MonitoRing - Magnetic induction measurement at your fingertip

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Abstract. The device presented in this paper is a sensor for monitoring pulse by measuring the bioimpedance of the thumb in an unobtrusive way. The sensor is based on magnetic induction measurement, a non-contact technique for measuring impedance changes of objects [1]. The sensor head of the presented system has the form of a ring and is worn on the finger. The developed technique renders the possibility of easy and unnoticed pulse recording during every day activities without the need for, e.g. electrodes, a pulse belt around the chest, or a pulse photoplethysmographic finger or ear clip.

1. Introduction
Cardiac pulse is an important vital sign for the bedside monitoring of patients as well as for homemonitoring devices. It is also a frequently used parameter in professional and consumer sport monitoring applications. Due to its easy access, the finger has become an established location for pulse plethysmographic recordings. This work presents a novel device for impedance plethysmography of the finger without the need for electrical or optical contact.

Commonly used photoplethysmographic (PPG) sensors applied as fingerclips are sometimes perceived as obtrusive and bothersome. In addition, they strongly suffer from motion artefacts, since LED and photosensor are only loosely coupled to the skin, and are therefore, merely useful in quiet scenarios. Using electrical impedance plethysmographs (EIP), ring electrodes are placed on the finger at fixed locations [2]. The necessary parallel alignment of these electrodes results in a difficult electrode application and is also a factor causing motion artefacts, since the geometrical alignment could change during motion.

The proposed system called MonitoRing is based on a single sensor head that can be worn as a ring around the finger. It is more convenient to wear and less obtrusive in comparison to commonly used finger plethysmographs. It is also less susceptible to motion artefacts, because it can be worn in a more stable contact to the skin (compared to PPG) and is based on only one measurement location instead of two. Additionally, the device does not need conductive or optical contact and could therefore also be worn above a textile layer (e.g. hand glove, sleeve). The sensoric part of the device is based on few electronic components, hence the device can easily be realized as a mobile design.
2. Methods

2.1. Measurement System

The physical principle of the device is based on eddy current induction (also called magnetic induction monitoring [1]). It is illustrated in Fig. 1(a).

![Figure 1. Principle (a) and system overview (b) of the MonitoRing device](image)

A coil formed as a ring around the thumb sends out an alternating magnetic field, which induces eddy currents into the thumb. The ring-coil is a frequency determining part of a Clapp oscillator, which is driving the coil’s current [3]. Hence, the sending frequency of the field emitted by the coil equals the oscillatory frequency. The eddy currents within the thumb reinduce a secondary alternating magnetic field affecting the primary one and changing the impedance of the coil. When the impedance distribution within the thumb (and thus the strength and orientation of the eddy currents) changes due to blood pulsation, the impedence of the coil changes and varies the oscillatory frequency of the Clapp oscillator. In this way, the oscillatory frequency is a simply measured signal, which correlates with the impedance distribution changes of the thumb caused by blood pulsation.

A block diagram of the system can be seen in Fig. 1(b). The output signal of the Clapp oscillator is high pass filtered and schmitt triggered before its frequency is measured by the use of a microcontroller (MSP430F5457A, Texas Instruments). The system is battery driven using two 3.3 V lithium batteries and comprises a wireless ZigBee connection to a PC, where the data is stored and visualized. The sampling frequency of the system is 95 Hz. The MonitoRing device is integrated into a small portable housing (64x42x18 mm), which can be attached to the arm or wrist.

2.2. Measurement Setup

The MonitoRing device was evaluated by measuring the pulse of a subject and comparing it to a simultaneously recorded photoplethysmographic (PPG) pulse reference (ChipOx, Corscience GmbH & Co. KG).

The ring-coil for measuring pulse at the thumb was tested at two different positions on the left thumb (see Fig. 2(a)). It consists of \( n=12 \) windings of high frequency litz (HFL) wire, that are wrapped around the finger. The resulting base sending frequency of the device was \( f_b = 3.8 \text{ MHz} \).

Furthermore, the application of a ring-coil as an arm bracelet was examined with a coil positioned around the forearm. For this purpose, three different sensor locations (see Fig. 2(b)) were tested with the coil realized by four windings of HFL wire \( (n = 4, \ f_b = 5 \text{ MHz}) \) similar to the ring-coil used for thumb measurement.
In order to investigate the device’s ability to monitor the cardiac pulse without mechanical contact between coil and skin, a pancake coil \( n = 3, f_b = 6 \text{ MHz} \) was printed on a printed circuit board (PCB) and the forearm was put through a hole in its middle without contact to the board (see Fig. 2(c)).

![Image](image.png)

**Figure 2.** Measurement positions of the ring coil on the thumb (a) and forearm (b). (c) shows the measurement setup for non-contact recording at the forearm.

### 3. Results

When the sensor coil is attached to the thumb in form of a ring, the device shows good correlation with the signal recorded by the reference PPG system (Pearson correlation coefficient \( \rho_{pos1} = -0.9452 \)). The result recorded at position 1 is presented in Fig. 3(a) and its corresponding Fourier Transform is given in Fig. 3(b). The average peak-to-peak change \( avPP \) of the oscillator within a cardiac cycle is 258.75 Hz and the signal-to-noise ratio \( SNR \) of the system is about 56.12 dB. When measuring at position 2 the pulse signal is also recordable but with a lower signal quality \( avPP = 226.71 \text{ Hz}, SNR = 17.52 \text{ dB}, \rho_{pos2} = -0.4157 \) .

![Image](image.png)

**Figure 3.** Result of a measurement with the ring-coil worn on the thumb (position 1). solid line: MonitoRing device; dashed line: plethysm. pulse reference (PPG).

Applying the MonitoRing onto the arm by HFL wire as described in section 2.2, the pulse signal could only be recorded on measurement position 4 \( avPP = 76.93 \text{ Hz}, SNR = 13.93 \text{ dB} \). This result is shown in Fig. 4(a) and 4(b). Using the non-contact measurement setup with a pancake coil printed on a PCB for arm measurement as shown in Fig. 2(c), it was not possible to recognize any signal content related to cardiac pulse.
Figure 4. Result of a measurement with the ring-coil worn on the forearm (position 2). solid line: MonitoRing device; dashed line: plethysm. pulse reference (PPG).

4. Discussion
The presented results indicate the system’s potential to monitor pulse at the fingertip. However, in order to ensure a comfortable wearability of the system, the electronic circuitry should be further miniaturized. Furthermore, for a robust and reliable signal more effort has to be spent into the investigation of the system’s sensitivity to motion artefacts. Especially, signals recorded at the measurement positions on the forearm show low quality, probably due to motion artefacts produced by contraction of the lower arm muscles.

When using a coil around the arm without contact between coil and skin, it was not possible to derive any pulse signal. This poses the question if the pulse signal derived using the other measurement setups (where the coil was directly worn on the skin) was actually evoked by impedance changes of the tissue or by changes of the coil diameter due to blood pulsation. This issue should be investigated in future. Nevertheless, in related studies the general sensitivity to impedance changes of objects was proven for similar magnetic induction sensors [3, 4].

5. Conclusion
Using magnetic induction measurement with the sensor coil worn as a ring around the fingertip, it is possible to monitor pulse with a SNR of 56.12 dB. When the ring-coil is located at a measurement position nearer to the base of the thumb, pulse measurement is still possible, but with a lower signal quality. Pulse measurement with the sensor coil worn as an arm bracelet, was only possible with the coil located in the middle of the forearm.

In conclusion, it can be stated that the described device represents a convenient method for plethysmographic pulse monitoring at the finger in an unobtrusive way.

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