Advantages of digital vs analog accelerometer-based sensor for respiratory motion correction

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Introduction:

Physiological motions influence considerably MRI image quality of moving organs by generating ghosting and/or blurring artifacts. To reduce or decrease their influence on the resulting image, information about the motion of imaged organs must be either included in prospective or retrospective method. For both, use of external or internal motion sensors capable of providing highly correlated information with imaged organ motion is needed. In MRI environment, due to several practical advantages (non-magnetic and low cost), pneumatic belts are most often used for respiratory motion monitoring. However, their main shortcomings such as signal drifts and leaks in pneumatic circuit and only delivering average displacement information of the underlying region limit their use especially as inputs in advanced image processing tools used for motion artifacts correction [1]. An alternative to these sensors based on use of accelerometers has already been proposed [2]. This MR-compatible accelerometer-based sensor provides precise information about the motion of a spot on which it is placed and in combination with other scattered sensors on different spots it gives useful information for motion compensated algorithms [3]. However, one of the main drawbacks of the proposed solution are fixed parameters of used instrumentation chain making it less adapted for some volunteers whose respiratory motions are smaller in magnitude. We propose a solution for this problem.

Materials and Methods:

The synoptic scheme of the external accelerometer-based sensor allowing dynamic changing of instrumentation chain parameters adapted to examined volunteers is presented in Figure 1. It is based on previous version of the sensor (black blocks). The main difference is added microcontroller unit (red block) introducing a capability of real-time changing of acquisition parameters directly from data acquisition system (magenta fatter-line link) and the simplified data transmission protocol (optical serial connection) which initially was based on Pulse-Width Modulation (PWM). The acquisition parameters can be changed manually during the examination depending on the magnitude of the delivered acceleration signal, which is patient / volunteer dependent. The fact that either offset can be changed during the data acquisition allows also decreasing of the influence of electromagnetic interferences (EMI) on instrumentation chain, often characterized by a DC offset which often occurs in MRI environment. The sensor output consists of an acceleration signal of the underlying region, in the direction perpendicular to the sensor. In order to derive displacement information, a double integration has to be performed.

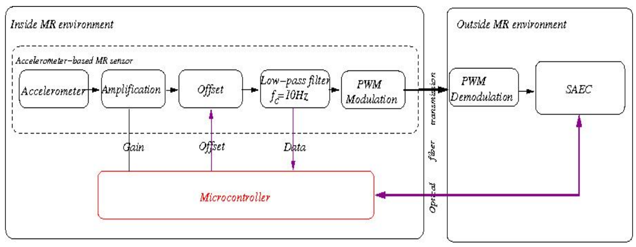

Fig.1: Synoptic scheme of proposed sensor based on previous version (black blocks)

To evaluate the proposed sensor, the first tests were performed on phantoms with a homemade mobile platform. This platform is composed of a removable part for the vertical translation motion and of a respirator that provides the inflation of an anesthesia balloon placed under the removable part. We also placed the previous accelerometer-based sensor onto the platform to compare it to the proposed one. The tests were carried out with the same parameters of sequences for phantoms and volunteers. Six SSFP sequences were realized with different magnitudes and frequencies of the respirator to simulate different respiratory modes.

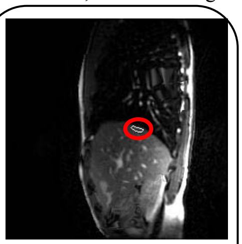

Fig.2: ROI used for displacement extraction

For the second test, a test protocol accepted by the ethics committee was implemented. Its main focuses are on comparison between accelerometer signals obtained from the previous and proposed solution, with respiratory signals obtained with pneumatic belts and fast imaging techniques. Ten healthy volunteers underwent a chest examination on a 1.5T or on a 3T MR scanner (Signa HDxt, GE Healthcare, Milwaukee, WI). Five of them (2 females and 3 males, age: 40± 16, weight: 68.4± 10kg, BMI: 23± 4) have the first accelerometer-based sensor with PWM modulation and the other five (2 females and 3 males, age: 29± 8, weight: 73.8± 13kg, BMI: 24± 3) have tested the new sensor with the microcontroller. For each subject, several temporal series in a sagittal plane were acquired with an SSFP sequence. The series were acquired in different respiratory modes, including breath-hold, free breathing and deep breathing. The corresponding accelerometer-based sensor was placed on the abdomen. All physiological signals were acquired and recorded using home-made data acquisition system - SAEC (*Signal Analyzer and Event Controller*) [4]. With the purpose of extracting diaphragmatic respiratory motion information directly from the image series, motion detection was performed with a Brox optical flow method [5] on every image series. The resulting respiratory signals were extracted from a region of interest (ROI) selected manually in the left upper part of the liver (*Fig.2*).

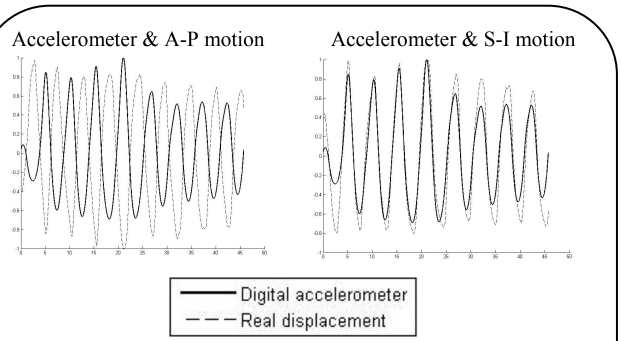

Fig.3: Normalized signals of real displacement (dotted black) and digital accelerometer in deep breathing.

	vs A-P motion		vs S-I motion	
	Deep breathing	Free breathing	Deep breathing	Free breathing
Acc Ana	0.78 (0.18)	0.71 (0.19)	0.75 (0.21)	0.82 (0.07)
Acc num	0.87 (0.12)	0.82 (0.10)	0.89 (0.08)	0.83 (0.09)

Table 1: Absolute value of correlation coefficient between internal displacement and signals extracted from either analogical accelerometer (Ana) or digital accelerometer (Num).

Results:

Table 1 illustrates a comparison between internal displacement signals extracted from the image series (*A-P and S-I motions*) and the signals from external sensors, comprising displacement signals estimated by the previous sensor (*Acc Ana*) and by the new one (*Acc Num*). As a quantitative measure for comparison, an average of correlation coefficient of the five volunteers for deep breathing and free breathing was used. It can be seen that the digital accelerometer-based sensor is better correlated to image-based displacement measures than the previous version. In the previous sensor, some problems appear when the volunteer had a low magnitude of respiration because of the fixed gain which could partly explain the difference in term of correlation coefficient between the two solutions. A snapshot of results obtained with the digital accelerometer on volunteers is presented in *Fig.3*. It can be shown that this sensor is well correlated with the internal displacement.

Conclusion:

This work is an amelioration of the previous accelerometer-based sensor. The addition of a microcontroller contributes to better adjustment of the amplification gain and offset which are necessary for some volunteers. In this form, this sensor can be used to measure other motion types with high or low magnitudes.

References: [1] Rousselet *et al.*, ISMRM 5024, (2010); [2] Rousselet *et al.*, ISMRM 1550, (2010); [3] Odille *et al.*, MRM. 60: 146-157 (2008); [4] Odille et al., IEEE T Bio-Med Eng April: 54 (4), (2007); [5] Brox *et al.*,Computer Vision-ECCV, pp25-36, (2004);