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# Non-contact Monitoring Techniques - Principles and Applications

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*Abstract*— **This work gives an overview about some non-contact methods for monitoring of physiological activity. In particular, the focus is on ballistocardiography, capacitive ECG, Infrared Thermography, Magnetic Impedance Monitroing and Photoplethymographic Imaging. The principles behind the methods are described and an inside into possible medical applications is offered.**

## I. INTRODUCTION

The interest and research in non-contact techniques for monitoring physiological activity have immensely raised during the last decade. This is mainly due to advances in the area of integrated circuits, microelectronics and signal processing.

Non-contact monitoring methods have a variety of advantages as compared to conventional contact constrained methods. Long-time monitoring of vital signs can help diseased and elderly people to live longer in their domestic environment. By integrating non-contact sensors into objects of daily use, like seating furnitures, beds or even clothes, the monitoring of vital signs can be seamlessly integrated into daily routine. In this way, vital signs monitoring is not longer a psychological burden for diseased people. Furthermore, the risk of forgetting the sensor application (especially for elderly people) is reduced. Also, in clinical applications there are a lot of benefits that can be gained by non-contact methods. The effort for nursing staff could be reduced, since complicated sensor positioning as well as sensor cleaning would not longer be necessary. An application, especially benefiting from the use of non-contact methods, is the monitoring of neonates inside of incubators. Because of their premature skin, they are very sensitive to skin irritations provoked by adhesive electrodes. On the other hand, nearly all of their physiological activities have to be monitored in a 24/7 service.

In the following, an overview of 5 non-contact methods for monitoring physiological activity is provided. The physical principles of each of the different techniques is described and the potential as well as some applications are discussed.

## II. METHODS

### A. Ballistocardiography (BCG)

Ballistocardiography belongs to a family of methods which measure cardiopulmonary activity by recording mechanical vibrations of the body. While the basic principle has been known since the late 19$^{th}$ century, the field is currently experiencing renewed interest. Note that techniques measuring cardiopulmonary vibrations on the body surface are known under a multitude of names such as seismocardiography, apexcardiography, mechanocardiography, kinetocardiography, as well as ballistocardiography. The original definitions often overlap or depend on specific measurement modalities. In the following, we will use the term ballistocardiography to describe this entire family of infrasonic cardiac vibration signals. All BCG signals share the common advantage that they can be recorded unobtrusively since they do not require direct skin contact. Since the only requirement for a BCG system is some sort of mechanical coupling between the patient and the sensor, modern BCG sensors have been integrated into various objects of daily life such as beds, (wheel-) chairs, or even weighing scales. Obviously, the bed represents a particularly promising place for long-term unobtrusive monitoring. Hence, a large number of groups have integrated a variety of sensors into beds such as, but not limited to, electromechanical film (EMFi) and polyvinylidene fluoride (PVDF) foils placed on top or beneath the mattress, pneumatic mattresses, hydraulic under-pillow sensors, or strain gauges on the bed frame. As they are completely passive and require no user interaction, these types of sensors are very well suited for long-term monitoring of patients at home or in a hospital's general ward.

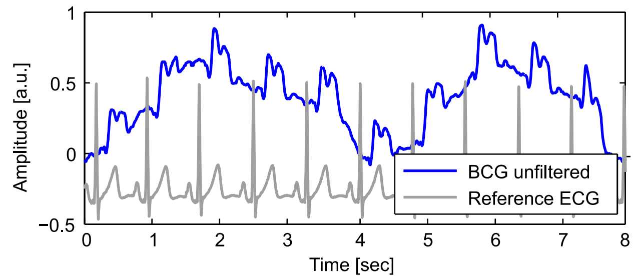


Fig. 1. Unfiltered BCG signal with a simultaneously recorded reference ECG. Both cardiac and respiratory components are clearly visible.

As the name implies, the term ballistocardiography denotes only the cardiac component of the signals recorded by the mechanical vibration sensors. However, since these sensors are sensitive to all forms of vibrations, they also register respiratory movements of the thorax (Fig. 1). The analysis of the cardiac (BCG) signal component is complicated by the fact that the BCG is an inherently three-dimensional signal. Therefore, the exact signal morphology is heavily dependent on the sensor modality and the exact position of the patient with respect to the sensor. Like most

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non-contact sensing approaches, BCGs also suffer from an increased susceptibility to motion artifacts. Despite these challenges, our group [1] as well as others [2] have managed to reliably extract beat-to-beat heart and breath-to-breath respiration rates from BCG. Even the detection of certain types of cardiac arrhythmias has been demonstrated [3].

### B. *Capacitive Electrocardiogram (cECG)*

Capacitive ECG is a special technique which allows to measure an ECG at a distance through cloths, whitout the necessity of undressing or even shaving. Note that often the term ’contactless ECG’ is used in the literature, even though this name might be misleading since the capacitive electrodes, which are used for this purpose, need a stable mechanical contact/distance to the subject in order to produce a reliable ECG. Nevertheless, electrodes are insulated against the skin of the subject by the clothes and sometimes also by another layer of insulating varnish. However, Wartzek et al. [4] have shown that a layer of highly insulating material may cause triboelectricity and along with this degrade the signal quality. Thus, latest developed systems omit these additional insulating layers.

The block diagram of a typical cECG device is given in Fig. 2. Core of the active electrodes is an operational amplifier, which stabilizes the potential on the body surface induced by the heart and decouples it from the consecutive signal processing unit. The signals from the two electrodes are subtracted by an instrumentational amplifier, leading to the well known ECG signal. In order to reduce the influences of common mode signal on the ECG, a so called ‘driven ground electrode’ (DGE) can be used, which couples the inverted and amplified added signal of the electrodes back to the subject. This way, the common mode rejection ratio (CMRR) of the system can significantly be enhanced. After the instrumentational amplifier, additional filter stages are necessary to limit the signal spectrum to the frequency band between 0.1 and 100 Hz.

cECG was first introduced in 1967 by Richardson et al. [5]. During the last decade, applications in bath tubs, chairs, beds or, the latest, even car seats were demonstrated. Also multichannel systems have already been developed, which could be used for homemonitoring or in ambulance. The great advantage of measuring an ECG through clothes lies in the fact that this allows to open many new areas of applications. On the other hand, cECG also creates new challenges: since the coupling impedance between the subject and the electrodes is very high, the input stage of the system needs to have a very high input impedance in order to avoid filter effects. Also, the coupling may not be as well-defined as with adhesive electrodes, leading to an increased amount of motion artifacts. In a clinical study, Czaplik et al. [6] demonstrated that capacitive ECG can be used for the screening of heart rhythm, but may be more challenging for diagnostic purposes since time invariant signal deformations (presumably due to the electrode coupling) may occur under certain conditions. Hardware solutions under current research

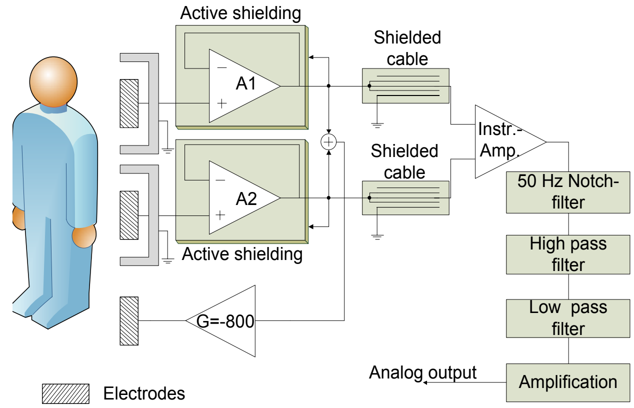


Fig. 2. Block diagram of a capacitive ECG measurement system (modified from [6]).

consider bootstrapping and active guarding of the electrodes.

### C. *Infrared Thermography (IRT)*

Infrared thermography involves the precise measurement of infrared radiation emitted by an object, which allows the surface temperature to be determined according to relatively simple physical laws and known properties of the surface. An object emits radiation with a distribution of wavelengths that is dependent on the object’s temperature and it´s spectral emissivity (or radiation efficiency per wavelength). The higher the object’s temperature, the higher the frequency of the emitted radiation. At room temperature, the typical range of wavelength lies between 7 µm - 14 µm (long wave infrared, LWIR). Infrared cameras can detect this infrared radiation, which is invisible to the human eye, and convert it to a digital image, whose pixel values represent thermal patterns across the object’s surface. Frequent and difficult calibration complicates precise measurements of absolute values. Nevertheless, thermal IR cameras are able to offer excellent determination of qualitative surface temperature.

IRT can examine many different aspects of thermal physiology, diagnose injury and disease. With the help of IRT, it is possible to detect centers of inflammation, weakly perfused subcutaneous regions or febrile temperatures. Although many physiological phenomena occur in the LWIR band, some phenomena, namely bioheat transfer processes, take place in the mid-wave IR or short-wave IR band. IRT is a useful technique for contact-free physiological monitoring of respiration [7]. Here, the mean thermal airflow of the patient’s nostrils can be recorded which correlates with breathing. The nostrils are detected and defined as a Region of Interest (ROI) which is then automatically tracked during measurement using image processing techniques. This method (IRT Respiratory Monitoring, IRTR) represents a promising option for passive non-contact measurement of respiration activity in premature infants and could be a supplement to neonatal IRT (NIRT). In a recent study by some of the authors, real-time IR thermograms of neonates inside incubators were collected [8]. The camera was positioned at a distance of

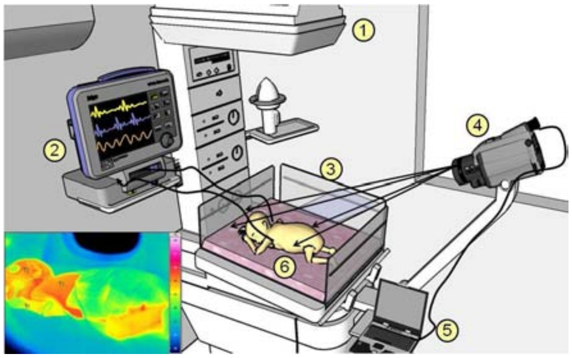


Fig. 3. Setup used for the neonatal infrared respiration monitoring technique (IRTR). (1) radiant warmer bed, (2) bedside monitor, (3) camera field of view (FOV), (4) IR thermal camera, (5) analysis workstation and (6) infant under NIRT imaging (from [9])

approximately 120 cm apart from the baby (Fig. 3).

The results of the IRTR method were promising and may be included into future neonatal monitoring modalities.

### D. Magnetic Induction Monitoring (MIM)

Magnetic induction monitoring is a non-contacting bioimpedance measurement technique based on eddy current induction. Already well known for non-destructive testing of metals, it's first application to biological tissue took place in 1968 [10]. The physical principle is based on Maxwell's theory (Fig. 4). A sensor-coil driven with an alternating current excites an alternating magnetic field, which induces eddy currents into the conductive tissue of a body in it´s vicinity. These induced eddy currents reexcite a secondary alternating magnetic field whose amplitude and orientation correlates with the impedance distribution within the body. The body's impedance distribution varies with physiological activity. This may be due to regional changes of tissue conductivity, which modulates the strength of the eddy currents and therewith the field strength, or by displacement of organ boundaries, which modulates the eddy current paths and therewith the orientation of the reinduced field.

The secondary alternating magnetic field, which includes the information about physiological activity, can be measured by direct or indirect measurement techniques ([11]). In direct measurement techniques, a second separate coil is used for measuring the reinduced field. In indirect measurement techniques, a single coil is used for exciting the primary field as well as for measuring the secondary one. Typical frequencies for the primary alternating magnetic field sent out by the coil lie between 5 - 20 MHz, affecting the strength of the eddy currents as well as the penetration depth of the field. Magnetic field strengths of the excitation field can reach 0.073 A/m, which is still in the range of medical safety.

By using electromagnetic coupling magnetic induction monitoring is a technique that works without the need for any contact. Although this property is the method's greatest advantage, it also bears some challenges. A big problem the method has to compete with is, that changes in the distance between coil and body-surface affect the signal much stronger than any inner-body process, so that motion of the body often inhibits the assessement of the physiological activity under investigation.

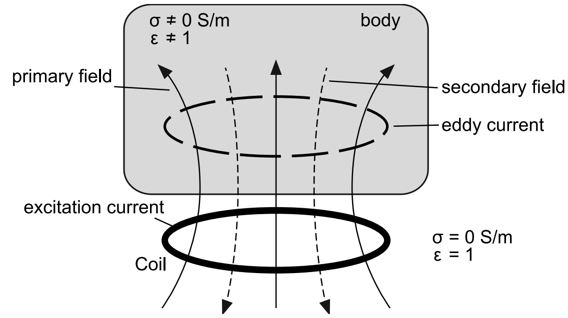


Fig. 4. Physical principle of magnetic induction monitoring (modified from [12]).

Since MIM measures the impedance of biological tissue, in theory it could substitute common contact constrained bioimpedance measurement devices in each of their applications. In practice, precise measurements of regional tissue impedance by MIM are hard to achieve and up to now only realized under laboratory conditions. In this context, extensive laboratory and simulative studies have been conducted by several research groups in order to investigate the method's potential for the detection of edema as well as for obtaining tomographic images by multichannel approaches (Magnetic Induction Tomography). Therefore, currently the most frequent use of MIM for in vivo experiments is monitoring respiration and pulse. Here the displacement of organ boundaries (lung and heart) vary the thoracic impedance distribution (and thus the paths of the eddy currents) resulting in a clear change of the reinduced field. MIM devices aiming at assessing respiration and pulse were integrated into incubators for monitoring neonates or into articles of daily use (e.g. chair, bed, clothes) for monitoring elderly adults in their domestic environment.

### E. Photoplethysmography Imaging (PPGI)

Photoplethysmography Imaging was introduced in 1996 [13]. It is a camera-based remote measurement method for visualisation of dermal blood vessels and for detecting perfusion in different skin areas. Enhancing classical skin contact photoplethysmography (PPG) without spatial resolution, it is based on the same basic principle: Measuring the optical damping of skin (in visible and near infrared (400 - 1000 nm), which is dependent on it´s current composition of blood and tissue, on the light path from a light source to a detector. This composition is modulated by blood volume changes, following venous and/or arterial hemodynamics by patient in rest or under exercise.

Classical PPG sensors consist of one or more light sources (usually light emitting diodes, LEDs) and one light detector (usually a photodiode or a phototransistor). Depending on the position of these components, measurements are conducted either in transmissive (e.g. in clips for earlobes or finger tips) or reflective mode (e.g. adhesive sensors stuck on

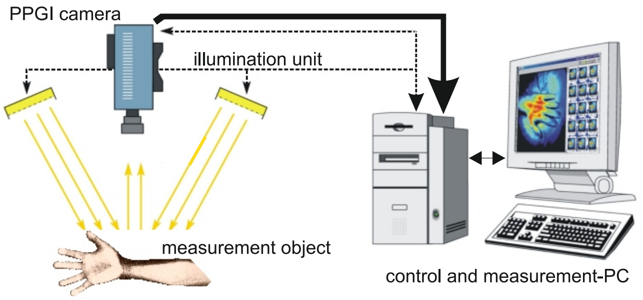


Fig. 5. PPGI measurement setup including illumination unit, PGI camera, PC and measurement object (modified from [15]).

skin surface). For PPGI measurements, a high resolution camera incl. a multi-wavelength tissue illumination array is used instead of the singular contact-sensor. This allows not only non-invasive, but also non-contact tissue perfusion assessment with some spatial resolution in the field of view (FOV) of the camera (compare PPGI measurement setup in Fig. 5). Thereby, every pixel of the camera's sensor array can be considered as a discrete reflective PPG sensor. Accordingly, PPGI is suitable for measuring the same vital parameters as PPG (venodynamic parameters like venous refilling time, muscle-pump efficacy or venous outflow and arterial blood volume pulse characteristics like heart rate, heart rate variability or arterial oxygen saturation). It can also be used to monitor wounds. Here, there is some connection to classical optical techniques in the visible frequency band [14].

A main difference between PPGI and PPG lies in the composition of the measured light intensities. In PPG recordings, direct light crosstalk caused by light scattering directly at the skin surface can be prevented mostly by optical barriers. For PPGI, this is not possible however. Direct scattered components represent the majority of the detected light intensities compared to intensities caused by light invaded into deeper layers of skin and additionally backscattered to skin surface and the camera. Hence, PPGI time series contain much larger DC components than PPG recordings according to much larger time-invariant surface scattering.

Main application areas for PPGI are anticipated wherever either simultaneous, comparable measurements at different locations of the body are necessary or an application of contact PPG sensors is not possible. An example for such a scenario is the assessment of skin perfusion reactions to allergic tests [15]. Another innovative scenario is the application of PPGI in neonate incubators.

## III. Summary & Conclusions

All 5 methods presented above do not rely on conductive contact. However, when speaking about non-contact techniques, we need to distinguish different types of contact. BCG and cECG are both dependent on mechanical contact or at least fixed distances, while IRT as well as PPGI require optical contact (intervisibility). MIM, as a sole exception, is not based on any contact, refering to traditionally used definitions. Nevertheless, this technique is based on electromagnetic coupling, which could also be impeded by several environmental conditions and is sensitive to motion.

Non-contacting monitoring methods can also be categorized into active and passive techniques. Since in PPGI and MIM, energy is induced into the body and a reflected energy is measured, those methods are explicitly active techniques. In contrast, BCG and IRT do not emit energy and hence can be categorized as passive methods. The fundamental principle of the capacitive ECG (recording the ECG via capacitive electrodes) is also a passive approach, but advanced devices become active by using the DGE for enhancing the CMRR.

If chosen carefully according to the desired physiological information and the circumstances of the measurement scenario, we believe that non-contact methods can be coequal substitutes for conventional methods, or even outperform them by a variety of further advantages.

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