Echo Like Inline Display of ECG and Respiratory Signals - Enhancing Diagnostic Capabilities in Cardiac MR Imaging

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Introduction: Assessment of cardiac function using cine MRI is a well established technique, showing high accuracy and reproducibility [1]. Studies are commonly viewed devoid of physiological data even though it can provide significant additional information to aid the interpretation of functional images, as demonstrated by echocardiography, where the combined presentation of the ECG trace with the echo images is common ground for image reading. In addition to the ECG signal MR systems also are capable of monitoring respiratory motion. Here we present an echo-like method for simultaneous recording of ECG and respiratory data, which is integrated in the image acquisition and reconstruction of cine MR images, with the aim of presenting this data in synchrony as graphical overlay together with the cardiac cine images. The availability of respiratory and ECG information in conjunction with the MR images may provide additional clinical value, for example, in monitoring heart rate changes with different respiratory states – e.g. autonomic reflex assessment in the *Valsalva* maneuver.

Methods:

Sequence Design: The complete scheme is designed and integrated on a clinical scanner (MAGNETOM Avanto, Siemens, Erlangen, Germany). The design requirements include continuously sampling physiological signals during the image acquisition and using them during reconstruction to create images with embedded signal traces. The current implementation is targeted for prospectively triggered/non-triggered free-breathing real-time cine and retrospectively gated breath-hold cine protocols. A TrueFisp based pulse sequence is modified to synchronously retrieve ECG and respiratory signal values from physiological monitoring unit (PMU) before every readout event. The resulting sampling rate for PMU data is defined by the echo-spacing of the acquisition, which is typically 2-3 ms for clinical protocols and therefore adequate for the display of ECG/respiratory traces. This information is then passed over to the image calculation environment (ICE, Siemens, Erlangen, Germany) along with each line of k-space data. Within the ICE environment, image reconstruction is performed using a functor-chain, where each functor in the chain implements functionality for one logical step in the reconstruction. Therefore, the PMU signal overlay is performed in three functor steps (Fig 1): 1) *PMUBufferFunctor* buffers the ECG and/or respiratory signal values in the order of acquisition, independent of the k-space reordering scheme. 2) *ImageBufferFunctor* stores images and corresponding header information in memory buffers. Finally, after all the cardiac phases for a specific slice are acquired, 3) *PMUOverlayFunctor* retrieves corresponding PMU data and images from memory buffers, creates a copy of the original image and inserts a graph overlay of ECG and respiratory signals onto every image header. This graph overlay consists of three parts: a trace of ECG and respiratory data, a box indicating the portion of ECG trace when data was acquired for corresponding image and a marker representing the acquisition k-space center line. These overlaid images are then sent out to the display in a separate DICOM series.

Volunteer Study: This implementation is tested in healthy volunteers using a prospectively triggered free-breathing real-time TrueFISP cine and a retrospectively gated segmented TrueFISP cine clinical protocols with the following parameters: Real-time cine - TR = 2.1 ms, TE = 0.9 ms, flip angle (FA) = 53°, slice thickness = 8 mm, matrix = 128x63, FOV = 320x400 mm^2, temporal resolution = 76.6 ms. Segmented cine - TR = 2.6 ms, TE = 1.1 ms, FA = 60°, slice thickness = 6 mm, matrix = 192x192, FOV = 400x400 mm^2, temp. res. = 33 ms (reconstructed). The volunteers were asked to perform a series of different breathing maneuvers to induce heart-rate and breathing pattern variations to test reliability of this approach. A wireless three lead VCG and respiratory cushion unit was used for cardiac and respiratory signal detection.

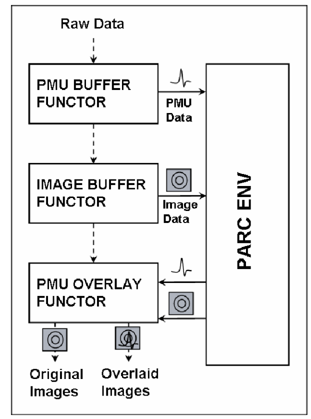

Figure 1: ICE functor chain. The first two functors respectively buffer physiological data and images into memory. The third functor utilizes these buffers to produce images with embedded physiological data traces.

Results: Fig. 2 shows the resulting images with the overlay of physiological data for real-time and segmented cine acquisitions. On the real-time cine images, an ECG trace and a respiratory signal trace are displayed for complete duration of acquisition for the corresponding slice. Whereas, for the segmented cine acquisitions, there is one ECG trace displayed for each heartbeat that was used in the acquisition of that slice. Different lengths on ECG traces for the segmented acquisition indicate variation in heart-rate. Additionally, graph overlays are part of the image header and not the pixel data. Consequently, their display location remains unaffected by window/level or zoom/pan settings of the corresponding image, which aids the visualization significantly.

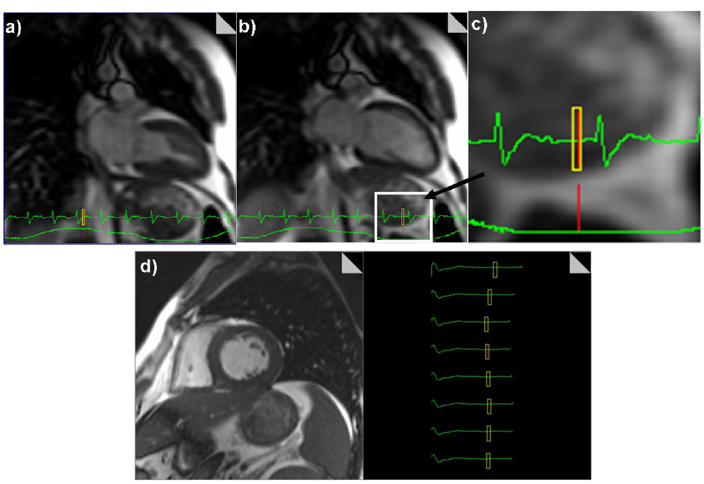

Figure 2: Real-time cine images acquired in a) systole and b) diastole are shown with an embedded ECG signal trace (upper trace) and a respiratory signal trace (lower trace), c) provides a closer look at these signal traces. The yellow box encloses the part of ECG trace when the corresponding image was acquired. The red line marks the acquisition of k-space center line on both the ECG and respiratory trace. d) segmented cine with each heartbeat displayed as a separate ECG trace. The variations in R-R interval can be clearly inferred from differing lengths of traces.

Discussion: Recording of ECG and respiratory data within cine images could be successfully demonstrated in healthy volunteers. Visual assessment of the overlaid images confirms the correspondence between image appearance and ECG/Respiratory states. Potential applications include monitoring of arrhythmia and its impact on image quality in the context of segmented data acquisition. In real time imaging, assessment of dyskinesis is facilitated by the presentation of the ECG with the image data so that true ECG indications of events within the cardiac cycle can be used for enhanced evaluation of wall motion abnormalities. However, the underlying assumption in this implementation is that PMU provides reasonably accurate signal information without significant drifts or delays. Moreover, the magneto-hydrodynamic effect could potentially distort these signals[2]. Nevertheless, if accurate signal information is available, it can be extended to retrospectively edit the k-space data based on irregular physiological trace patterns such as arrhythmia and improve the image quality, as it is currently already done with CT data.

References: [1] Longmore DB, Lancet, 1985. [2] Tendforde TS, Bioelectromagnetics, 1983.