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Contactless respiratory monitoring system for magnetic resonance imaging applications using a laser range sensor

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Abstract: During a magnetic resonance imaging (MRI) exam, a respiratory signal can be required for different purposes, e.g. for patient monitoring, motion compensation or for research studies such as in functional MRI. In addition, respiratory information can be used as a biofeedback for the patient in order to control breath holds or shallow breathing. To reduce patient preparation time or distortions of the MR imaging system, we propose the use of a contactless approach for gathering information about the respiratory activity. An experimental setup based on a commercially available laser range sensor was used to detect respiratory induced motion of the chest or abdomen. This setup was tested using a motion phantom and different human subjects in an MRI scanner. A nasal airflow sensor served as a reference. For both, the phantom as well as the different human subjects, the motion frequency was precisely measured. These results show that a low cost, contactless, laser-based approach can be used to obtain information about the respiratory motion during an MRI exam.

Keywords: laser range sensor; MRI; patient monitoring; remote monitoring; respiration.

1 Introduction

During magnetic resonance imaging (MRI), information about the respiratory activity of a patient or subject can be required for different purposes, e.g. for general monitoring, for motion compensation, or for functional MRI studies [1]. Respiratory information is also used in biofeedback systems which support the patient to breathe flat and continuously, e.g. in radiation therapy [2, 3].

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Respiratory activity is typically measured using belts or nasal airflow sensors. However, these methods require additional patient preparation time and the required technical components and cables can be disturbing during interventions. In addition, any electrical device has the potential to distort the acquired MRI raw data causing artefacts in the resulting diagnostic images.

Different methods exist which enable a contactless distance measurement. Based on variations in distance, one can draw inferences about the respiratory activity. Ultrawideband radar is one method which is based the reflective measurement of GHz signals [4–6]. Other methods include camera based systems using optical fiducials placed on the patient's torso [7, 8]. However, this method requires an additional preparation of the patients and a long distance line of sight between the fiducials and the camera placed outside the bore of the MRI. Temperature variations caused by respiration can also be captured using infrared thermography [9, 10]. The disadvantage of infrared thermography is the high cost of the camera and the incompatibility with the MRI environment.

In radiation therapy and imaging, laser optical displacement sensors were used to track the respiratory motion [11, 12]. Such a setup is advantageous since it does not require an additional preparation of the subject or patient. Since there is no contact with the patient, sterilization is not an issue, i.e. it therefore could also be used in an open surgery and for paediatric imaging avoiding the placement of electrodes.

This work proposes a setup based on a laser range sensor used to gather information about a patient's respiratory activity during MRI exams.

2 Material and methods

2.1 Measurement setup

The experimental setup is shown in Figure 1. A laser range scanner (Fluke 419D, Fluke, USA) with a measurement

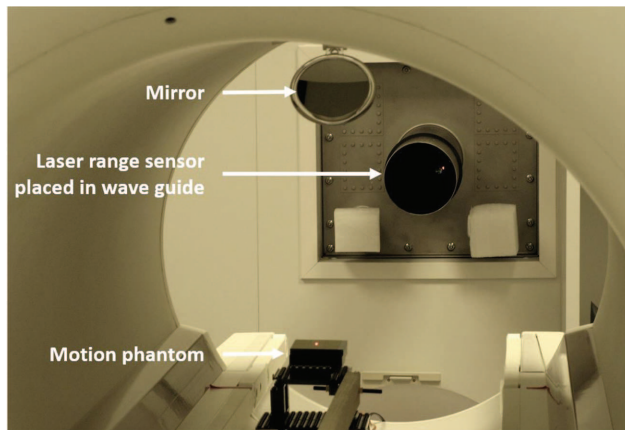


Figure 1: Experimental setup using a motion phantom to demonstrate the functionality of the developed setup. The laser is placed in the MR scanner's technical room pointing through the wave guide into bore. A mirror was mounted on top of the bore to reflect the laser beam onto the motion phantom.

rate of 2 Hz and a resolution of 1 mm was placed outside the shielded MRI cabin. In our particular setup, the laser beam was directed through the wave guide of the MRI cabin which was 1.5 m behind the bore of the MR scanner. However, other positions inside the MRI cabin are possible but could require additional mirrors. In order to direct the laser beam to the chest of the subject, a mirror was required inside the bore. Therefore, a swivelling mirror was placed on the upper side of the bore. This experimental setup is depicted in Figure 1. In the preliminary experimental setup, the display from the laser range sensor was read out in real-time using a standard webcam. The acquired, non-equidistant signal samples were linearly and equidistantly interpolated (sampling rate: 5 Hz) and low-pass filtered (5th order Butterworth filter with a cutoff frequency of 1 Hz) to achieve a smoother data visualization.

In order to ensure that the obtained motion was caused by the respiratory activity, a reference signal was required. Therefore, a nasal airflow sensor made from thermocouples connected to a micro-computer (*Raspberry Pi + e-Health sensor platform*) was used.

2.2 Motion phantom

To quantitatively evaluate the functional principle of the proposed measurement technique, an oscillating motion phantom was constructed using an electromechanical, microcontroller driven setup (Lego, Denmark). The peak-to-peak amplitude of the simulated respiratory motion was set to 15 mm with a frequency of 0.28 Hz (which

corresponds to respiratory rate of 16.6 breaths per minute). This frequency corresponds to the typical respiratory rate of healthy adults which is in the range of 7 to 20 breaths per minute [13].

2.3 Subject measurements

The experimental setup using the laser range sensor and the nasal airflow sensor as reference were tested with four healthy, male subjects (age 33 ± 5 years) during spontaneous breathing in an MRI scanner (Magnetom Skyra, Siemens, Germany). Both subjects were placed in a head first, supine position where the mirror was adjusted such that the laser beam pointed to the subject's abdominal area as shown in Figure 2. In order to be able to obtain the respiratory motion using the proposed laser-based setup, the subjects wear skintight clothes. No additional restriction were made considering the clothes' color or material.

3 Results

3.1 Motion phantom

The results obtained from the measurements on the motion phantom are depicted in Figure 3. From the acquired data, a frequency of 0.28 Hz can be observed which corresponds to the actual frequency of the motion phantom. The average peak-to-peak amplitude of the interpolated, low-pass filtered signals was 16 mm.

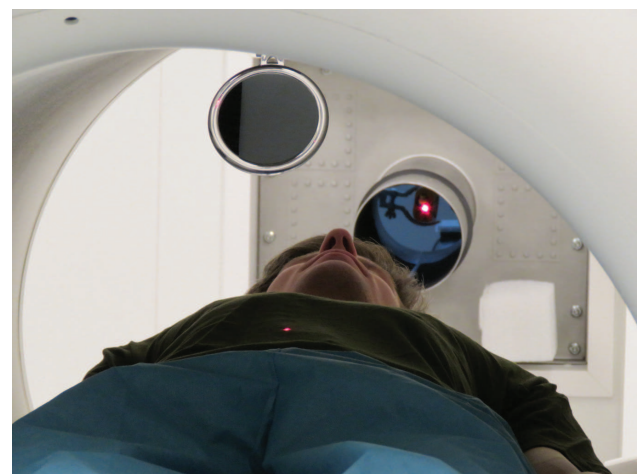


Figure 2: Experimental setup for the laser based acquisition of respiratory activity of a subject placed inside an MRI scanner.

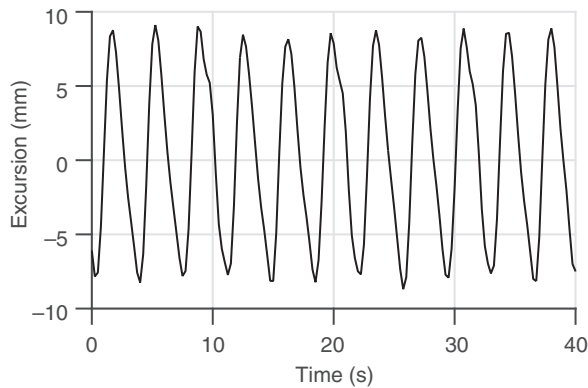


Figure 3: Observed excursion on the motion phantom using the laser range sensor.

3.2 Subject measurements

Exemplary measurements of four freely breathing human subjects are shown in Figure 4. The nasal airflow sensor produces a signal during expiration only. This is due to the used thermocouples. At the same time, the distance between the laser range sensor and the surface of the torso increases. The results show that the two signals are in good agreement for all subjects, i.e. the same respiratory rates (averaged over one minute) were computed from the two signals for each subject. The average peak-to-peak amplitudes varied between 15 mm and 35 mm among the individuals.

4 Discussion and conclusion

This work provides a proof-of-principle that a low-cost laser range sensor can be used to acquire information about respiratory activity during an MRI exam. Using a dedicated motion phantom, it was shown that the proposed setup allowed a precise estimation of the respiratory rate. The magnitude of motion observed in the phantom measurements was overestimated by 1 mm. This overestimation was caused by the interpolation and low-pass filtering of the signal which was used for a more smooth data visualisation due to the low sampling rate (2 Hz) of the respiratory signal.

The measurements on the four healthy human subjects showed that the laser based measurement setup can provide information about the respiratory activity. This was proven using a nasal airflow sensor as reference. In order to use the proposed setup for different types of MRI exams (clinical exams, interventions, research imaging), dedicated, skintight clothes should be provided for the subject in order to be able to observe the respiratory motion. Loose clothing could result in a low-pass filtering effect of the respiratory motion which would hamper the estimation of respiratory motion using the laser based setup.

Future work will include several improvements of the current setup. In order to obtain a more precise measurement of the respiratory activity, e.g. for motion

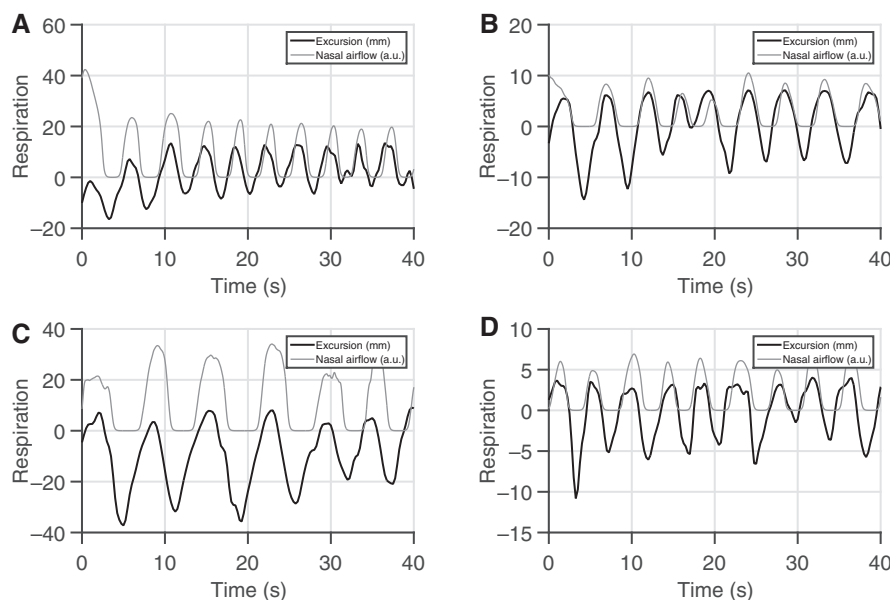


Figure 4: Respiratory chest motion signals acquired using the laser range sensor (thick black line) and the corresponding signals from the nasal airflow sensors (thin grey line) from four different subjects. (A) Measured respiration of subject #1. (B) Measured respiration of subject #2. (C) Measured respiration of subject #3. (D) Measured respiration of subject #4.

compensation purposes, a laser range sensor with a higher sampling rate and spatial resolution as well as a direct analogue or digital data output will be used. To reduce the still existing line of sight problem, the sensor will be placed in a different position and additional mirrors will be used to provide a path for the laser beam which is less likely to be interrupted by the clinical staff working in the MRI environment. To prove the robustness of this approach, a further study on a larger population will be performed. It is planned to use the acquired respiratory data in a biofeedback system to support or motivate subjects or patients during a continuously, flat breathing.

The proposed setup can be integrated in standard MRI systems. Since the laser range sensor is placed outside the MRI scanner cabin, no MRI compatibility or safety issues arise. Due to the remote, contactless nature of this measurement setup, patient preparation time during MRI exams or MRI guided interventions will be reduced.

Author's Statement

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