Remote Monitoring of Vital Signs

Subjects: Pharmacology & Pharmacy
Contributor: Fatema-Tuz-Zohra Khanam

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.

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

1. Introduction

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.

2. Remote Monitoring of Vital Signs Using Computer Vision Systems

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-inducted 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.

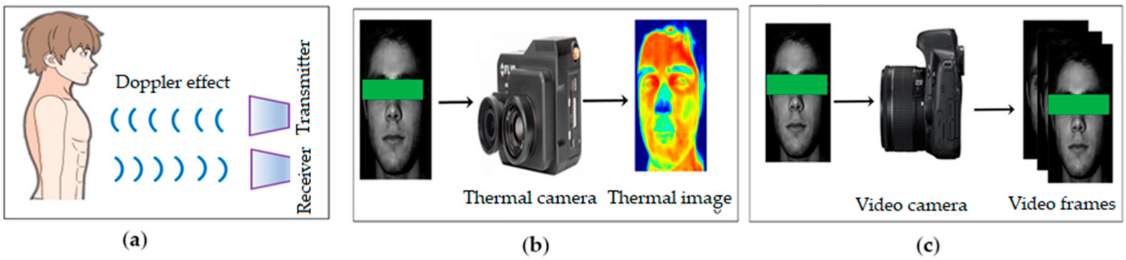

Figure 1. Contactless measuring methods. (**a**) The Doppler effect; (**b**) thermal imaging; (**c**) video camera imaging.

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.

References

1. Christoph Bruser; Christoph Hoog Antink; Tobias Wartzek; Marian Walter; Steffen Leonhardt; Christoph Brueser; Ambient and Unobtrusive Cardiorespiratory Monitoring Techniques. *IEEE Reviews in Biomedical Engineering* **2015**, *8*, 30-43, 10.1109/rbme.2015.2414661.
2. Xun Chen; Juan Cheng; Rencheng Song; Yu Liu; Rabab Ward; Z. Jane Wang; Video-Based Heart Rate Measurement: Recent Advances and Future Prospects. *IEEE Transactions on Instrumentation and Measurement* **2019**, *68*, 3600-3615, 10.1109/tim.2018.2879706.
3. Fang Zhao; Meng Li; Yi Qian; Joe Z. Tsien; Remote Measurements of Heart and Respiration Rates for Telemedicine. *PLOS ONE* **2013**, *8*, e71384, 10.1371/journal.pone.0071384.
4. J. Kranjec; S. Beguš; G. Geršak; J. Drnovsek; Non-contact heart rate and heart rate variability measurements: A review. *Biomedical Signal Processing and Control* **2014**, *13*, 102-112, 10.1016/j.bspc.2014.03.004.
5. Philipp V. Rouast; Marc T. P. Adam; Raymond Chiong; David Cornforth; Ewa Lux; Remote heart rate measurement using low-cost RGB face video: a technical literature review. *Frontiers of Computer Science* **2018**, *12*, 858-872, 10.1007/s11704-016-6243-6.
6. Shobha Phansalkar; Judy Edworthy; Elizabeth Hellier; Diane L Seger; Angela Schedlbauer; Anthony J Avery; David W Bates; A review of human factors principles for the design and implementation of medication safety alerts in clinical information systems. *Journal of the American Medical Informatics Association* **2010**, *17*, 493-501, 10.1136/jamia.2010.005264.
7. Yu Sun; Nitish Thakor; Photoplethysmography Revisited: From Contact to Noncontact, From Point to Imaging.. *IEEE Transactions on Biomedical Engineering* **2015**, *63*, 463-77, 10.1109/TBME.2015.2476337.
8. Peter H Charlton; Timothy Bonnici; Lionel Tarassenko; Jordi Alastruey; David Clifton; Richard Beale; Peter Watkinson; Extraction of respiratory signals from the electrocardiogram and photoplethysmogram: technical and physiological determinants. *Physiological Measurement* **2017**, *38*, 669-690, 10.1088/1361-6579/aa670e.
9. Ali Al-Naji; Kim Gibson; Javaan Chahl; Remote sensing of physiological signs using a machine vision system. *Journal of Medical Engineering & Technology* **2017**, *41*, 396-405, 10.1080/03091902.2017.1313326.
10. Lonneke A.M. Aarts; Vincent Jeanne; John P. Cleary; C. Lieber; J. Stuart Nelson; Sidarto Bambang Oetomo; Wim Verkruysse; Non-contact heart rate monitoring utilizing camera photoplethysmography in the neonatal intensive care unit — A pilot study. *Early Human Development* **2013**, *89*, 943-948, 10.1016/j.earlhumdev.2013.09.016.
11. S. Zaunseder; A. Henning; D. Wedekind; A. Trumpp; H. Malberg; Unobtrusive acquisition of cardiorespiratory signals Kontaktlose Erfassung kardiorespiratorischer Signale. *Somnologie* **2017**, *21*, 93-100, https://link.springer.com/article/10.1007%2Fs11818-017-0112-x.
12. Ali Al-Naji; Kim Gibson; Sang-Heon Lee; Javaan Chahl; Monitoring of Cardiorespiratory Signal: Principles of Remote Measurements and Review of Methods. *IEEE Access* **2017**, *5*, 15776-15790, 10.1109/access.2017.2735419.
13. Scalise, L. Non contact heart monitoring. In Advances in Electrocardiograms-Methods and Analysis; IntechOpen: London, UK, 2012.
14. Peter P. Tarjan; Richard McFee; Electrodeless Measurements of the Effective Resistivity of the Human Torso and Head by Magnetic Induction. *IEEE Transactions on Biomedical Engineering* **1968**, *4*, 266-278, 10.1109/TBME.1968.4502577.
15. Guardo, R.; Trudelle, S.; Adler, A.; Boulay, C.; Savard, P. Contactless recording of cardiac related thoracic conductivity changes. In Proceedings of the 1995 IEEE 17th International Conference of the Engineering in Medicine and Biology Society, Montreal, QC, Canada, 20–23 September 1995; pp. 1581–1582.
16. Richer, A.; Adler, A. Eddy current based flexible sensor for contactless measurement of breathing. In Proceedings of the 2005 IEEE Instrumentation and Measurement Technology Conference Proceedings, Ottawa, ON, Canada, 16–19 May 2005; pp. 257–260.
17. Matthias Steffen; Adrian Aleksandrowicz; Steffen Leonhardt; Mobile Noncontact Monitoring of Heart and Lung Activity. *IEEE Transactions on Biomedical Circuits and Systems* **2007**, *1*, 250-257, 10.1109/tbcas.2008.915633.
18. Vetter, P.; Leicht, L.; Leonhardt, S.; Teichmann, D. Integration of an electromagnetic coupled sensor into a driver seat for vital sign monitoring: Initial insight. In Proceedings of the 2017 IEEE International Conference on Vehicular Electronics and Safety (ICVES), Vienna, Austria, 27–28 June 2017; pp. 185–190.

19. Harikesh Dalal; Ananjan Basu; Mahesh P. Abegaonkar; Remote sensing of vital sign of human body with radio frequency. *CSI Transactions on ICT* **2017**, *5*, 161-166, 10.1007/s40012-016-0154-4.
20. Muhammad Saqib Rabbani; Hooshang Ghafouri-Shiraz; Ultra-Wide Patch Antenna Array Design at 60 GHz Band for Remote Vital Sign Monitoring with Doppler Radar Principle. *Journal of Infrared, Millimeter, and Terahertz Waves* **2016**, *38*, 548-566, 10.1007/s10762-016-0344-z.
21. Scalise, L.; Marchionni, P.; Ercoli, I. Optical method for measurement of respiration rate. In Proceedings of the 2010 IEEE International Workshop on Medical Measurements and Applications, Ottawa, ON, Canada, 30 April–1 May 2010; pp. 19–22
22. B. Lohman; O. Boric-Lubecke; V.M. Lubecke; P.W. Ong; M.M. Sondhi; A digital signal processor for Doppler radar sensing of vital signs. *IEEE Engineering in Medicine and Biology Magazine* **2002**, *21*, 161-164, 10.1109/memb.2002.1044188.
23. Marco Mercuri; Yao-Hong Liu; Ilde Lorato; Tom Torfs; Andre Bourdoux; Chris Van Hoof; Frequency-Tracking CW Doppler Radar Solving Small-Angle Approximation and Null Point Issues in Non-Contact Vital Signs Monitoring. *IEEE Transactions on Biomedical Circuits and Systems* **2017**, *11*, 671-680, 10.1109/TBCAS.2016.2647560.
24. Mehrdad Nosrati; Shahram Shahsavari; Sanghoon Lee; Hua Wang; Negar Tavassolian; A Concurrent Dual-Beam Phased-Array Doppler Radar Using MIMO Beamforming Techniques for Short-Range Vital-Signs Monitoring. *IEEE Transactions on Antennas and Propagation* **2019**, *67*, 2390-2404, 10.1109/tap.2019.2893337.
25. P. Marchionni; L. Scalise; I. Ercoli; Enrico Primo Tomasini; An optical measurement method for the simultaneous assessment of respiration and heart rates in preterm infants. *Review of Scientific Instruments* **2013**, *84*, 121705, 10.1063/1.4845635.
26. Erik J. Sirevaag; Sara Casaccia; Edward A. Richter; Joseph A. O'sullivan; Lorenzo Scalise; John W. Rohrbaugh; Cardiorespiratory interactions: Noncontact assessment using laser Doppler vibrometry. *Psychophysiology* **2016**, *53*, 847-867, 10.1111/psyp.12638.
27. D W Holdsworth; C J D Norley; R Frayne; D A Steinman; B K Rutt; Characterization of common carotid artery blood-flow waveforms in normal human subjects.. *Physiological Measurement* **1999**, *20*, 219-240, 10.1088/0967-3334/20/3/301.
28. Philippe Arlotto; Michel Grimaldi; Roomila Naeck; Jean-Marc Ginoux; An Ultrasonic Contactless Sensor for Breathing Monitoring. *Sensors* **2014**, *14*, 15371-15386, 10.3390/s140815371.
29. Se Dong Min; Dae Joong Yoon; Sung Won Yoon; Yong Hyeon Yun; Myoungho Lee; A study on a non-contacting respiration signal monitoring system using Doppler ultrasound. *Medical & Biological Engineering & Computing* **2007**, *45*, 1113-1119, 10.1007/s11517-007-0246-2.
30. Yang, M.; Liu, Q.; Turner, T.; Wu, Y. Vital sign estimation from passive thermal video. In Proceedings of the 2008 IEEE Conference on Computer Vision and Pattern Recognition, Anchorage, AK, USA, 23–28 June 2008; pp. 1–8.
31. Stephanie Bennett; Tarek Nasser El Harake; Rafik Goubran; Frank Knoefel; Adaptive Eulerian Video Processing of Thermal Video: An Experimental Analysis. *IEEE Transactions on Instrumentation and Measurement* **2017**, *66*, 2516-2524, 10.1109/TIM.2017.2684518.
32. J.-F. Cardoso; Blind signal separation: statistical principles. *Proceedings of the IEEE* **1998**, *86*, 2009-2025, 10.1109/5.720250.
33. Heather E. Elphick; Abdulkadir Hamidu Alkali; Ruth K. Kingshott; Derek Burke; Reza Saatchi; Exploratory Study to Evaluate Respiratory Rate Using a Thermal Imaging Camera. *Respiration* **2019**, *97*, 205-212, 10.1159/000490546.
34. Luca, C.; Corciovă, C.; Andriţoi, D.; Ciorap, R. The Use of Thermal Imaging Techniques as a Method of Monitoring the New Born. In Proceedings of the 6th International Conference on Advancements of Medicine and Health Care through Technology, Cluj-Napoca, Romania, 17–20 October 2018; pp. 35–39
35. Abbas K Abbas; Konrad Heimann; Katrin Jergus; Thorsten Orlikowsky; Steffen Leonhardt; Neonatal non-contact respiratory monitoring based on real-time infrared thermography. *BioMedical Engineering OnLine* **2011**, *10*, 93, 10.1186/1475-925X-10-93.
36. Nikolai Blanik; Abbas K. Abbas; Boudewijn Venema; Vladimir Blazek; Steffen Leonhardt; Hybrid optical imaging technology for long-term remote monitoring of skin perfusion and temperature behavior. *Journal of Biomedical Optics* **2014**, *19*, 16012, 10.1117/1.jbo.19.1.016012.
37. Ronan Chauvin; Mathieu Hamel; Simon Brière; Francois Ferland; François Grondin; Dominic Létourneau; Michel Tousignant; Francois Michaud; Chauvin R.; Hamel M.; et al. Contact-Free Respiration Rate Monitoring Using a Pan–Tilt Thermal Camera for Stationary Bike Telerehabilitation Sessions. *IEEE Systems Journal* **2014**, *10*, 1046-1055, 10.1109/jsyst.2014.2336372.

38. Carina Barbosa Pereira; Xinchi Yu; Michael Czaplik; Rolf Rossaint; Vladimir Blazek; Steffen Leonhardt; Remote monitoring of breathing dynamics using infrared thermography.. *Biomedical Optics Express* **2015**, *6*, 4378-4394, 10.1364/BOE.6.004378.

39. Marc Garbey; Nanfei Sun; Arcangelo Merla; Ioannis Pavlidis; Contact-Free Measurement of Cardiac Pulse Based on the Analysis of Thermal Imagery. *IEEE Transactions on Biomedical Engineering* **2007**, *54*, 1418-1426, 10.1109/TBME.2007.891930.

40. Ioannis Pavlidis; J. Dowdall; N. Sun; C. Puri; J. Fei; M. Garbey; Interacting with human physiology. *Computer Vision and Image Understanding* **2007**, *108*, 150-170, 10.1016/j.cviu.2006.11.018.

41. Sun, N.; Garbey, M.; Merla, A.; Pavlidis, I. Imaging the cardiovascular pulse. In Proceedings of the 2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05), San Diego, CA, USA, 20–25 June 2005; pp. 416–421.

42. Chekmenev, S.Y.; Farag, A.A.; Miller, W.M.; Essock, E.A.; Bhatnagar, A. Multiresolution approach for noncontact measurements of arterial pulse using thermal imaging. In Augmented Vision Perception in Infrared; Springer Science and Business Media LLC: Berlin, Germany, 2009; pp. 87–112.

43. Abbas, A.K.; Heiman, K.; Orlikowsky, T.; Leonhardt, S. Non-Contact Respiratory Monitoring Based on Real-Time IR-Thermography. In Proceedings of the World Congress on Medical Physics and Biomedical Engineering, Munich, Germany, 7–12 September 2009; pp. 1306–1309.

44. Kari Pulli; Anatoly Baksheev; Kirill Kornyakov; Victor Eruhimov; Real-time computer vision with OpenCV. *Communications of the ACM* **2012**, *55*, 61-69, 10.1145/2184319.2184337.

Retrieved from https://encyclopedia.pub/entry/history/show/8204