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Optical cardiac and respiratory device for synchronized MRI on small animal

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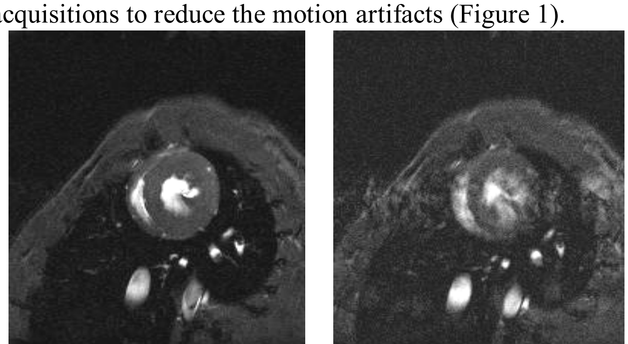
Abstract—**Respiratory and cardiac motion must be overcome if MRI of the thorax or abdomen is to be performed satisfactorily. An optical-based device designed to synchronize MRI acquisition on small animal was developed using a pair of optical fibers. Light from a laser diode was focused into the transmit fiber and impinged upon the moving skin. The reflected light was detected by the receive fiber and then caries to a light-voltage photodiode, were the signal was amplified and filtered. The recorded optical-based signals are well correlated with both respiratory and heart motions. The signal amplitude recorded on both rats and mice were large enough to perform an easy adjustment of gating level with good differentiation between cardiac and respiratory signal. The device developed using thin fibers is simple to use even when space available around the mice is limited (narrow coils). The signal is totally unaffected by radiofrequency impulsions or magnetic field gradients used for imaging.**

This optical-based trigger system was used successfully for dual cardiac and respiratory synchronization of rat and mice for heart and liver examinations at 4.7T.

I. Introduction

Magnetic resonance imaging (MRI) is one of the major modality used for diagnosis both on human and small animals. However, MRI on living organism involves the monitoring of both respiratory and heart motions in the thorax and abdominal region in order to synchronize acquisitions to reduce the motion artifacts (Figure 1).



a) b)

Figure 1. Images of heart obtained on normal rat: a) with dual cardiac and respiratory triggering; b) without synchronization.

Today, the signal conventionally used to measure cardiac cycle is the electrocardiograph (ECG) signal. However, this electric signal is affected by radiofrequency field used for MR imaging as well as by the magnetic field gradients applied for image encoding [1]-[4]. Because of the weak amplitude of the ECG signal recorded on small animals, it is difficult to obtain an uncorrupted ECG.

For respiratory motion, an air cushion [5] associated to a pressure sensor is commonly used (Figure 2). However because it has relatively large dimension, it is limited to be used within narrow diameter coils or with dedicated phased array coils that are in close contact with animal skin.

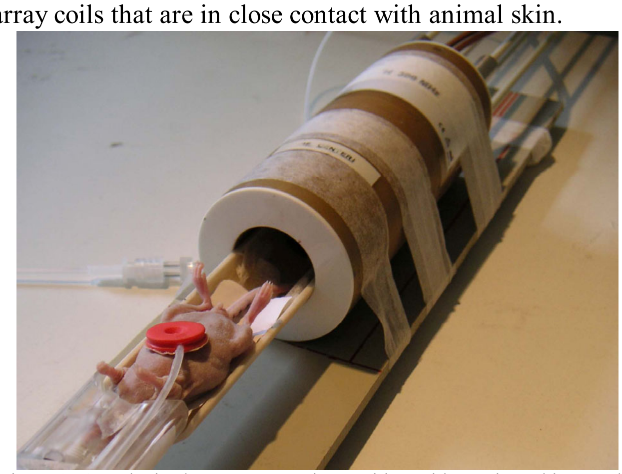


Figure 2. Anesthetized mouse on supine position with an air cushion on the thorax just before it insertion in the MRI coil

In addition, light propagation in biological materials or in standard optical fibers is not affected by radiofrequency fields. That is why a fibered optical-based system is expected to provide physiological signals that are not influenced by electromagnetic noise of MRI platforms. Finally, optical fibers are generally flexible, and typical diameter is several hundreds of microns. Such characteristics make it compatible with highly confined environments like small animal coils.

The goal of this work was to develop a fully optical-based device able to monitor the respiratory and cardiac cycles using fiber optics and to be used to synchronize small animal MRI.

II. Material and Methods

A. Principle

As light from the transmit fiber impinged upon a moving surface (such as animal thorax skin), the amount of diffusely reflected and backscattered light detected by the receiver increases as the surface moves closer to the probe tip and decreases as it moves away. This light variation is

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proportional to the movement of the area of interest, being the thorax region in our case.

B. Electronic circuit

Two 200 µm optical fibers were used: one for transmission and the other for detection of light. The two fibers were optically insulated to decrease the ambient light noise. The tip of both fibers was stripped on a 2 cm length. The fiber's tips were bundled together with epoxy glue. The fiber tips were cleaved and polished to maximize light detection. Using an HFBR-1405 fiber optical transmitter (Agilent Technologies Inc., Santa Clara, CA, USA) a continuous 820 nm wave light was focused into the transmit fiber. The detected light was carried by the receive fiber to a light-voltage amplified photodiode, a HFBR-2405 fiber optical receiver (Figure 3).

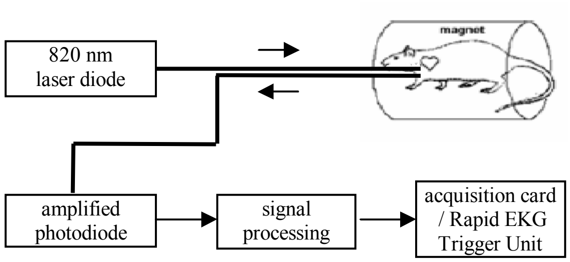


Figure 3: Schematics of the fiber-optic monitoring device

The output voltage was proportional to the received light and was passed to a custom-built signal-processing circuit for further amplification and filtering. The signal processing circuit consists in two active wide band pass filter and adjustable gain amplifier inserted between these two filters. Each active wide band pass filter is composed of a 0.2 Hz active Sallen-Key high pass filter and a 30 Hz active Sallen-Key low pass filter. The adjustable gain amplifier is an operational amplifier in inverting configuration with an adjustable gain in scale of 100/1,000/10,000.

The signal was then recorded by an acquisition card (PMD-1208FS, Measurement Computing, Middleboro, MA 02346, USA) for signal recording and display.

For MRI synchronized acquisition the signal processing circuit was interconnected with a Rapid Biomedical ECG Trigger Unit HR V2.0 (Rapid Biomedical, Würzburg, Germany). By replacing the original ECG sensor of this unit with designed device, the cardiac and respiratory gating levels were independently adjusted to generate a trigger signal for MRI acquisition triggering.

C. MRI acquisition protocol

Gaseous anesthesia was performed on animals with approved system (Minerve Equipement Vétérinaire, Esternay, France) using an induction box and a mixed gas of air (30% oxygen) at a concentration of 4% isoflurane (Laboratoire Belamont, Boulogne Billancourt, France). The animals were then placed in supine position on a dedicated plastic bed, which contains a regulated water heating system. During MRI scanning the level of anesthesia was maintained at 2.7% isoflurane administered at a 1liter/min rate.

The fiber optical pair was fixed using soft medical adhesive tape on thorax skin (Figure 4) and the animals were inserted inside the MRI coil.

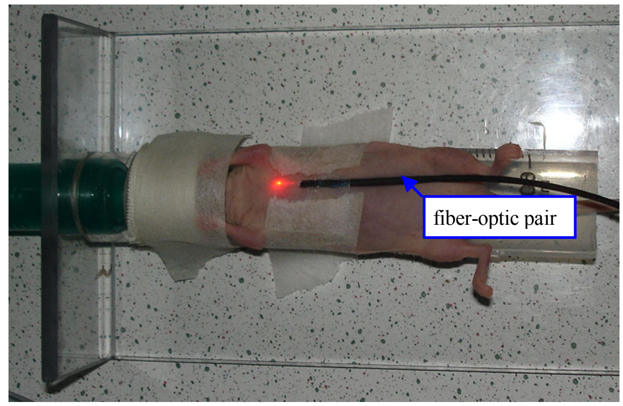


Figure 4. Anesthetized mouse on supine position with optical fiber fixed on the thorax.

Ethical guidelines for experimental investigations with animals were followed, and the experimental protocol was approved by the animal Ethics Committee of our institution.

The experiments were performed on a Bruker 4.7T Biospec system (Bruker, Ettlingen, Germany), using a transmitting birdcage coil with 98 mm outer diameter and 72 mm inner diameter (Rapid Biomedical, Würzburg, Germany). The maximum gradient amplitude available is 270 mT/m and the clear bore diameter is 100 mm.

The efficiency of our optical device was assessed both on heart and liver imaging on small animals (rats and mice). Images synchronized with the optical device were then compared with images acquired with an air cushions sensor and also with images acquired without synchronization.

For heart imaging a CINE FLASH sequence with the following parameters FOV = 40 x 40 mm^2, 192 x 256 matrix, 15 frames, 4 averages and TR/TE = 15/2.9 ms was used.

For liver imaging a fat suppressed Spin-Echo (SE) with following parameters: FOV = 30x30 mm with 0.5 mm slice thickness, TR/TE = 6000/20 ms, 256x256 matrix, 36 slices was used.

III. RESULTS

The optical-based signals were well correlated with both respiratory and heart motions. Because only the fiber-optical pair was introduced within the magnet (the electronic circuits are deported and located outside the magnet), the physiological signals were totally unaffected by the electromagnetic fields (RF and gradients) of MRI system. The signal quality is thus totally independent of RF flip angle pulse and sequence used even in Echo Planar Imaging (EPI) acquisition with fast gradient switching.

Signal amplitude was large enough to perform an easy adjustment of gating level with good differentiation between cardiac and respiratory signal (Figure 5). The sharp shape of the respiratory profile is due to the gaseous anesthesia used.

The fiber optical pair was placed in various locations on the thorax and the variation of signal amplitude was independent of location. The adjustable amplifier gain offers compatibility with different experimental conditions, positions of the fiber, and animal size.

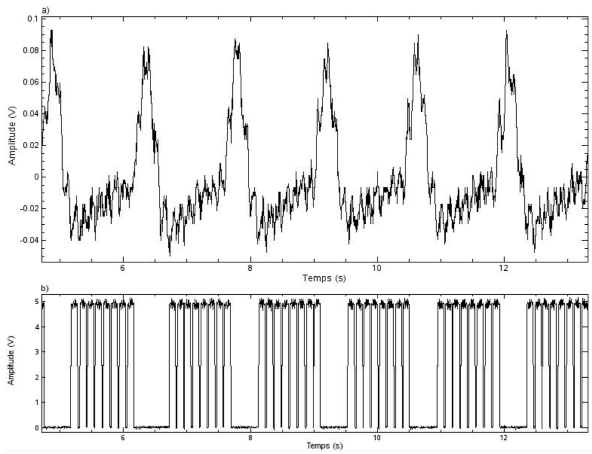
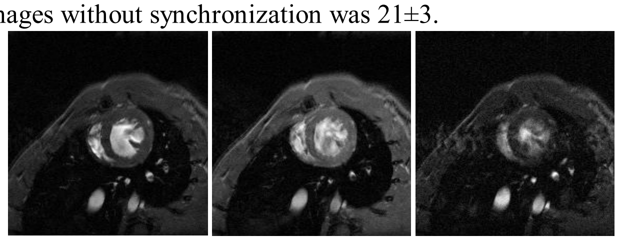


Figure 5. The optical-based signal: a) the largest peaks are attributed to respiratory cycle and the small oscillations are attributed to heart motion; b) the output trigger signal from Rapid Biomedical ECG Trigger Unit

Interfaced with Rapid ECG Trigger Unit, the gating level was adjusted for respiratory synchronized MRI acquisition, or for dual, respiratory and cardiac, synchronized MRI acquisition (Figure 5), depending on needs.

The acquired MR images of rat heart reveal no visible moving artifacts (Figure 6).

Compared with air cushion sensor the optical device synchronized MRI acquisition shows no visible differences (Figure 7). The Signal-to-Noise Ratio (SNR) measured in the myocardium was 51±2 on image with optical synchronized method and was 50±2 on image performed with air cushion. In comparison, the SNR measured on images without synchronization was 21±3.



a) b) c)

Figure 7. MRI images acquired on a rat heart using a CINE FLASH sequence: a) synchronized with the optical equipment, b) synchronize with air cushion sensor, c) without synchronization.

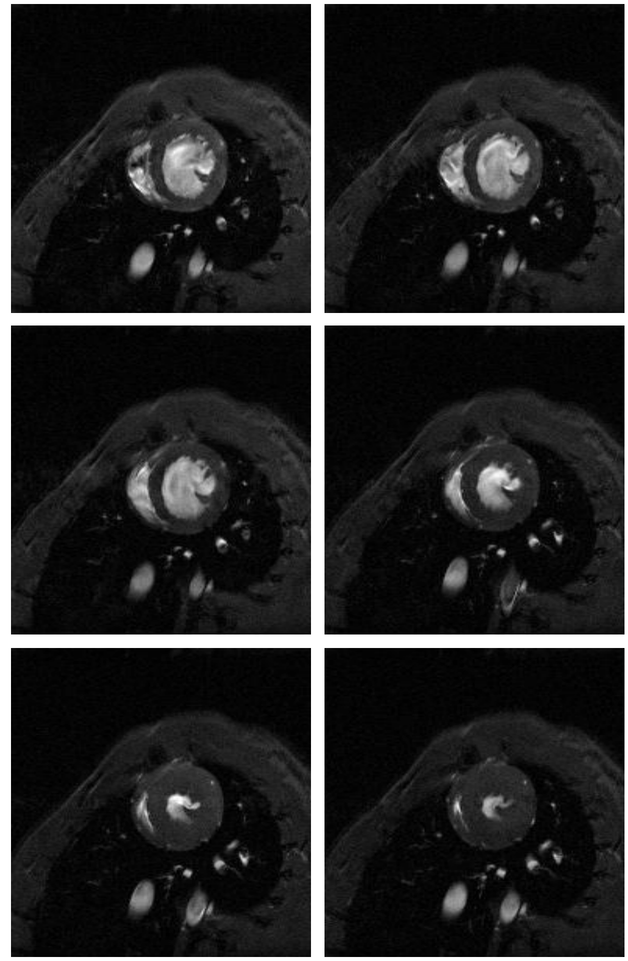
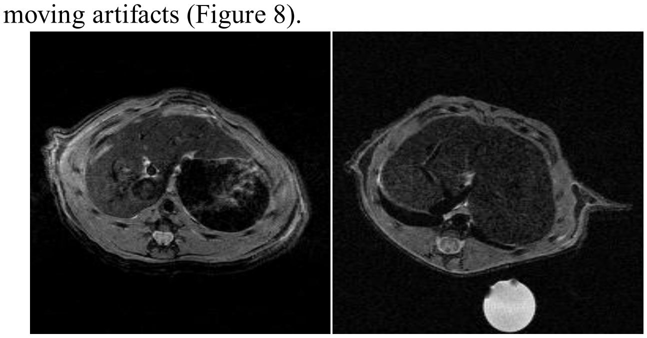


Figure 6. The acquired MRI image of a rat heart, using a CINE FLASH sequence, synchronized using the optical-based device. Images displayed correspond to 6 out of 15 cardiac phases with a cardiac period of 225 ms.

The MRI images acquired with a synchronized fat suppressed Spin-Echo on rats and mice liver reveal no moving artifacts (Figure 8).



a) b)

Figure 8. MRI images acquired a) on a rat liver; b) and on a mouse liver using a fat suppressed Spin-Echo with optical device synchronization.

IV. CONCLUSION

Full optical-based signal from heart and respiratory motion were recorded on mice and rats. Such signal is suitable to be used for dual synchronization of MRI acquisitions on thorax and abdomen.

The adjustments of gating level can be performed either via the acquisition card using real-time software, either interconnecting the designed optical dive with Rapid ECG Trigger Unit.

The Rapid ECG Trigger Unit offers an easy way to perform all the getting adjustment. From the optical based signal the respiratory and cardiac signal are extracted and each is amplified and filtered to the desired level. The synchronized trigger pulse can be generated by respiratory motion, cardiac motion, or by a combination of both based on a dual cardiac-respiratory triggering.

The fiber optical pair is extremely thin (less than 1 mm diameter) and is very easy to install even within small volume MRI coil.

The fiber optical pair was placed in various locations on the thorax and the variation of signal amplitude was independent of location. This optical-based signal could be a real alternative compared first to air cushions used for respiratory monitoring but also to conventional ECG signal.

The full optical-based device was used successfully for cardiac imaging and applied for liver imaging of nude mice. It is expected to be used for numerous high resolution MRI investigations for which gating procedures are critical such as lungs [6] or vascular network [7].

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