and benign).

3. OVERVIEW OF THE IMAGE PROCESSING ALGORITHMS EMPLOYED

3.1. Color image processing (quantitative analysis of color areas and velocity estimation)

The approach used for color Doppler image processing is the following: first we remove the gray portions in the image (or in the ROI determined by user) and then analyze the remaining color area.

The ROI is delimitated by specialized personnel, having three possibilities of drawing the wanted shape: rectangle, ellipse, and free-hand.

To separate colors from "non-colors" (gray levels) we use a straightforward principle, based on color components attributes in the (R, G, B) cube. The RGB distance is calculated according to Equation 3:

$$d_{RGB} = \sqrt{(R-B)^2 + (R-G)^2 + (B-G)^2} \quad (3)$$

If d_{RGB}, calculated for a specific pixel, is close to 0, then it can be considered a gray level pixel.

The color histogram of the distances of each color to the gray standard is built (given by the Equation 3); afterwards, a simple histogram thresholding is applied, where the threshold selection is user-defined. The default value was empirically chosen (based on a set of images of interest) as $T = 40$.

To estimate the velocity represented by one color pixel in the image, regarding the color representation scale, provided by the echograph: first, compute the RGB distance for the selected pixel color and then find the closest RGB distance in the scale matching the one of the selected pixel; the final result is validated by the dominant component check.

3.2. Video Processing (Wash-in Wash-out curve estimation)

The procedure of video sequence processing aiming to plot the wash-in wash-out curve is the following: first, the user manually sets a ROI (usually determined by an ellipse) on the first frame of the video sequence. Then, this ROI is considered for the entire sequence, in the same spatial position. This assumes a small movement of the patient during the investigation. In the predefined ROI, the mean luminance value is computed as: $Y_{mean} = \frac{\sum_{i=1}^{N} y_i}{N}$, where N is the number of pixels inside the ROI, and y_i is the gray level of pixel i. The mean luminance values are computed and stored in real-time (i. e. during the sequence playback) in a vector indexed by the frame position, which will afterwards be converted in ms.

Finally the algorithm displays the curve mean luminance vs. time on the entire sequence by linear interpolation between these values.

Problems can arise if the ROI size is too large; in this case, even small tissue motions can affect the mean value in the ROI in an unwanted way. A solution we propose to this problem is to randomly select a set of sub-ROIs of small size (e. g. 5 *x* 5 pixels, as in [5]), compute a luminance vs. time plot on each sub-ROI and apply some statistics on these results; then, by interpreting the mean and variance of the set of curves, we can get a more accurate estimate of the real curve.

4. EXPERIMENTAL RESULTS

Figure 1 shows the result of applying the color segmentation algorithm over a color Doppler digitized image. It can be seen that the algorithm works with good results. The quantification of color is very simple – we'll need only to count the number of pixels that do not have the color black or the color of the borders of the ellipse.

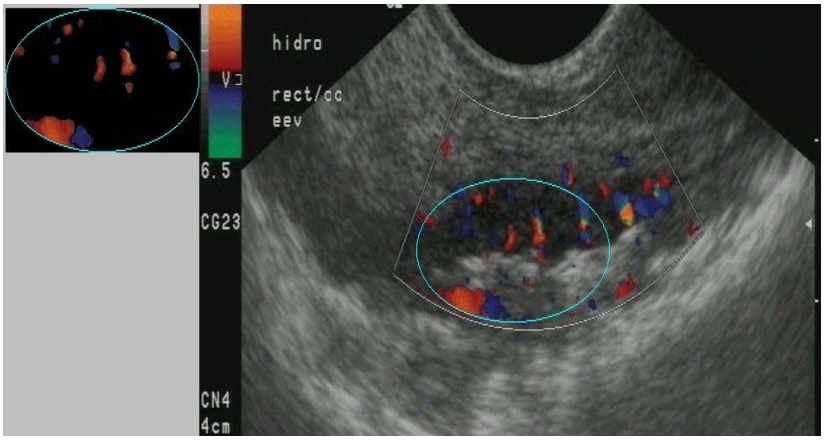


Figure 1. Removal of gray-level pixels and calculating color density within the ellipse

The results of color segmentation with different thresholds are presented in Figure 2, and Figure 3 a), b) and c).:

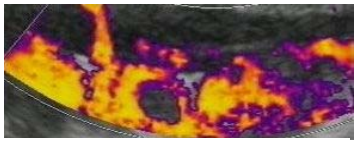
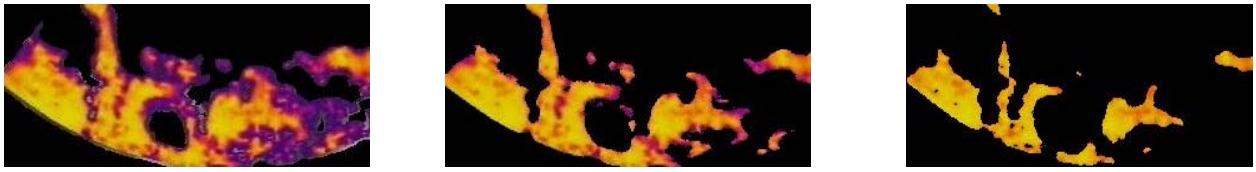


Figure 2 Original ROI



a) threshold of 40 **b) threshold of 120** **c) threshold of 200**

Figure 3. Color segmentation using different thresholds

Estimating the velocity:

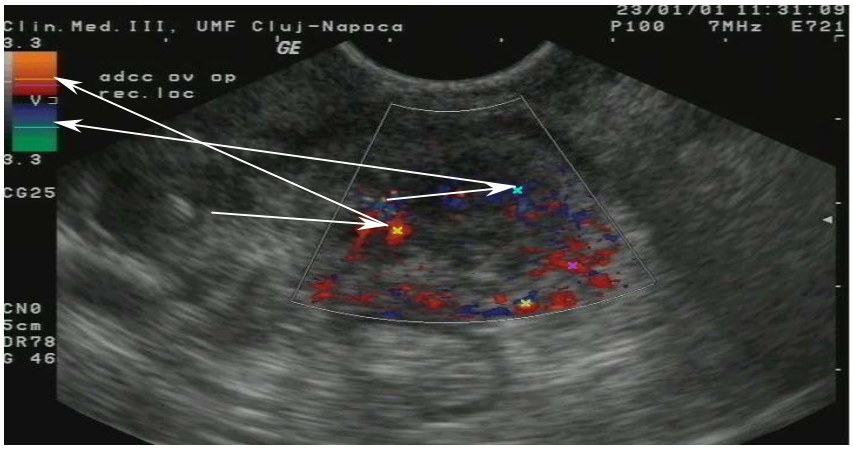


Figure 4. Every colored "x" on the image has a corresponding line on the color scale, which approximates the velocity

Drawing the wash-in wash-out plot within the ellipse is shown in Figure 5; the ellipse was defined on the first frame of the video sequence.

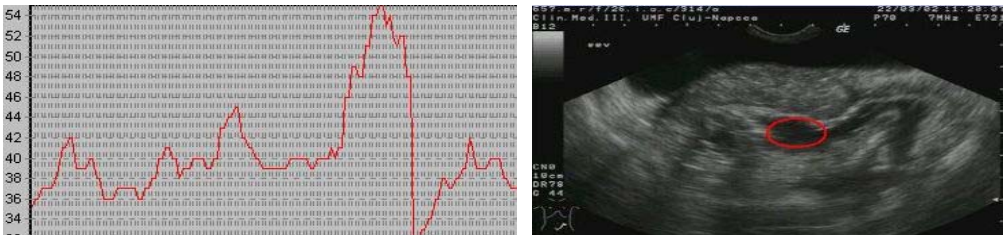


Figure 5. Frame-by-frame computing of mean intensity plot within the ROI

5. CONCLUSIONS

The applicability of our image processing algorithms is continuously tested on a set of color Doppler endovaginal echographic images, as well as on video sequences.

The final objectives are to provide a viable software product, which, in combination with practical experience, helps medical personnel: 1) to locate and classify tumors (as malignant and benign) in such images, and 2) to provide useful data, so the health state of the patient can be observed before and after the chemotherapy.

In our future work we'll try to optimize and enhance the image processing algorithms (especially the tracking of ROI in video processing), and combine these with an image database, so it can be maintained an accurate evidence of the patients and also have a statistics which to be used by the medical personnel to give a more accurate diagnosis.

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