Trigger delay adaptation during coronary MRA by prediction of heart rate variations

M. Buehrer[1], S. Kozerke[1], P. Boesiger[1]

[1]Institute for Biomedical Engineering, University and ETH Zürich, Zürich, Switzerland

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.

This work presents two trigger delay prediction algorithms. The first one uses the concept of a neural network which calculates the duration of the upcoming RR-interval and its related trigger delay based on three previous RR-intervals. The second algorithm predicts the upcoming RR-interval as the average of the five previous RR-intervals. Both algorithms were tested relative to a constant trigger delay on healthy volunteers.

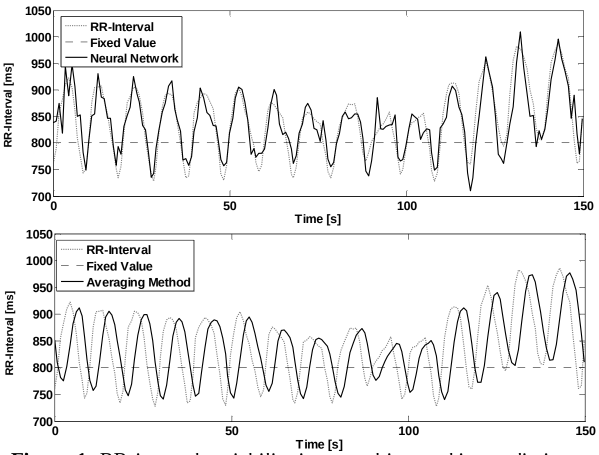

Figure 1: RR-interval variability in one subject and its prediction. (a) The neural network prediction. (b) The averaging method.

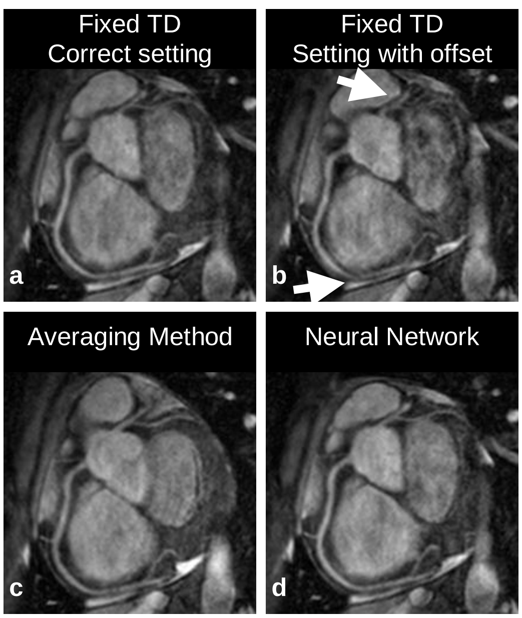

Figure 3: Comparison between coronary MRA's obtained with a) a fixed trigger delay correctly set (estimation = 70bpm, true value = 67bpm), b) a fixed trigger delay with an offset (estimation = 80bpm, true value = 68bpm), c) the averaging method, d) the neural network prediction of the trigger delay.

Methods

The neural network consisted of three input neurons, two layers of ten hidden neurons and one output neuron. The three previous RR-intervals were given as input values. As output the network provided the predicted RR-interval. Since neural networks are learning systems, a training phase is needed, which was performed after the navigator preparation phase of the scan using all available RR-interval data recorded during the preparation phase. Furthermore, the network was retrained after every detected trigger in the ECG with the most recent data available. With the averaging algorithm, the actual RR prediction was based on an average of the five previous RR-intervals.

To test both algorithms, simulations were performed in Matlab (The MathWorks, Natick, MA, USA) using data which were recorded from ten different in-vivo measurements of five healthy subjects. Thereby the accuracy of the trigger delay prediction from the neuronal network was compared with errors induced by a conventional, fixed trigger delay selection and the averaging method. In a second step, the neuronal network, as well as the averaging method were implemented on a 1.5T Philips Intera system (Philips Medical System, Best, NL) and the RR-interval prediction was tested in first experiments on one healthy subjects. For imaging, a 3D free-breathing navigator-gated steady-state free precession sequence was used. Scan parameters were: 270mm^2 field of view, 272x272 matrix, T2-preparation, fat-suppression, TR = 5.1ms, TE = 2.6ms, flip angle = 75°, 16 excitations per cardiac cycle.

Results

The simulation results showed that the neural network was able to learn the relationship between the previous RR-intervals and the upcoming one and predicted the changes of the patients HR accurately (Figure 1). As a consequence, the trigger delay errors for each cardiac cycle could be minimized, when compared with a predefined fixed value. The averaging method performed worse than the neural network but still better than a fixed value (Figure 2). Also RR-interval prediction by the neural network and the averaging method could be successfully applied in vivo. Example angiograms with and without adaptive trigger delay are shown in Figure 3. It is seen that the image quality when using a fixed value is highly dependent on the estimation of the cardiac frequency while the prediction algorithms are more robust. The vessel sharpness [ref. Botnar] in the four different cases was as follows: Fixed TD: 39.3%, Fixed TD with offset: 37.3%, Averaging Method: 38.1%, Neural Network: 40.0%.

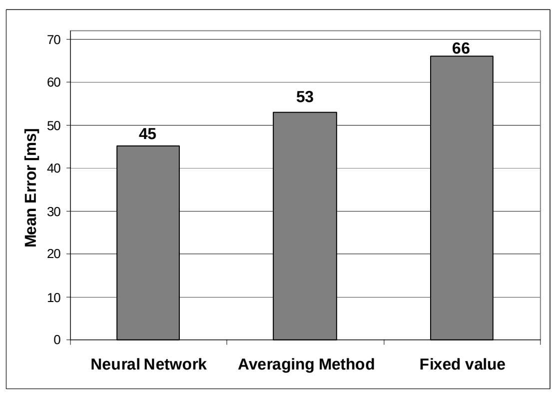

Figure 2: The trigger delay errors for all three different methods based on simulation results. The average errors over all ten different datasets are shown.

Discussion

Both the neural network as well as the averaging method for real-time adaptation of the trigger delay were successfully tested in first in-vivo measurements. Both algorithms followed the patient specific changes in the HR with good accuracy. Further studies are warranted to validate the algorithms in a larger study population.

References

[1] Stuber M. et al. Radiology **212**: 579-587 (1999) ; [2] Hayano, J. et al, Circulation **94**: 842-847 (1996)