Improving Patient Monitoring during Magnetic Resonance Imaging: Real-time Restoration and Analysis of the Electrocardiogram

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Object

The ECG used for patient monitoring during MRI unfortunately suffers from severe artefacts. These artefacts are not the same as seen during standard patient monitoring and are due to the special environment of MRI. A modelling of these artefacts may help in finding solutions for the suppression of these artefacts that are superimposed the ECG signal. Therefore, the Linear and Time Invariant system of the generation of magnetic field gradient artefacts was validated during our work. We applied filters based on the Linear and Time-Invariant system for the offline and online suppression of the remaining superimposed artefacts during worst case scenarios. We studied and analysed the suppression performances of these algorithms. We used them to measure real-time analysis performance of the ECG acquired during MRI. The Wiener filtering was used to generate reference annotations of the ECG beats. The LMS filter suppressed the magnetic field gradient artefacts online before the restored ECG signal was fed into the beat and rhythm algorithm (arrhythmia module) in real-time. An significant improvement of the arrhythmia module performance was found enabling reliable patient monitoring and MRI synchronization.

Methods and Materials

Offline suppression was done by Wiener filtering (1). The impulse response of the magnetic field gradient artefact generation was calculated after complete acquisition of the ECG signal or after a training sequence. The suppression was done online based on the noise canceller configuration. Online suppression was done by an adaptive filter based in the LMS filter and noise canceller configuration (1). QRS detection and beat annotation was performed with the real-time arrhythmia module (SCHILLER AG, Baar, Switzerland). The performance measurements were done on the SAEC system (2), which is a LabVIEW RT environment (National Instruments, Austin, Texas) with all algorithms linked as DLL (originally written in C). Reference annotations were done using the AnnoTool written in Matlab (Mathworks, Natick, MA). Annotations performance measurements were taken using the PhysioToolkit (www.physionet.org) as described in (3). The ECG signal was acquired using the ECG sensor of the Maglife patient monitoring system (SCHIILER Médical, Wissembourg, France). The MRI was a 1.5 T Excite HD machine (GE, Milwaukee, WI).

Results

The amplitude of magnetic field gradient artefacts using Wiener filtering (offline suppression) was 87% for 95% of 234 measurements. The amplitude reduction using the LMS filter (online suppression) was between 80% and 100% depending on the measurement (ECG simulator, ECG acquired on arms or legs and clinical ECG signal acquisition). The trigger sensitivity of the arrhythmia module improved from 91.7% to 99.7% (positive prediction improved from 88.2% to 99.5%) using real-time magnetic field gradient suppression (1496 beat were annotated). Further, the extra systole positive prediction improved from 12.7% to 61.0% (false positive rate improved from 16.7% to 1.6%).

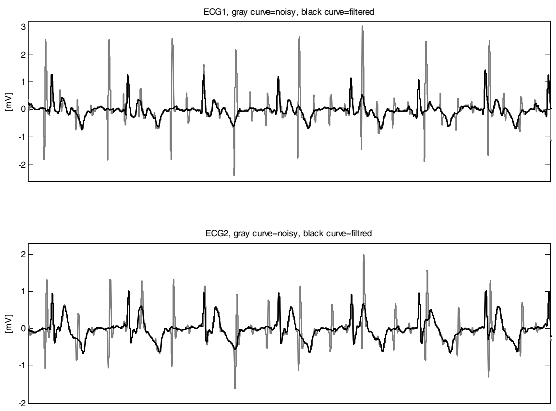

Fig. 1 Example of offline magnetic field gradient suppression using Wiener filtering (Grass sequence, FOV = 10 cm, head image, ECG electrodes horizontal on thorax). The artefact amplitude reduction is greater than 99%. The suppression is so good that the offline method can be used as reference method for comparison and performance measurement for online suppression algorithms.

Conclusions and Summary

Magnetic field gradient artefact suppression algorithms improve patient monitoring during MRI. The offline suppression is good enough to help during annotation of an ECG with artefacts acquired during MRI. Furthermore, it may help improving the performances of the online suppression. The LMS filter allows reliable ECG signal analysis (HR calculation, beat and rhyme analysis) after convergence, and the ECG signal displayed can be interpreted by sight. Retrospective and prospective synchronization of the MRI directly profits from our results. A larger performance study (including more abnormal ECG beats and arrhythmias) is our next aim.

References

1) Widrow B et al, Adaptive Signal Processing. Oppenheim AV, editor. New Jersey: Prentice-Hall; 1985.
2) Odille F et al, Signal Analyzer and Event Controller (SAEC) for improved patient monitoring and optimum synchronization of MR acquisitions. Journal of Magnetic Resonance Imaging submitted
3) Testing and reporting performance results of cardiac rhythm and ST-Segment measurement algorithms. ANSI/AAMI EC57