31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

OFSETH: Smart medical textile for continuous monitoring of respiratory motions under magnetic resonance imaging

J. De jonckheere[1], F. Narbonneau[2], M. Jeanne[1,3], D. Kinet[2], J. Witt[4], K. Krebber[4], B. Paquet[5], A. Depré[6], R. Logier[1]

[1]INSERM CIC-IT 807, CHRU de Lille, 2 Avenue Oscar Lambret, 59037 Lille Cedex, France
[2]MULTITEL, 2 rue Pierre et Marie Curie, 7000 Mons, Belgium
[3]Clinique d'Anesthésie Réanimation, Hôp. Salengro, CHRU de Lille, 2 Avenue Oscar Lambret, 59037 Lille Cedex, France
[4]BAM, Unter den Eichen 44-46, D-12203 Berlin, Germany
[5]CENTEXBEL, Avenue du parc, 38 Hervé (Chaineux) 4650, Belgium
[6]ELASTA, 15 Texielstraat, 8790 Waregem, Belgium

Abstract - **The potential impact of optical fiber sensors embedded into medical textiles for the continuous monitoring of the patient during Magnetic Resonance Imaging is presented. We report on two pure optical sensing technologies for respiratory movements monitoring – a macro bending sensor and a Bragg grating sensor, designed to measure the elongation due to abdominal and thoracic motions during breathing. We demonstrate that the two sensors can successfully sense textile elongation between, 0% and 3%, while maintaining the stretching properties of the textile substrates for a good comfort of the patient.**

Keywords— **MRI, smart textile, healthcare monitoring, optical sensor, respiratory sensor**

I. Introduction

Monitoring of patients during Magnetic Resonance Imaging (MRI) presents a lot of disagreements due to the presence of metallic and electronic components in the MRI field. Indeed, sensors including either metallic parts or electrical conductive wires can cause disturbance of the MRI result and burns on patient skin [1]. Alternatively, optical sensors offer the advantage of being free from metallic or electrical conductive wires, and in addition, can be remotely interrogated via an optical fiber cable allowing locating the monitoring unit out of the MRI field. Therefore, the use of optical sensors allows to provide a monitoring device fully compatible with the MRI environment.

Optical fibers sensors have already demonstrated great capabilities for many applications where non-invasive concerns, electromagnetic compatibility, risk of explosion [2] or need for distributed measurement [3] limit the use of standard technologies. Up to now their use as embedded sensors in technical textiles for medical applications has not been implemented in clinical routine despite their expected positive impact. This is mainly due to the restricted usability of the sensors from the medical staff point of view, as well as to their poor compatibility with cost-effective industrial textile processes, where manual operations such as confection have to be reduced to a minimum However, due to their fibrous nature, optical fibers have a serious advantage over other kind of sensors when integration into textiles is considered. Indeed, an optical fiber is in some way a yarn and can ideally be processed like standard textile yarns, where in addition sensing will occur in the core of the optical fiber.

In this context, the European project OFSETH (Optical Fiber Sensors Embedded into technical Textiles for Healthcare – FPI-ST-2004-027869) [4, 5] investigates how measurements of various vital parameters like cardiac signals, pulse oximetry or respiratory motions can be performed through pure optical devices and techniques, while in the same time textile processes like weaving, knitting, crochet and stitching for the embedding of the optical fiber are evaluated.

In this paper we report on two optical fiber sensors embedded into technical textile for the monitoring of the respiratory motions.

II. Methods and Material

A. Macro-bends in optical fibres

Since 70' and 80', as optical fibers were progressively developed and installed, the bending effects in optical fibers have been largely studied [6]. Indeed, the power attenuation coming from the coupling of guided modes into radiations modes dues to theses bending represents an important limitation to the data transmission over long distance. Consequently, fiber designs as well as cabling processes have been continuously optimized for a higher robustness to bending effects [7]. However, since some years, the use of macro-bending sensors [8] becomes more popular in the case where no fine precision regarding elongation measurement is requested. Macro-bending sensors have major advantages. First, their interrogation is very simple and requires low cost and compact equipment. Second, their integration into textile fabrics may be very straight forward, owing to their easy design. Especially, a macro-bending transducer is very simple to achieve using a stretchable substrate, such as an elastic textile fabric, containing an optical fiber (Fig.1).

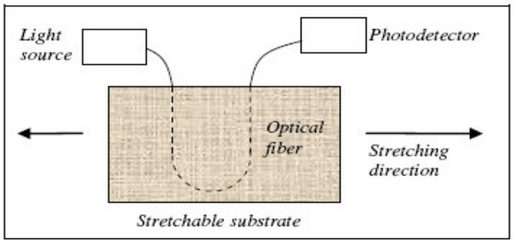

Fig.1 – Simple arrangement of a macro-bending sensor. Curvature changes when substrate is stretched.

In fig. 1, when the substrate is stretching, the bending radius increases reducing optical losses in the fiber, and vice-versa. The intensity variations at the output of the optical fiber then represent the relative variations of the substrate length. Therefore, connecting the embedded optical fiber to a light source and a photodiode will allow a real time measurement of the frequency of the substrate length variations.

In the frame of this project, one interest is to develop a sensor sufficiently sensitive and compatible with the textile fabrication process. In this context different techniques of embedding were tested (hand-stitching, weaving, crochet….). The final design allowing to fulfill our request corresponds to a standard optical fiber embedding in an elastic bandage by a crochet process with a "sinusoidal" shape (Fig. 2).

Fig.2 : Optical fiber embedded into textile during its process of fabrication

Optical losses induced by fibre attenuation, dynamic of the sensor and the SNR (signal-to-noise Ratio) are a trade-off between the operation wavelength and the optical source (Fabry Perot laser diode, broad-band source or LED). Finally, in order to reduce connection points, the macrobending sensor operates in reflection and a LED at 1310 nm is used to maintain a sufficient SNR and optical power level at the detection even if dynamic is more poor at this wavelength. Nevertheless, as we operate in reflection, the dynamic is enhanced by round-trip in the sensor.

With such a sensor positioned on the abdomen, it becomes possible to link the variation of an optical power to the movement of the abdomen taking place naturally during the breath (Fig. 3).

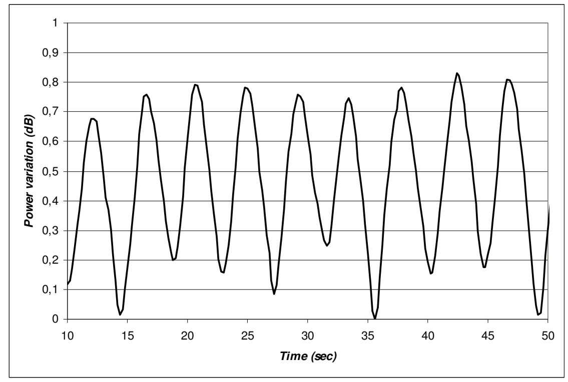

Fig.3: "Belt sensor" tested on adult human. Cycle of power variation corresponding to a same frequency of respiration

This sensor has been tested on a simulator (Fig. 4) to evaluate the signal stability after several elongation cycles. The Fig. 5 sensitivity curve show that after 172800 cycles (192 hour at 15 cpm) of a 2% elongation, the sensor shows a high stability (variations <10%) concerning sensitivity (Fig. 5). These tests have been performed for elongations from 2 to 32%. The results show that the sensor keeps its sensitivity/stability performances for elongations from 2 to 15%.

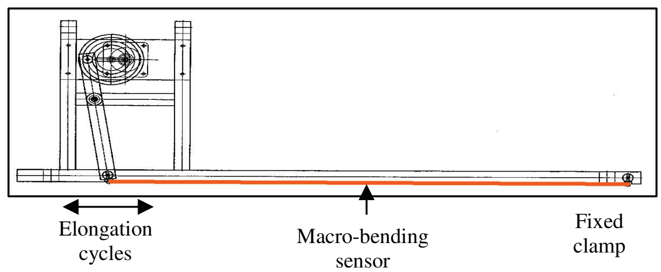

Fig. 4: Elongation simulator

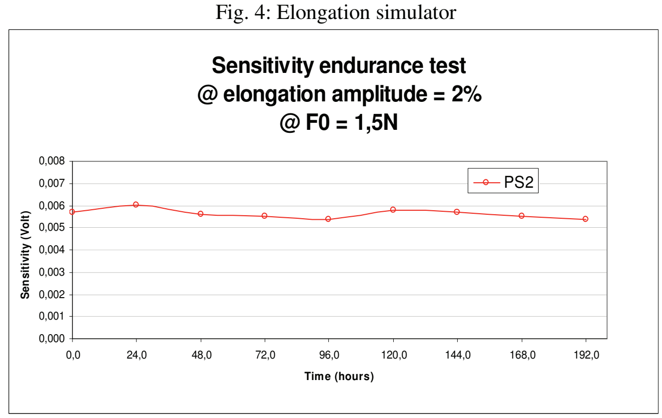

Fig.5: Macro bending sensor : Test on simulator

Furthermore, the sensor shows low sensibility to temperature and humidity variations. Preliminary washability tests also shows good results too but need to be completed to determine the maximum number of washing cycles.

B. Fiber Bragg grating sensor

Monitoring of both movements (thoracic and abdominal) of patients during MRI exam is crucial. Unfortunately, thoracic movements are very small in magnitude and it appears that the bending sensor is not always sufficiently sensitive to monitor any kind of movement at that place. Indeed, abdominal movements are about 1% of elongation whereas thoracic are about 0.1%.

There are several ways for detecting elongation using an optical fiber. For instance, the fiber strain itself can be locally detected through monitoring of the spectrum changes of the light being injected in the fiber and reflected by an intra-core reflective filter called fiber Bragg grating (FBG) [9], which is sensitive to strain variation. Indeed, through such a filter, the reflected color issued from a light source changes with the strain applied to the FBG inducing a wavelength change on the reflected light spectrum (Fig. 6).

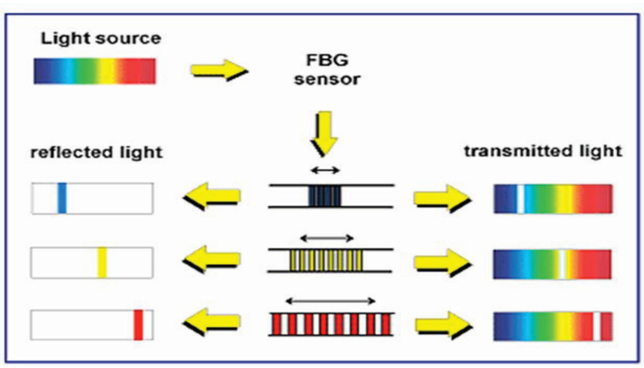

Fig. 6: FBG working principle

Therefore, elongation of the FBG can be computed by measuring the wavelength of the reflected light using a spectrometer.

Several techniques for embedding silica FBG into textile fabric has been investigated with the objectives to ensure the good placement of the FBG, to minimize parasitic effects in terms of mechanical strains and optical losses and to convert all the textile elongation into a mechanical force applied to the FBG sensor. For that, the sensor design includes fibre loops at each FBG extremity (Fig. 7).

This sensor has been tested on a simulator to evaluate the signal stability after several elongation cycles. The Fig. 8 sensitivity curve show that after 85 hour at 12 cpm 0.4% elongation cycles, the sensor shows a high sensitivity but also good results in terms of stability (Fig. 8). Furthermore, preliminary tests show low sensibility to temperature and humidity variations.

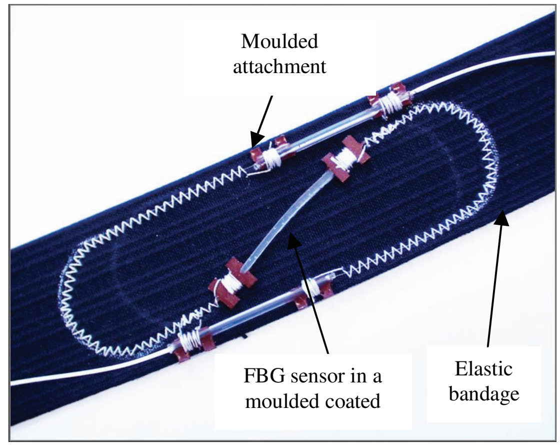

Fig. 7: FBG textile integration

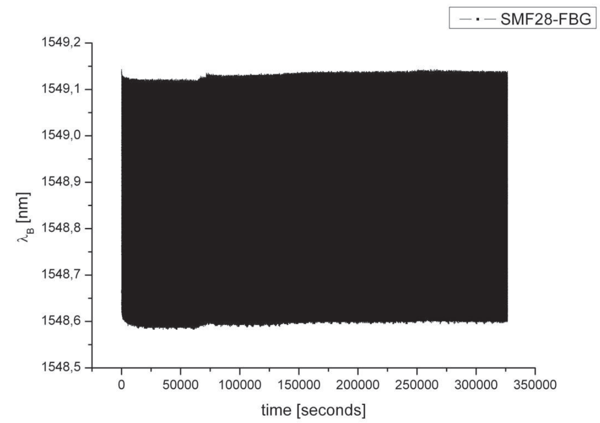

Fig. 8: FBG sensor performance

C. Final monitoring system

Integrated the two systems in a wearable solution would allow to continuously monitor both the thoracic and the abdominal movements. Nevertheless, due to the variability of age, size and weight of the patients, the wearable solution needs to be adaptable, flexible and comfortable enough. On the other hand, concerning the garment placing, some places should be kept clear, like the pre-cordium, in order to facilitate resuscitation in case of cardiac arrest or Hemodynamical failure, and give vital information on Hemodynamical status during resuscitation. Access to the intra-venous infusion line should also be kept clear, for easy access during anesthesia or for resuscitation purpose. Absence of venous or even arterial garrot should be strongly assessed, particularly if the cloth is a circular one.

On the other hand, as the acquisition module and the monitor contain electronic components, they need to be placed out of the MRI field. The transmission between the garment and the acquisition module will then be done by optical fibers. Therefore, the whole system will look like as follow:

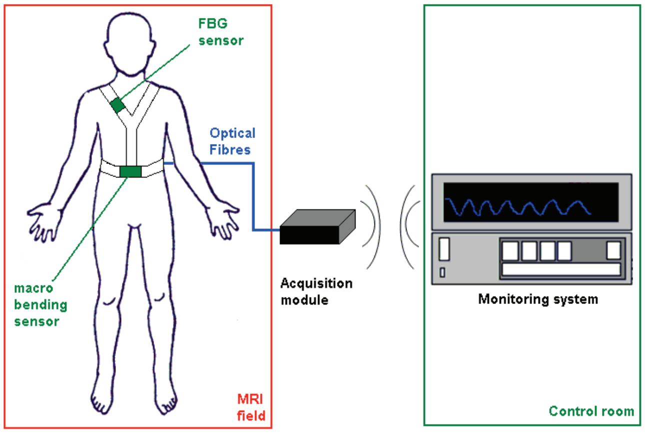

Fig. 9: Monitoring system

This harness has been tested on several healthy volunteers. Fig. 10 shows the typical signal patterns for both thoracic and abdominal movements.

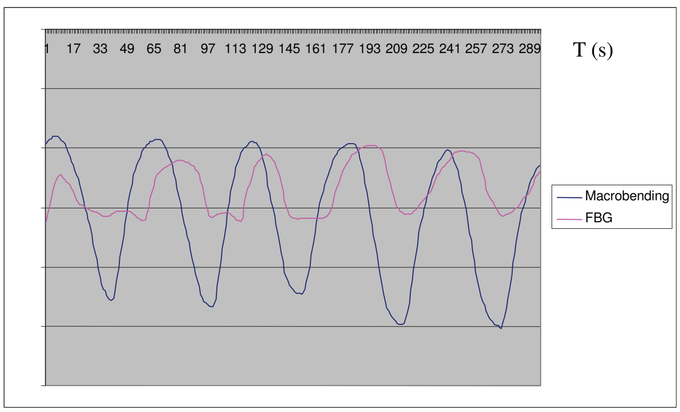

Fig. 10: Abdominal and thoracic movements signals

IV. CONCLUSION/DISCUSSION

In this paper, we report on optical fibre sensors embedded into textile fabrics for the monitoring of respiratory movements in MRI environment. Two designs (macro-bending, FBG) allowing sensing textile elongations between 0% and 3% have been investigated and successfully demonstrated. During this work, we also focus on the influence of different patients' morphology on the sensors performances, as well as on the textile integration issues. The combination of the two respiratory sensors was also studied to obtain a device that is easy to place around patients and that let free all vitals organs for medical staff actions. Therefore, the OFSETH harness allows an efficient continuous measurement of thoracic and abdominal movements which can be of precious help regarding several clinical situations.

For example, anesthesia for MRI examination uses the same drugs as anesthesia for any surgical procedure. Even if spontaneous respiration can be preserved most of the time, spontaneous respiration during anesthesia is constantly at risk of being impaired by anesthetic drugs or by upper airway obstruction. Abdominal as well as thoracic respiratory movements need monitoring in order to assess adequate ventilation. Phase analysis of the two signals could help medical staff to detect specific obstruction patterns. The preliminary tests on healthy volunteers have shown that such a measure is possible and easy with the OFSETH harness.

The two developed sensors can also provide an efficient solution for the correction of several motion artefacts on the MRI result. Indeed, artefacts due to physiological motions (heart beat, respiration…) are of short period and induce a blooming effect on the MRI result [10]. The use of synchronisation devices allows reducing or avoiding these effects. For example, a cardiac synchronisation system triggers the acquisition at a cardiac cycle given time to avoid heart beat and vascular artefacts. For such an application, the choice of the sensor is an essential element regarding the image quality. Positioned at certain strategic places according to the investigated organ, the presented sensors constitute an efficient and adapted solution for respiratory synchronisation of the MRI acquisition.

ACKNOWLEDGEMENT

This work has received research funding from the EU 6th Framework Program under contract number IST-2004-027869. The views expressed here are those of the authors only. The Community is not liable for any use that may be made of the information contained therein.

REFERENCES

[1] Dempsey MF, Condon B. "Thermal injuries associated with MRI", Clinical Radiology 2001; 56: 457-65
[2] Prinse, Wim C and al, "Development of fiber optic sensors at TNO for explosion and shock wave measurements", Proc. SPIE Vol. 4183, p. 748-758, 24th International Congress on High-Speed Photography and Photonics, 2001.
[3] John P. Dakin, "Distributed optical fiber sensors", ", Proc. SPIE Vol. 1797, p. 76-108, Distributed and Multiplexed Fiber Optic Sensors II, 1993 .
[4] www.ofseth.org
[5] J.De jonckheere, F. Narbonneau, D. Kinet, J. Zinke, B. Paquet, A. Depres, M. Jeanne, R. Logier – « Optical fibre sensors embedded into technical textile for a continuous monitoring of patients under magnetic resonance imaging – Proceeding of the 30th Annual International conference of the IEEE Engineering in the Medicine and Biology Society, Vncouver, August 2008.
[6] H. F. Taylor, "Bending effects in optical fibers", *Journal of Lightw. Techn. Vol. LT-2(5),* 1984
[7] http://www.corningcablesystems.com/web/library/litindex.nsf/$ALL/EVO-803-EN/$FILE/EVO-803-EN.pdf
[8] Sung-Hoon Jung and al. "Water sensor using macrobending-sensitive fiber for real-time submersion monitoring", Optics Communications, Vol.260, Issue 1 (2006) pp. 105-108
[9] Andreas Othonos, Kyriacos Kalli, David Pureur and Alain Mugnier, "Fibre Bragg Gratings" Chapter 5, Wavelength Filters in Fiber Optics Springer Berlin/Heidelberg, 2006.
[10] D. Doyon, E.A. Cabanis et Al. « IRM-Imagerie par résonance magnétique-4èm » édition »-Masson, 1994.