In vivo 7T MR imaging triggered by phase information obtained from video signals of the human skin

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Target audience: Clinicians and scientists interested in contactless pulse triggering methods.

Purpose: Subtle color variations of the human skin due to the pseudo-periodic influx of blood allow the estimation of cardiac activity from video signals [1]. Recently, it has been shown that a cardiac signal can be extracted from a video stream recorded by a MRI in-bore camera. By applying frequency filtering [2] and magnification [3] techniques, a signal comparable to the one obtained by pulse oximetry can be obtained. This approach offers the possibility to overcome the limitations of contact-based triggering hardware such as pulse oximetry or electrocardiography, namely interferences at high field strengths, limited application areas, and preparation time.

The purpose of this work is to evaluate the feasibility of real-time pulse triggering using a video signal of the well-perfused forehead. In contrast to previous approaches without triggering that rely on frequency processing of averaged pixel intensities over time, we present a method that incorporates phase information for trigger computation.

Method: The method relies on two assumptions: (a) The subject is in sinus rhythm and has a heart rate in the range of 48 to 180 bpm; (b) The acquired signal of the skin color variations is pseudo-periodic similar to the cardiac cycle and exhibits a distinctive peak in the Fourier spectrum which is associated with the cardiac activity.

A MRI in-bore camera *(12M-i, MRC Systems, Heidelberg, Germany; B/W, 720x576 pixel, 25 fps)* was installed above the subject's head in a 7T scanner *(Magnetom 7T, Siemens, Erlangen, Germany).* An off-the-shelf video projector was used to provide illumination inside the bore. An algorithm was developed in C^{++}11 using its multi-threading capabilities and the OpenCV [4] and ROOT [5] libraries. Before starting the application, a fixed 400x400 pixel region-of-interest (ROI) was manually placed to cover most of the subject's forehead. The algorithm consists of two parallel threads: (T1) The first acquires individual frames from the camera, computes the mean pixel value inside the ROI, and writes each value into a list, filling it from front to back; (T2) The second thread continuously fetches the mean values from the list in back to front order (time-reversed) and normalizes the amplitudes to lie between 0 and 1. According to assumption (a) and the frame rate FPS=25 of the camera, there is a large margin between the highest frequency of interest 3Hz≡180bpm and the Nyquist frequency of 12.5Hz. It would be sufficient to use N=32 frames to capture the lowest frequency $(N*FPS^{-1})^{-1}$ ≈0.78Hz≡46bpm of interest; however, in order to increase robustness a four times greater interval M=128 was used, which corresponds to a signal length T=M/FPS=5.12s. To reduce spectral leakage, a Hamming window was applied and the signal was zero-padded to a length of 256 before applying the Fast Fourier Transform. After obtaining the spectrum F(k) with k=0,1,2...,255 bins, only the interval of expected heart rates l=9,10,...,30 according to assumption (a) was considered. From the magnitudes of the remaining bins |F(l)|, the bin with the maximum value at frequency f_{peak} [Hz] was detected and the corresponding phase angle ϕ_{peak} [deg] was obtained from the same bin considering the phase spectrum ∠(F(l)). The bin of f_{peak} was smoothed over 4M frames using a moving average to increase robustness. Finally, the delay Δt [s] until the peak of the next blood influx occurs was computed using $\Delta t = \phi_{peak}/(360*f_{peak})$ if $\phi_{peak}>0$ and $\Delta t = f_{peak}^{-1} - |\phi_{peak}/(360*f_{peak})|$ otherwise. After waiting Δt seconds, a trigger was issued if the time elapsed since the previous trigger was larger than the minimum delay between two heart beats according to (a). If the maximum delay was exceeded, a trigger was enforced.

The triggers computed from the vendor-provided pulse oximeter and with our algorithm were saved simultaneously during nonenhanced MR angiography of the lower extremities of one volunteer (m, 30 years), who fulfilled the first assumption. The measurement protocol incorporated 60s of no imaging and 60s of imaging followed again by 60s of no imaging.

Results: Fig. 1) shows the setup in the MR bore and Fig. 2) shows measurement results. The course of the triggers obtained by pulse oximetry is reproduced by the proposed algorithm; however, triggers are missed at the beginning due to an insufficient number of values needed for accurate computation of f_{peak}. While the pulse oximeter is heavily distorted during imaging, triggers computed from our method are more robust. Inaccuracy of our approach occurs during the last third of measurement due to head motion of the volunteer.
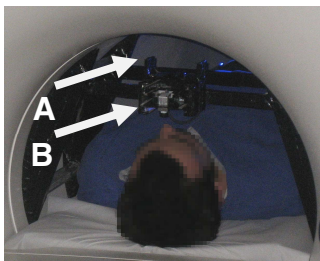
Fig. 1) Experimental setup in the 7T MR bore: **A)** Light from video projector **B)** Camera
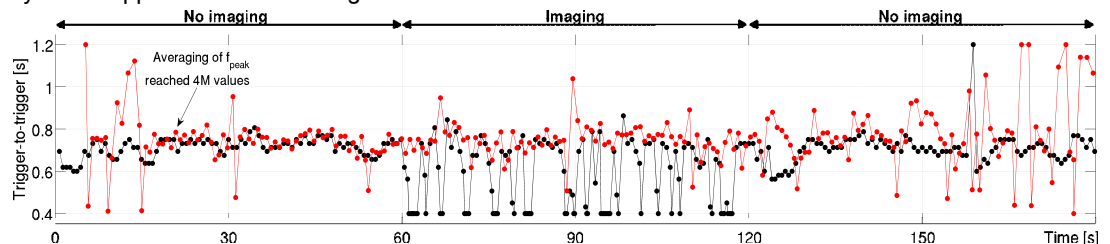
Fig. 2) Elapsed time between two successive triggers based on vendor-determined pulse oximetry (black dots) and based on our algorithm (red dots). The first triggers of our algorithm occur after T=5.12 seconds. Stable results are obtained after 4M frames, corresponding to 20.48s. Values are cropped to the trigger spacing interval [0.4,1.2]. During the time interval 20-60 seconds, the mean and standard deviation of trigger spacing from pulse oximetry (0.73±0.03) are quantitatively similar to the trigger spacing computed by our algorithm (0.74±0.07).

Discussion and Conclusion: These initial results suggest that our approach (1) is able to reproduce the triggers obtained by pulse oximetry, (2) outperforms pulse oximetry triggering in case of interference caused by gradient vibrations during 7T nonenhanced MR angiography, and (3) suffers in the case of patient head movement, which may require additional work such as motion correction.

References: [1] Verkruysse, et al. Opt. Express 2008 16(26) [2] Maclaren, et al. Proc ISMRM 2014 #0890 [3] Spicher, et al. Proc ISMRM 2014 #4824 [4] http://opencv.org/ [5] http://root.cern.ch