Prediction of heart rate variation during coronary MRA, using a neuronal network

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Introduction:

In electrocardiographically (ECG) triggered coronary MRA data acquisition is limited to a short cardiac rest period during mid-diastole. Prior to the scan the trigger delay between the R-wave of the ECG and the data acquisition has to be set to a fixed value, dependent on the actual heart-rate (HR) of the patient [1]. However, HR and therefore trigger delay can vary considerably over scan time due to several factors, such as nervousness of the patient or respiratory induced synchronous variations of the HR, which is a well known phenomenon [2]. Consequently this HR variability directly influences the cardiac rest period and the optimal trigger delay. To ensure that data acquisition always takes place during mid-diastole, the trigger delay needs to be adapted in real-time to changes of the HR.

We therefore developed a trigger delay prediction algorithm using the concept of a neural network. Based on the respiratory motion pattern (measured by the MR-navigator) and the related changes of the HR, the network calculates the duration of the upcoming RR-interval and its related trigger delay increase or decrease. The in-vivo feasibility of the approach is demonstrated

Methods:

For the prediction of the next RR-interval a neural network with six input neurons, one output neuron and a linear transfer function were used. The relative differences of the last seven navigator values were given as input values. As output the network provided the difference between the last measured RR-interval and the one to be predicted. Since neural networks are learning systems, a training phase was needed, which was performed with the data provided by an ECG triggered localizer scan, typically used for planning of the coronary MRA. Since HR variability is patient specific, the network was trained separately for every subject. As training function the Widrow-Hoff learning algorithm [3] was used. Given RR_i as the duration of the i-th cardiac cycle and N_i as its corresponding respiratory navigator, the network predicted the duration of the next RR-interval RR_{i+1} by:

$$RR_{i+1} = RR_i + w_1(N_i – N_{i-1}) + w_2(N_{i-1} – N_{i-2}) + \dots + w_6(N_{i-5} – N_{i-6})$$

with the coefficients $w_1,\dots w_6$ (weights) determined by the network in the training phase.

First, simulations were performed in Matlab (The MathWorks, Natick, MA, USA) using respiratory navigator data and corresponding cardiac cycle durations, recorded from in-vivo measurements in six healthy subjects. Thereby the accuracy of the trigger delay prediction by the neuronal network was compared with errors induced by a conventional, fixed trigger delay selection. In a second step, the neuronal network together with the training algorithm was implemented on a 1.5T Philips Intera and the RR-interval prediction was tested in first experiments on two healthy subjects. For imaging, a 3D free-breathing navigator-gated steady-state free precession sequence was used. Additional scan parameters were: 270mm^2 field of view, 272x272 matrix, T2-prepared, fat-suppressed, TR = 5.1ms, TE = 2.6ms, flip angle = 75°, 16 excitations per cardiac cycle.

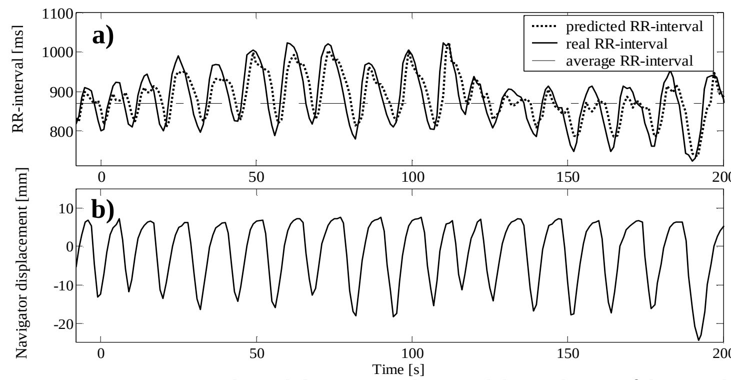

Figure 1: RR-interval variability in one subject and the prediction of the neural network (a). Note the good correlation between RR-interval variations and respiratory navigator (b).

Results:

RR-interval prediction by the neural network could be successfully applied in vivo. The network was able to learn the relationship between respiratory navigator and HR variability and predicted the changes of the patients HR accurately (Figure 1). As a consequence, the trigger delay errors for each cardiac cycle can be minimized, when compared with a predefined fixed value. As demonstrated by the simulation results (Figure 2) these trigger delay errors depend heavily on the pre-estimation of the average HR (Figure 2). Example angiograms with and without adaptive trigger delay are shown in Figure 3.

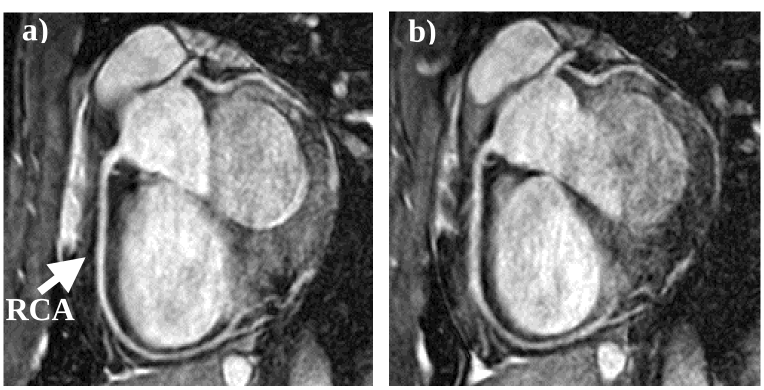

Figure 3: Comparison between coronary MRA's obtained with a) a prospective trigger delay adaptation, calculated in real-time by a neuronal network and b) the conventional approach, where the trigger delay is set to a fixed value.

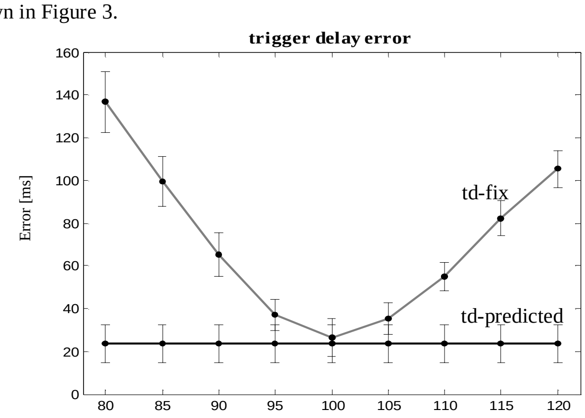

Figure 2: Conventionally, the trigger delay has to be set prior to the scan, according to the expected average HR. This may lead to large delay errors, if the HR is under- or overestimated (100% = average HR). Using the real-time trigger delay adaptation, the mean absolute trigger delay error becomes independent of any estimation about the expected average HR

Conclusions:

A neural network for real-time adaptation of the trigger delay by prediction of the next RR-interval was implemented and successfully tested in first in-vivo measurements. The network follows the patient specific changes in the HR. Hence no pre-estimation of the average expected HR and its related trigger delay, is needed.

References: [1] Stuber M. et al. Radiology **212**: 579-587 (1999)
[2] Hayano, J. et al, Circulation **94**: 842-847 (1996)
[3] Hagan, M. T. et al., Neural Network Design, Boston, MA: PWS Publishing, 1996.