Image Based Real-Time Monitoring of Cardiac Parameters for Stress Testing or Interventions

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Introduction

Standard cardiac monitoring devices such as the ECG are disturbed by the magnetic field and are of little diagnostic use during MR imaging. Real time updates on heart function and structure during a procedure are critical for interventional cardiovascular MRI as well as cardiac stress testing. A framework for image based physiological cardiac monitoring to assess the global and regional cardiac function in real time [1] is proposed.

Materials and Methods

Image acquisition

Short axis real time images at basal, mid and apical positions were acquired using a real-time TrueFISP (SSFP) shared phases sequence with free breathing. Two healthy subjects (male, 26 female,28) were imaged on a Siemens Symphony 1.5T system TE /α 1.32ms/55, matrix 102x128, Grappa x 2, slice thickness 8 mm, output frame rate 86ms. Seven patients, 2 with previous myocardial infarction (52 +/- 8.5 years, 3 females, 4 males) were imaged using a Siemens Espree 1.5T system (Siemens Medical Solutions, Erlangen, Germany) TE/α 1.37ms/50, matrix 192x144,TSENSE x 4 [2], slice thickness 6 mm, output frame rate 65 ms. For 5 of 7 patients only a mid short axis slice was acquired. The proposed acquisition scheme to monitor global function is shown Figure 1.

Figure 1: proposed acquisition scheme for monitoring

Image Segmentation

Initially the user selects a point in the LV blood pool and a rectangular ROI covering the whole heart. In the learning phase an Expectation-Maximization (EM) algorithm is used to fit 2 Gaussians distributions--one for blood and one for non-blood into the image histogram. After the learning phase (Figure 1) a lookup table is used to assign gray values in an image to blood or non-blood distribution. Afterwards a morphologically open operation is performed to close small holes in the blood pool area and separate the blood pool areas of the LV and RV which might be still connected after the previous EM segmentation step. The LV blood pool is the area covered by the class around the centroid.

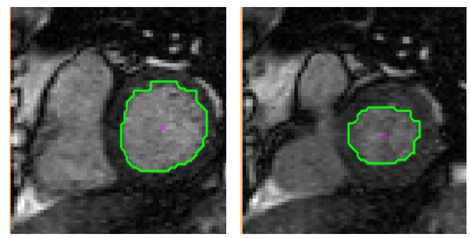

Figure 2: patient with chronic MI (a) ED segmentation, (b) ES segmentation,

Time series analysis and Change detection

The end systolic volume (ESV) and the end diastolic volume (EDV) for each cardiac cycle (Figure 3 (a)) are continuously estimated by Simpson's rule for global EF. For subjects with midventricular images only, parameters were area-based only. The heart rate is taken as inverse of the time differences between two consecutive EDV phases. It is assumed that the volume derived from the segmentation algorithm contains Gaussian distributed measurement uncertainties. Three separate, recursive Kalman filters are used for predicting and correcting the states of EDV, ESV and HR. The respiratory signal was derived by low pass filtering of the blood pool's centroid's displacement. A change occurs if significant differences between consecutive residuals, the difference between the directly measured and the Kalman filtered signal (Figure 3 (b)) are found. A CUSUM [3] algorithm for change detection on the HR and the EF is used.

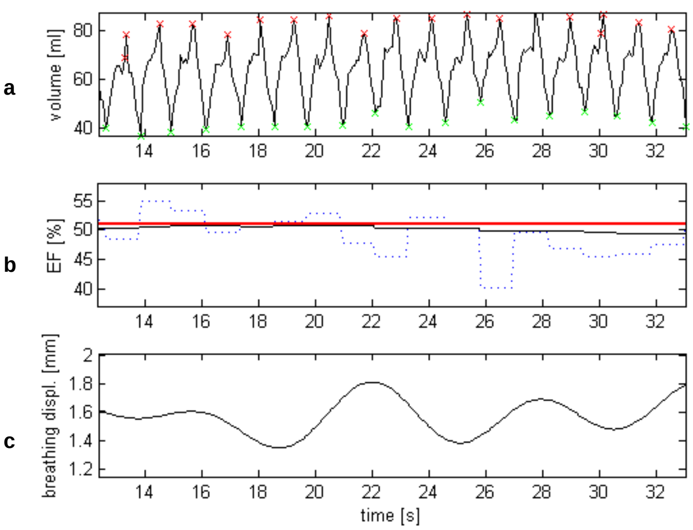

Figure 3: Monitoring data of a 51 year old patient with a chronic MI (a) Time volume curve with estimated EDV (red cross) and ESV (green cross) (b) EF over time: blue dotted line : EF calculated with directly measured EDV and ESV, black thin solid line: EF calculated by EDV, ESV corrected by Kalman filter, red thick solid line: EF calculated by Argus (c) Respiratory signal based on the displacement of the LV centroid

Validation methods

As an initial validation, the segmentation-derived contour data was superimposed on the real time images for a qualitative assessment. A z-test was used to test statistically significant differences intra-patient between the estimated HR/EF the HR recorded by the ECG and EF calculated offline with the post processing software Argus (Siemens Medical Solutions) on a stack of short-axis images acquired before the real time image acquisition. Physiological changes were induced by artificially manipulating the EF and HR signals.

Results

The visual qualitative inspection of the contours on the real time images showed good correspondence for 81% percent of the data. For one mid slice data set the algorithm could not follow the LV area due to a low CNR. The z-test showed that there was no significant difference except in one case in the values obtained for EF and HR. Global EF for volunteers was between 56.7 and 59.9% and patients between 54 and 62%, consistent with the limited volume of the ventricle covered. The change detection system showed either changes in artificially decreased EF or increased HR in locations where they were expected with a low rate of false alarms.

Conclusion and Further Work

The results show the feasibility of a real time framework for global and regional LV function assessment. The proposed monitoring and online change detection of abrupt changes in the EF or HR make it possible to monitor the cardiac physiological function of a patient in real time during an MRI-guided intervention or cardiac stress test without the use of ECG. In an MRI environment image based methods can deliver relevant physiologic information despite the disturbed ECG.

References:
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