

Remote Monitoring of Vital Signs Using Computer Vision Systems

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Techniques for noncontact measurement of vital signs using camera imaging technologies have been attracting increasing attention. For noncontact physiological assessments, computer vision-based methods appear to be an advantageous approach that could be robust, hygienic, reliable, safe, cost effective and suitable for long distance and long-term monitoring. In addition, video techniques allow measurements from multiple individuals opportunistically and simultaneously in groups. This paper aims to explore the progress of the technology from controlled clinical scenarios with fixed monitoring installations and controlled lighting, towards uncontrolled environments, crowds and moving sensor platforms. We focus on the diversity of applications and scenarios being studied in this topic. From this review it emerges that automatic multiple regions of interest (ROIs) selection, removal of noise artefacts caused by both illumination variations and motion artefacts, simultaneous multiple person monitoring, long distance detection, multi-camera fusion and accepted publicly available datasets are topics that still require research to enable the technology to mature into many real-world applications.

The monitoring of human vital signs, for example respiratory rate (RR), blood oxygen saturation (SpO₂), heart rate (HR), heart rate variability (HRV) and blood pressure (BP) plays a significant role in modern clinical care of patients in hospitals and at home [1]. Applications include medical diagnosis, training programs, fitness assessment, lie detection and stress measurement [2]. There are various instruments for measuring these vital signs, such as electrocardiograms (ECGs), pulse oximeters, nasal thermocouples, respiratory belt transducers and piezoelectric transducers [3]. These instruments require direct physical contact with the human body as they use contact-based, sensor modalities, straps, probes or electrodes [4]. These instruments may cause skin infection, injury, or harmful reactions on patients especially premature babies, aged people or burns victims who have fragile skin [5]. Moreover, there is a risk of entanglement or strangulation of infants who are attached to monitors by means of wires and leads [6]. These instruments are also not appropriate for long term monitoring as they may cause discomfort, irritation and a cumulative risk of fungal and bacterial infection [7]. In addition, a reduced amplitude of chest wall expansion can affect the respiratory rate (RR) input signal from the impedance lead [8]. Furthermore, cost is an important issue as the monitoring electrodes and leads are only intended and certified for a single use, followed by disposal [9]. Placement of the sensors with self-adhesive pads leads to difficulties with wet, oily, dirty or hairy subjects which is a limitation of these technologies in emergency situations [10]. Accuracy is another issue with conventional contact methods since they are sensitive to artefacts produced by the subject's movement [11]. Therefore, to minimise these limitations, there is a need for an alternative method where vital signs can be measured without any physical contact.

As presented in Figure 1, there are several noncontact means based on magnetic induction, the Doppler effect, thermal imaging and video camera imaging which can be an effective alternative means of monitoring vital signs with acceptable reliability and accuracy [12]. These methods depend on the observation of physical and physiological variations including skin colour, temperature, impedance changes, head motion, arterial pulse motion, and importantly, thoracic and abdominal motion due to the activity of both the respiratory and cardiovascular systems. Magnetic induction-based methods can detect the impedance changes caused by blood and air volume variations due to the mechanical action of the heart, diaphragm and thorax. The basic principle is to induce eddy currents in the tissue and to calculate the re-induced magnetic field externally; the impedance changes can then be observed remotely to extract vital signs [13]. The method uses a simple arrangement based on multiple coils [14] or a single coil [15] integrated into a mattress [16], bed [17] or seat [18]. However, the method is highly susceptible to relative movements between coil and body.

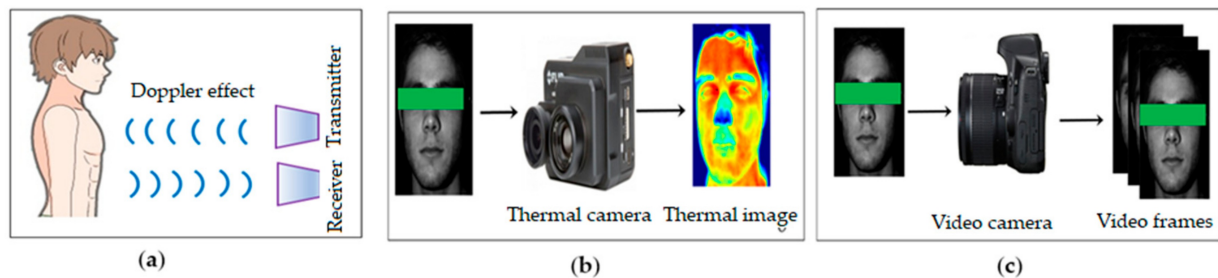


Figure 1. Contactless measuring methods. (a) The Doppler effect; (b) thermal imaging; (c) video camera imaging.

The Doppler effect is an active noncontact method that can detect subtle chest movements due to cardiorespiratory activity. In this method, vital signs are extracted using a Doppler radar [19,20], or laser sensors [21] as well as digital signal processing (DSP) techniques [22] where the phase shift between the transmitted waves and the reflected received waves from a region of interest (ROI) are calculated. There are three types of Doppler-based methods—Doppler with electromagnetics [23,24], lasers [25,26], and ultrasonics [27,28,29].

Thermal imaging [30,31] is a passive noncontact method that can detect the radiation emitted from particular parts of the human body in the infrared (IR) range of the electromagnetic spectrum to measure the physiological signal using a thermal camera [32,33,34]. Thermal imaging-based methods extract vital signs by measuring temperature changes around the nostril area [35,36,37,38] as well as heat differences due to pulsating blood flow in the main superficial arteries at various regions such as the carotid artery in the neck [39,40] and temporal artery in the forehead [41,42]. However, both Doppler- and thermal imaging-based approaches are susceptible to noise and motion artefacts and constrain the movement of the subjects due to the high cost of the sensor, preventing saturation sampling of the environment. Their relatively low resolution limits the detection range and specificity to one subject. Moreover, these methods need exposed ROI and specialized hardware, making them costly [4]. They are also constrained to short-term monitoring and monitoring a single subject at a time. Additionally, Doppler-based methods may have biological effects on humans [43] with unknown future population risks if broadly adopted.

Digital cameras offer high resolution, in spatial (number of pixels per degree), temporal (number of frames per second), intensity (number of bits per pixel) and in spectrum (at least 3 visible channels, with hyperspectral options increasingly common), all due to consumer market demand. Furthermore, a large base of research assets exist for processing imagery, much of it free for use, for example; OpenCV [44]. Flexibility with visible light optical design, offering panoramic, microscopic and telescopic solutions in well integrated commercial product families allows diverse measurement scenarios. Tailored fields of view allow analysis of multiple ROIs in parallel, or in series based on availability. The mass market has led to low cost [4,12] and affordable optics that can be used in almost any conceivable application scenario [9].

Video camera imaging is a passive contactless method where video cameras are used to extract different physiological signals from several regions of the human body, exploiting two principles. The first principle relies on skin colour variations due to cardiorespiratory activity, photoplethysmography (PPG). Vital signs are measured by exploiting variations in the reflectance properties of human skin from video, which causes variation in brightness values in sequences of images. The second principle depends on cyclic body motion owing to cardiorespiratory activity in techniques that can be broadly characterised as motion-based methods. The motion in the regions of the head, arterial pulse, and thoracic and abdominal region are included in this method. For noncontact physiological assessments, camera imaging based methods seem to be a promising approach since they are robust, reliable, safe, cost-effective, suitable for long distance and long-term monitoring as well as multiple person detection simultaneously [12].

Camera imaging-based methods have been attracting increasing attention in the literature. This paper aims to explore the progress of video camera imaging-based technology from controlled clinical scenarios with fixed monitoring installations and controlled lighting, towards uncontrolled environments, crowds and moving sensor platforms. We focus on the diversity of applications and scenarios being studied in this topic. We emphasise visible light sensing since these cameras represent the largest installed base, the lowest costs, the highest rate of improvement and the greatest opportunity to insert new capability into existing devices. First, we discuss studies of motion and colour-based methods.

Then, we discuss the considerations and scenarios appropriate to colour-based methods, for example, in the presence of motion artefacts, illumination variation, different sensors, different subjects, different vital signs, multiple ROIs, long distance and multiple persons. Additionally, potential application of iPPG in both clinical and non-clinical sectors are described. We then consider research gaps and challenges of existing studies that may inform researchers who wish to further progress the techniques and applications.

Keywords

vital signs; remote monitoring; video camera imaging; imaging photoplethysmography



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