Automatic Echocardiographical Feature Extraction for Left Ventricular Wall Motion and Volume Changes Visualization

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Abstract- **This paper describes a new fully automatic fuzzy multiresolution-based system for cardiac left ventricular (LV) sequence analysis. The edge detection process utilized in the system uses multiscale spatial and temporal information in a fuzzy multiresolution framework to identify a single moving edge point for each one of the epicardial and endocardial boundaries for all frames in a cardiac cycle. The raw extracted boundaries are processed in the wavelet domain and finally scale-space filtering is used to define the close LV boundaries. The system is used to automatically extract ejection fractions and volume changes for real short axis echocardiographic data. The dynamics of the LV wall are also visualized.**

***Keywords* - Echocardiography, LV Quantification and Wall Motion Visualization**

I. INTRODUCTION

There is currently significant demand for automatic quantification of cardiac function using 2-dimensional echocardiographical images. This allows noninvasive determination of LV volumes, ejection fraction and regional wall motion. Most approaches are based upon the identification of the endocardial and epicardial boundaries of the LV cavity on frames coincident with the end-systole (ES) and end-diastole (ED) of the frames recorded in a complete cardiac cycle [1]. The automatic processing of such images is a difficult task due to the poor spatial and contrast resolutions, a high level of speckle noise, and artifacts from such intracavity organs such as papillary muscles and heart valves, dropout inherent in the ultrasound image formation process and image variability.

Linker et al [2]-[4] demonstrated that conventional object detection techniques are not appropriate for echocardiogrphical sequence analysis. Alternative approaches have been proposed for 2DE image analysis in the past including, Simulating Annealing [5], Markov Random Fields [6], Multiple Active Contour Models [7], Artificial Neural Networks [8], Relaxation Principle [9], Optical Flow[10] and Morphological Filters [11].

This paper presents a new fuzzy multiscale-based technique for automatic cardiac left ventricular (LV) epicardial and endocardial boundary detection and tracking on a sequence of echocardiographic frames of a complete cardiac cycle. The proposed method is a center-based approach [12]. Section II describes the complete system. In this section particular emphasis is given to the fuzzy based multiscale edge detection process that is central to the robustness of the method. In Section III the performance of the complete system is evaluated for real 2DE images. Conclusions are given in Section IV.

II. AUTOMATIC ECHOCARDIOGRAPHICAL ANALYZER

The automatic echocardiographical analyzer is illustrated in Figure 1. A complete cardiac cycle is input and each frame is initially analyzed.

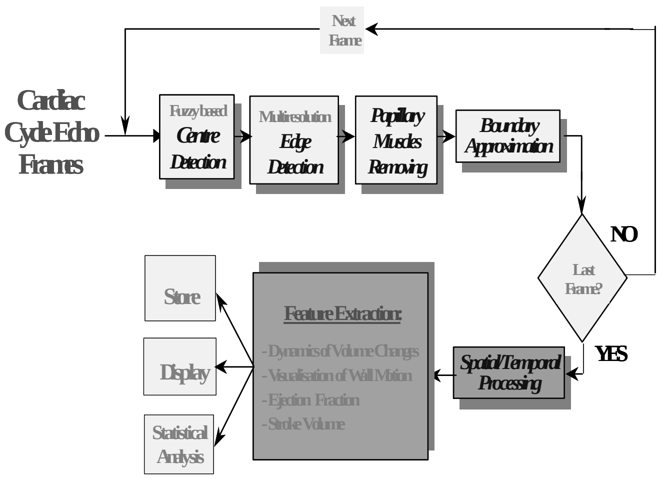

Figure 1: Automatic Echocardiogrphical Sequence Analyser

A. Centre Detection:

An automatic fuzzy based method for estimating the location of the Left Ventricular Centre Point (LVCP) in a single frame of 2DE images was previously developed and presented in [12]. The method incorporates knowledge about the left ventricular geometry, position in the standard echo views, and the image intensity information in a fuzzy based framework to define a few number of candidate pixels for LVCP. The robustness of the fuzzy reasoning based Center Detection process has been described in [12].

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Abstract

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B. Fuzzy Multiresolution Edge Detection:

The edge detection procedure uses a fuzzy multiresolution (FMED) [13] method that simultaneously exploits fuzziness in the spatial and temporal domains.

FMED is a multiresolution edge detection technique in which the signal information at various resolutions is provided using the wavelet transform. Multiresolution edge detection schemes have been developed to not only separate events at different scales of the signal arising from distinct physical processes, but also to solve the problem of deciding on the operator size which is important in making a trade off between the detection and localization performances of edge operators [14].

Generally, in any multiresolution edge detection algorithm the aim is to find an answer to the question ``how to effectively combine the edge information at different resolutions in order to come up with robust edge detection results?" The essence of the FMED technique is the belief that there is ambiguity in edge detection and localization confined to any resolution of the signal at any wavelet scale. The main ambiguity source is the fact that in finer scales the signal to noise ratio is normally poor whereas in the coarse scales the localization ability is the main reason for uncertainty. The novelty of FMED lies in the use of the fuzzy set theory and associated operators to combine the scale information in a fuzzy manner, which has been shown to be superior to the Sobel and Mallat's edge detection techniques in edge detection from very noisy signals [13].

C. Hybrid Fuzzy Temporal FMED for Edge Tracking (HFT-FMED):

Many LV boundary extraction methods rely on using only the image intensity information and are in fact designed for still 2DE image processing. A human expert observer, on the other hand, often uses temporal image sequences as another important a priori source of information, by considering neighbouring frames to not only track the LV borders, but also to effectively pick up the boundary pieces (edge points) in the regions of very poor contrast. Indeed, since many systemic and subjective factors, including time gain compensation and the thickness of the patient's chest affects the gray level intensity of the edge, the motion information over the cycle provides a very useful source of information for deciding where the LV boundary edge points are in a series of 2DEs. This observation motivated us to improve the ability of the fuzzy based edge detection technique (described in the previous part) by using the temporal information of a moving noisy edge. With this aim, we compare three snapshots at times t-1, t, and t+1 of a moving noisy edge together (in groups of two), to define a new fuzzy subset representing the motion information in the signal domain at time t. The resulting fuzzy subset is then used in conjunction with the *Edge* fuzzy set of the FMED technique for edge detection in the signal at time t to form a modified FMED for edge tracking (HFT-FMED) [15].

D. Boundary Extraction and Post Processing:

The papillary muscle artifacts are minimized from the resulting processed frame using multiresolution based median filtering as described by Setarehdan et al in [15]. The extracted boundaries for each frame of the cardiac cycle are finally processed using a further multiresolution approach.

In the present work, we design and use non-linear 2D scale-space and scale-time filters to selectively compress the wavelet coefficients in some particular regions of the wavelet plane by weighting them with different values. Knowledge is applied for appropriate 2D scale-space filter designed for epicardial and endocardial boundaries with reference to the expected angular directions for the very low intensity contrast regions, the expected angular directions for papillary muscles, and finally the expected frequency scales produced by the noisy structures.

Based on the above information and following a statistical study which is carried out on synthetic data to minimize the difference between the computer generated and known defined boundaries, a set of 2D scale-space and scale-time filter characteristics were designed and utilised.

III. RESULTS

This section presents the experimental results of application of the previously described automatic HFT-FMED based technique for epicardial and endocardial boundaries detection and tracking in a sequence of 2DE frames of a cardiac cycle. In all examples presented, the number of scan lines is set to 60. This number has been chosen based on experimental results. Smaller values would increase the missed boundary portions while, the larger values would not lead to noticeable improvements on the contour estimates. The number of echo frames recorded in a complete cardiac cycle is different for different patients and in different situations. Although, it is possible to define the number of frames in a cardiac cycle by simply using an ECG triggered counter, the present work assumes this value as an input, which is defined by inspecting the cardiac cycle.

The real echocardiographic images used in this study were typical SA parasternal mid-papillary muscle level and LA apical two-chamber and four-chamber echocardiographic images obtained from different healthy subjects and in different instants of the cardiac cycle in the Cardiology Department of the Western Infirmary in Glasgow. The images were generated on a HP ultrasound system, which was operating at 3MHz. The images were digitised into 128 gray levels. Figs. 2(a) shows one frame from a set of 25 frames of a complete cardiac cycle. The cycle was processed by the

HTF-FMED based LV boundary extraction and tracking technique and the estimated boundaries of a single frame is shown in Figs. 2(b) superimposed on the real images.

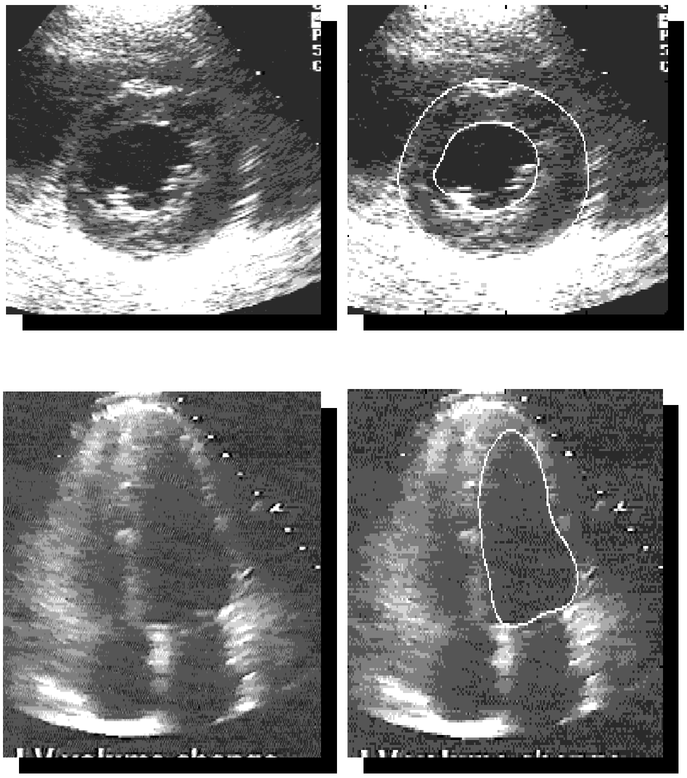

Figure 2(a) Real 2DE SA and LA View

Figure 2(b) Extracted Boundaries using the HFT-FMED

Figure 3 shows the various outputs from the analyzer for a real 2DE SA echo. Figure 3(a) illustrates the extracted boundaries while figure 3(b) illustrates the boundaries in 3-dimensional form following the spatial/temporal filter procedure. Figure 3(c) shows the extent of wall motion that is computed over the complete cardiac cycle. The values in figure 3(d) are those obtained for the end-diastole (EDV) and end-systole (ESV) LV volumes and estimated ejection fraction (EJ) [15]. Finally figure 3(e) illustrates the volume (v) change and dv/dt over three repeated cardiac cycles.

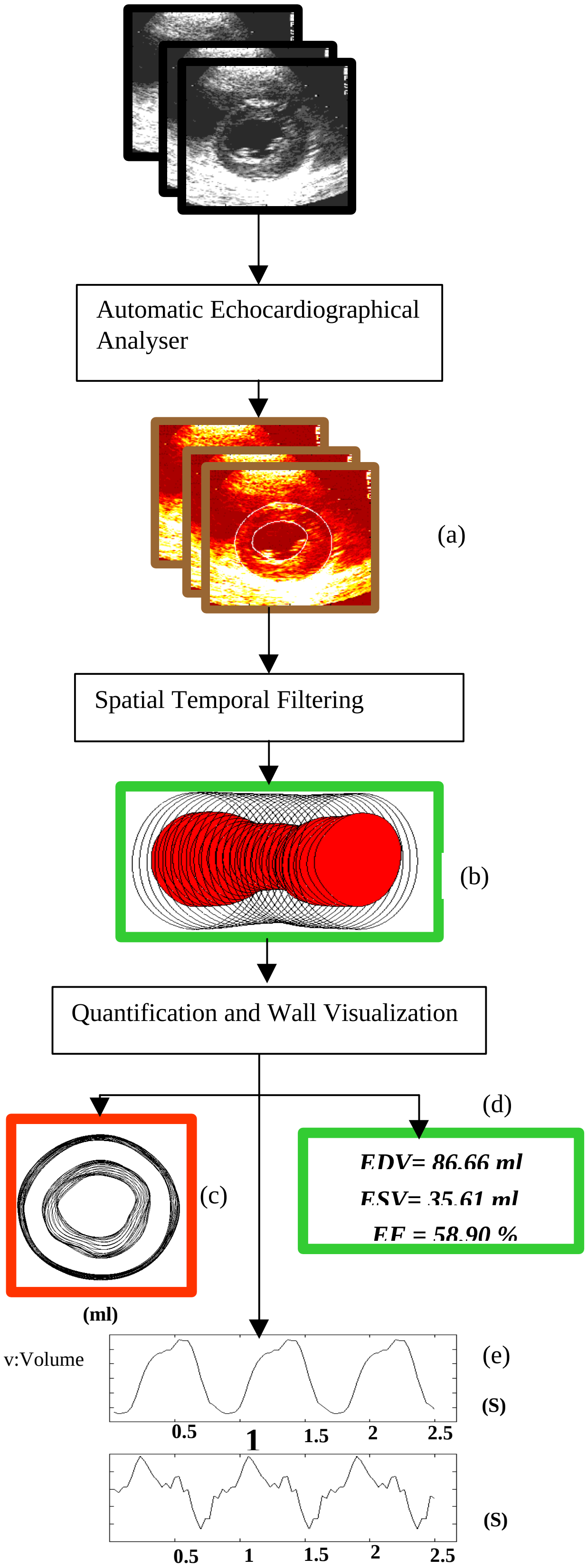

Figure 3 Outputs from Echocardiographical Analyser

IV. DISCUSSION

In this paper a new automatic algorithm for endocardial and epicardial boundary estimation in sequences of SA mid-papillary muscle level echocardiographic images was presented. The algorithm is based on the robust edge detection and tracking technique of HFT-FMED, which uses the intensity and motion information of a moving edge in a fuzzy based framework. HFT-FMED defines a single moving edge point for each one of the epicardial and endocardial boundaries in the frames of a complete cardiac cycle. These build an edge matrix of size for each boundary with the rows representing the spatial and the columns representing the temporal relationship of the edge points in the cardiac cycle.

The prior information on the spatial, temporal and frequency domains properties of the boundaries are then used in a multiresolution based procedure to remove the noisy structures and papillary muscles from the boundaries to define the closed continuous LV boundaries. The algorithm was tested on real echo sequences for LV quantification and LV wall motion visualisation.

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REFERENCES

[1] N.B.Schiller,``Two-Dimensional Echocardiographic Determination of Left Ventricular Volume, Systolic Function, and Mass" *Summary and Discussion of the 1989 Recommendations of the American Society of Echocardiography. Supplement I Circulation*, Vol. 84, No. 3, pp. I280-I287, September 1991.

[2] D.T.Linker, A.S.Pearlman, T.K.Lewellen, L.H.Huntsman, W.E.Moritz, ``Automated Endocardial Definition of 2-D Echocardiograms: A Comparison of Four Standard Edge Detectors and Improved Thresholding Techniques," *Proc. comput. Cardiology*, pp. 395-398, 1982.

[3] C.H.Chu, E.J.Delp, and A.J.Buda, ``Detecting left ventricular endocardial and epicardial boundaries by digital two-dimensional echocardiography," *IEEE Trans. Med. Imag*, Vol. 7, No. 2, June 1988, pp. 81-90.

[4] D.Adam, O.Hareuveni and S.Sideman, ``Semiautomated Border Tracking of Cine Echocardiographic Ventricular Images," *IEEE Trans. Med. Imag*, Vol. MI-6, No. 3, pp. 266-271, Sep. 1987.

[5] N.Friedland and D.Adam, ``Automatic ventricular cavity boundary detection from sequential ultrasound images using simulated annealing," *IEEE Trans. Med. Imag*, Vol. 8, pp. 344-353, Dec. 1989.

[6] J.M.B.Dias and J.M.N.Leitao,``Wall Position and Thickness Estimation from Sequences of Echocardiographic Images," *IEEE Trans. Med. Imag*, Vol. 15, No. 1, pp. 25-38, Feb. 1996.

[7] V.Chalana, D.T.Linker,D.R.Haynor, and Y.Kim, ``A Multiple Active Contour Model for Cardiac Boundary Detection on Echocardiographic Sequences," *IEEE Trans. Med. Imag*, Vol. 15, No. 3, pp. 290-298, June 1996.

[8] I.A.Hunter, J.J.Soraghan, and T.McDonagh, ``Fully Automatic Left Ventricular Boundary Extraction in Echocardiographic Images." *Proc. comput. Cardiology, Vienna*, pp. 741-744, Sept. 1995.

[9] Y.Xin, P.Boekaerts, M.Bister, Y.Taeymans, and J.Cornelis, ``Left Ventricular Boundary Detection in Echocardiographical Images Using Artificial Neural Networks," *6th European Signal Processing Conference*, pp. 1199-1202, 1992.

[10] Y.N.Sun, and C.T.Tsai, ``Segmentation of Echocardiograms Using A Neural Network," *Microprocessing and Microprogramming*, Vol. 35, pp. 791-798 , 1992.

[11] W.S.Chou, C.M.Wu, Y.C.Chen, and K.S.Hsieh ``Detecting myocardial boundaries of left ventricle from a single 2DE image," *Pattern recognition*, Vol. 23, No. 7, pp. 799-806, 1990.

[12] S.K.Setarehdan and J.J.Soraghan, ``Automatic Left Ventricular Centre Point Extraction in Echocardiographic Images", *Signal Processing Journal, EURASIP, Elsevier Science Publications*, Vol. 61, Issue 3, 1997.

[13] S.K.Setarehdan and J.J.Soraghan "Fuzzy Multiscale Edge Detection (FMED) Applied to automatic left ventricle boundary extraction", *Proc 7^th^ Int Conf Image Processing and its Applications, Manchester*, UK, July 1999, pp 552-556.

[14] J.Canny,``A computational approach to edge detection," *IEEE Trans. Pattern Anal. Machine Intell.*, Vol. 8, pp. 679-698, 1986.

[15] S.K.Setarehdan and J.J.Soraghan, "Automatic Cardiac LV Boundary Detection and Tracking using Hybrid Fuzzy Temporal and Fuzzy Multiscale Edge Detection" *IEEE Trans Biomedical Engineering*, Vol 46, No 11, pp1364-1378, Nov 1999.