Echocardiographic Image Sequence Compression Based On Spatial Active Appearance Model

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INTRODUCTION

Echocardiography is a popular medical imaging modality due to its noninvasive and versatile behavior. There are no known side effects, and the measuring equipment is small and inexpensive relative to other options, such as MRI or CT. Reducing storage requirements and making data access user friendly are two important motivations for applying compression to ultrasound images, with the retention of diagnostic information being critical (Chiu, Vaisey, & Atkins, 2001).

A typical echocardiography image consists of a nonrectangular scanned area and a passive background, which may contain patient related text or limited graphics (e.g., a single channel ECG signal). The resulting spatial variation in image statistics presents a hard task to coding methods that use a single partition strategy. For example, many modern image compression algorithms, such as zero-tree coding (Shapiro, 1993) and set partitioning in hierarchical trees (SPIHT) (Said & Pearlman, 1996), are based on the wavelet transform, which partitions the input images into frequency bands whose size decreases logarithmically from high frequencies to low ones. This kind of decomposition strategy works well when the input images are statistically homogeneous, but not in the case of echocardiography image sequences.

Usually the medical applications do not tolerate much loss in fidelity, so the distortion free methods, such as context-based adaptive lossless image coding (CALIC) (Wu & Memon, 1997) have been recently adapted to "near-lossless" situations (Wu & Bao, 2000) with good results. Erickson, Manduca, Palisson, Persons, Earnest, and Savcenko (1998) have compared SPIHT and JPEG methods to compress magnetic resonance imaging (MRI) and ultrasound images. They concluded that wavelet-based methods are subjectively far superior to JPEG compressed at moderately high bit rates. Medical images are typically stored in databases, so it is possible for computers to extract patterns or semantic connections based on a large collection of annotated or classified images. Such automatically extracted patterns can improve the processing and classifying performance of the computers.

In the recent past, researchers in the image analysis community have successfully used statistical modeling techniques to segment, classify, annotate and compress images. Particularly, variations of hidden Markov models (HMMs) have been developed and successfully applied for image and video processing. The key issue in using such complex models is the estimation of system parameters, which is usually a computationally expensive task. In practice, often a tradeoff is accepted between estimation accuracy and running time of the parameter estimation method (Joshi, Li, & Wang, 2006).

Such a statistical information-based estimation highly depends on biological parameters. In our case, the most important task in efficient echocardiography image compression is the accurate detection of QRS complexes from the simultaneously measured ECG signal. Due to the quasiperiodic behavior of the ECG signal and echocardiography image sequences, the parameters of the patient model can be more precisely estimated.

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Active appearance models (AAM), introduced by Cootes, Edwards, and Taylor (2001), are promising image segmentation tools that may provide solutions to most pending problems of echocardiography, as they rely on both shape and appearance (intensity and/or texture) information. Bosch et al. (2002) proposed a robust and time-continuous delineation of 2-D endocardial contours along a full cardiac cycle, using an extended AAM, trained on phase-normalized four-chamber sequences.

To understand the physiology and patho-physiology of the heart, not only the electrical activity and spatial distribution of its structures is important, but also their movement during normal and abnormal cardiac cycles. The ECG signal is measured simultaneously with echocardiography sequence recording in order to localize the investigated events (Szilágyi, Szilágyi, & Benyó, 2007b).

Several papers in the literature have already reported the usage of spatial AAM (Mitchell, Bosch, Lelieveldt, van der Geest, Reiber, & Sonka, 2002; Stegmann & Pedersen, 2005). The present work has the following contributions:

- We developed a heart reconstruction algorithm including time dependent wall boundaries in order to estimate the image variances that allow a better compression rate at a fixed image quality than conventional methods.
- Reported techniques classify ultrasound images only as belonging to systolic or diastolic interval. Our approach distinguishes normal and extra beats, and processes the corresponding images accordingly.

MATERIALS AND METHODS

Simultaneous echocardiography sequence recording and ECG signal measurement were carried out using a 2-D echocardiograph that produces 30 frames per second, and a 12-lead ECG monitoring system that samples at 500 Hz frequency and 12-bit resolution. Each image frame received a time stamp, which served for synchronization with ECG events. Two different series of measurements were recorded. The first series, which served for AAM training, consisted of 35 patients (12 of whom having extraventricular beats), 20 ultrasound sequences for each patient, of 10-15 seconds length each sequence, with previously established transducer placements. Based on these data, an a priori information database was created, which organized the ultrasound images grouped by corresponding ECG events.

The second series of measurements, which involved eight patients, consisted of two stages. In the first stage, the same measurements were performed as were performed in the first series, in order to provide patient-specific training data for the AAM. In the second stage, several measurements were performed using different placements and positions of the transducer. In this order, image sequences were recorded at eight parallel cross sections in horizontal and rotated (45° to the left and to the right) positions with a 1 cm inter-slice distance. We used 10 common axis planes that were placed at front, lateral and back side of the torso. For each patient a total number of $10 \times 8 \times 3 = 240$, at least 2-3 second long image sequences were created.

The duration of the recorded image sequences was restricted by the quasiperiodic behavior of the ECG signal. The spatial movement of the heart is constrained by the course of the depolarization-repolarization cycle (Szilágyi, Szilágyi, & Benyó, 2007a). For example, normal and ectopic beats imply different spatial heart movements. The studied ECG parameters were: shape of QRS beat, QT, and RR distances. These parameters characterize the nature of a QRS complex, and were determined as presented in Szilágyi et al. (2007a). ECG event clustering was accomplished using Hermite functions and self-organizing maps (Lagerholm, Peterson, Braccini, Edenbrandt, & Sörnmo, 2000). Two main event clusters were created: normal and ventricular extra beats. This latter group, because of the patient specific manifestation of ventricular extras, had to be dealt with separately patient by patient. QRS beats not belonging to any cluster were excluded from further processing, together with their corresponding ultrasound sub-sequences. A further condition for normal QRS complexes to be included was having RR distance between 700-800 ms and QT distance between 350-400 ms. A detailed presentation of ECG processing is presented in section (a) in Figure 1 (Szilágyi et al. 2007a).

The time-varying evolution of the cardiac volume is determined by the interconnection of electrical and mechanical phenomena. In a whole cardiac cycle there are two extremity values. The maximal volume can be coupled with the starting moment of ventricular contraction. The moment of minimal volume shortly

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