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Article

# Review on Contactless Vital Sign Monitoring: Techniques and Applications of Remote Photoplethysmography and Photoplethysmography for Remote Health Monitoring

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**Abstract:** In recent years, companies and governments globally have been investing heavily in the advancement of contactless sensor technologies aimed at reducing the necessity for direct physical interactions betwixt patients and healthcare providers. As a result, healthcare research on cutting-edge contactless technologies has advanced rapidly, especially for infants along with elderly individuals with chronic conditions who need continuous, real-time monitoring and management. Thus, Contactless Vital Sign Monitoring (CVSM) is a newly introduced technology. CVSM employing techniques like remote photoplethysmography (rPPG) together with traditional photoplethysmography (PPG), has gained major attention because of its ability to measure physiological parameters without the requirement for physical contact. Thus, this paper explores the applications of rPPG and PPG in Remote Health Monitoring (RHM). To detect subtle changes in blood volume, rPPG utilizes ambient or controlled light reflected from a subject's skin, enabling the estimation of Vital Signs (VSs) like Heart Rate (HR), Respiratory Rate (RR), along with oxygen saturation. But, PPG relies on direct optical sensors placed on the skin to capture similar physiological data. Thus, the review's current objective is to analyze PPG and rPPG in RHM. This study also discusses the key parameters utilized in the analysis of PPG and rPPG for RHM along with the clinical application.
**Keywords:** Remote health monitoring, photoplethysmography, Physical contact, Remote photoplethysmography, Contactless vital sign monitoring, and health care.

## 1. Introduction

Currently, due to advancements in healthcare and improved living conditions, people are having a healthy life. Therefore, the world's population is increasing at an unprecedented rate, leading to significant demographic shifts and posing both opportunities and challenges for global societies. Specifically, the percentage of the population, mainly above 60 years, will increase along with exceeding the population of children under the age of 5 in the years between 2015 and 2050 [1]. VS measurements are found to be more important for improving healthcare, confirming the well-being of children, and contributing to the exceeding population of healthy children.

Usually, VS measurements like HR, RR, and blood oxygen saturation depend on direct physical contact with sensors like ECG electrodes, pulse oximeters, or wearable devices [2]. Yet, the development of contactless monitoring technologies has become increasingly important to ensure accurate and comfortable health assessments with the exceeding population of children. The use of non-invasive technologies to remotely measure physiological parameters like HR, respiration rate, along with blood oxygen levels without requiring physical contact with the ind-

individual is termed CVSM [3]. The population of children exceeds expectations as the CVSM system ensures early detection and timely intervention of health issues, contributing to lower mortality rates and improved overall health outcomes. CVSM systems utilize non-invasive methods and offer better replacement by providing real time monitoring without the requirement for physical sensors attached to the body. The techniques for contactless monitoring VSs include radar, infrared thermography, camera-based systems, and PPG [4]. Among radar, infrared thermography, and camera-based systems, PPG is more important for RHM due to its ability to provide accurate and continuous measurement of VSs like HR and blood oxygen saturation in a non-invasive manner. In clinical practice, PPG is usually wielded for measuring the oxygen saturation level (SpO2) in the blood along with pulse rate, which is a patient's VS. The same principle of PPG is used in remote PPG (rPPG), which allows contactless measurements [5]. rPPG, which has attracted much attention as of researchers recently, is a non-contact methodology to appraise HR as of video recordings. It is famous that rPPG signals could be extracted from lower-resolution videos [6].

It was noted that there are different applications of PPG and rPPG by reviewing the existing research articles in the literature. Researchers have acquired useful data associated with RR, cardiovascular diseases, blood pressure, neurological disorders, etc., by processing PPG signals and rPPG signals. Clinically, PPG signal and rPPG can be useful for assessing a variety of physiological traits. They are important for the development of reasonably priced and efficient monitoring, screening, and diagnostic instruments in various healthcare domains. Publications along with citations of the words "PPG" OR "rPPG" are depicted in Figure 1. The year range considered in the review is between 2014 and to present as of the Web of Science report.

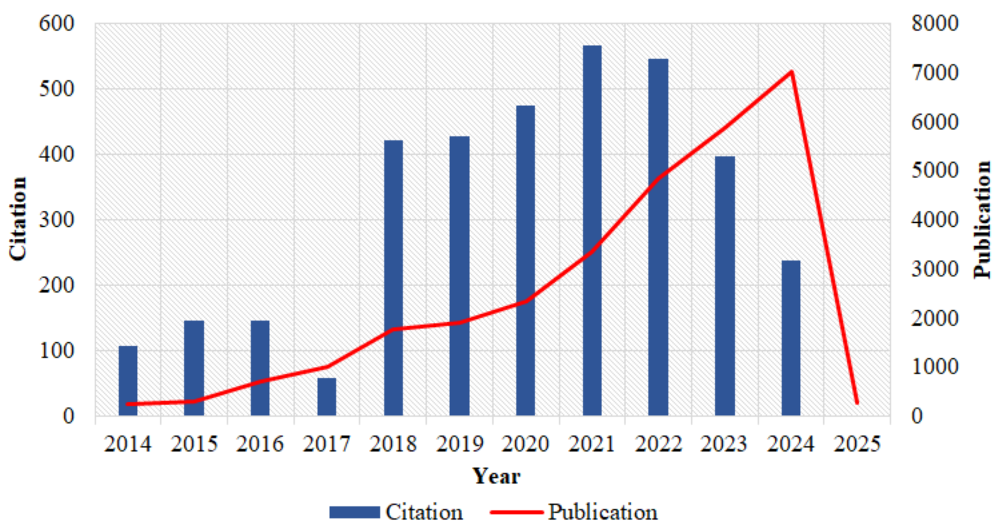


Figure 1: Web of Science publications and citations of the words" PPG" OR "rPPG

Different kinds of reviews have been done on PPG and rPPG signals' applications. Chiefly, some reviews concentrate on the medical utilization of PPG and rPPG like Blood pressure [7], Pulse rate [8], etc., while others concentrate on exploring the type of sensor or the way in which the signal is analyzed. More than 10 years ago, Sebastian, et al [9] published an attractive review about heartbeat detection (one of the applications from PPG and rPPG) and analysis from videos. 3 years ago, Junyung, et al [10] explored an integrative review with the combination of PPG analysis and its applications and reviewed the current state and future prospects of PPG, including its measurement principle and mechanism, waveform characteristics, representative noise, pre-processing technology, feature extraction technology, and post-processing technology. It also gave a thorough engineering assessment of PPG based on prior research and literature. But, it is still required to concentrate on RHM using CVSM techniques (PPG and rPPG). The core objective of our review is to explore the developments in RHM using CVSM, specifically focusing on the techniques and applications of rPPG and PPG for tracking VSs without the need for physical contact.

Presently, PPG and rPPG have been significant tools for monitoring as well as screening different kinds of respiratory along with neurological diseases. The deployed tools in PPG and rPPG studies have not fully covered the improvements in RHM. Thorough analysis and classification of these signals represent a major advancement in creating practical and user-friendly PPG- and rPPG-based tools for various applications. In order to do this and to answer the important questions, existing literature's systematic review on PPG and rPPG for RHM and applications in various clinical backgrounds has been conducted.

(1)What are the developments in RHM using CVSM, particularly when concentrating on PPG and rPPG?

(2)What are the applications of PPG and rPPG for RHM?

Here, the current literature on advancements and uses of PPG along with rPPG in RHM attempts to close this gap in the review.

Categorizing the literature and highlighting trends and significance of the utilization of PPG and rPPG in RHM are the current review's core objectives. Likewise, an attempt has been made to analyze the present utilization of PPG and rPPG in healthcare more correctly as well as systematically. Further, all peer-reviewed articles on the usage of PPG along with rPPG signals are compiled and the applications of both techniques in RHM are reviewed. This review aims to serve as a foundation for future applications in RHM using PPG and rPPG architecture design.

The remaining part is categorized as follows: In section 2, the literature review is explained. Techniques of CVSM for RHM and different kinds of applications of PPG and rPPG for RHM are explained in section 3. Lastly, the conclusions are explored in section 4.

## 2. Method of Systematic Review

The existing PPG and rPPG research articles were found and collected as part of a systematic literature search. The process was performed to collect necessary related data and to provide detailed answers to our particular study objectives, which would further direct future research studies on the clinical applications of both PPG and rPPG. The PRISMA 2020 systematic guidelines are utilized in this systematic review for the purpose of attaining accurate information even though there are significantly different guidelines. This systematic literature review is categorized into 4 significant steps as elucidated further:

### *2.1. Search and identification of data sources*

Gathering more publications as much as possible is the main purpose of the systematic literature review and this can be done by a basic keyword-based search. After reviewing more significant databases and search engines based on the keyword search, Web of Science, Scopus, ProQuest, Elsevier, IEEEXplore, ScienceDirect, and ACM Digital Library are some of the significant databases used for searching the research articles regarding the keywords "PPG" OR "rPPG" OR "RHM". In this systematic literature review, significant PPG and rPPG application literature have been included with more concentration on new research articles. Additionally, we have also included some of the old research papers that are in the PPG and rPPG domain.

### *2.2. Eligibility*

The following criteria are attained based on the eligibility for a more concentrated search.

- A1: In the review paper, the Publication year of the articles was from 2014 to 2025.
- A2: Important work with a high number of citations prior to 2015 that established a new horizon in PPG and rPPG fields was examined.
- A3: The papers comprising keywords that weren't found in the title or abstract were excluded. Then, the count of papers was decreased to approximately 500.

### *2.3. Process of selection*

The key citations in the original set of 500 papers were considered for ensuring adequate search coverage. This was accomplished by reviewing each paper's reference list. Every abstract was read along with analyzed to determine their relevance to our aims. This was obtained by taking into account '4' more criteria:

- A4: Only works that saw the usage of PPG and rPPG as one of their primary contributions were included.
- A5: Only studies in the healthcare area were taken (other areas like industry along with education were not considered). Figure 2 explains the systematic review based on the PRISMA flowchart 2020.

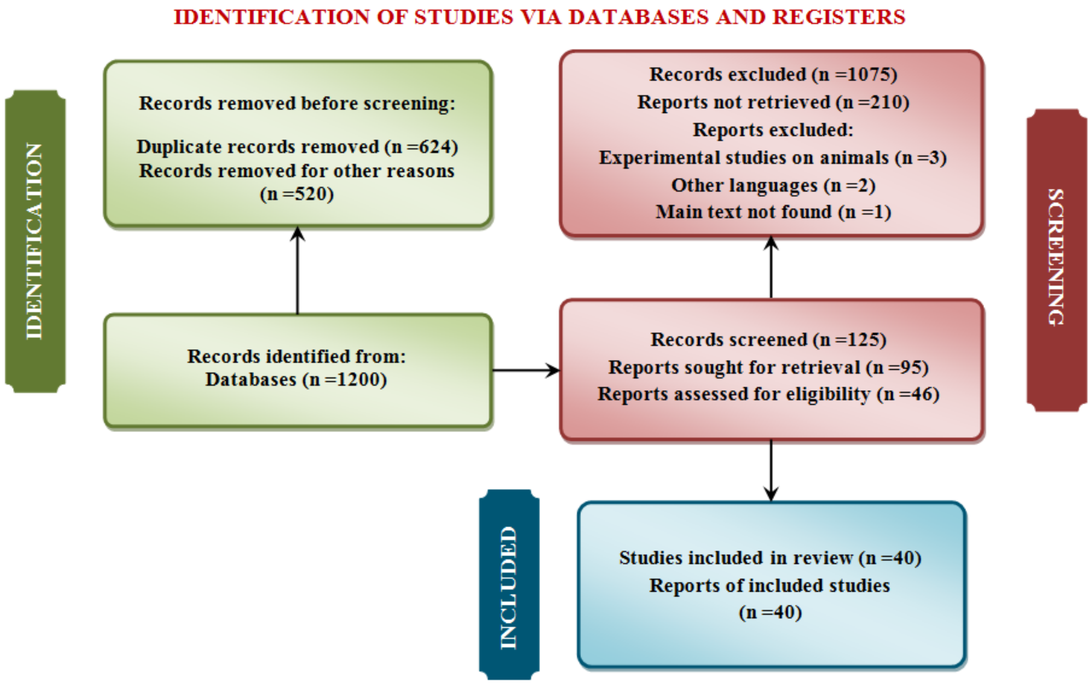


Figure 2: Systematic review based on PRISMA flowchart 2020

## 3. 3. Contactless vital sign monitoring techniques and their applications in remote health monitoring

By providing non-invasive ways to remotely track key physiological parameters like HR, RR, along with blood oxygen saturation (SpO2), CVSM techniques have revolutionized the healthcare landscape [11,12]. These techniques are especially beneficial for RHM, where continuous health tracking is essential but physical contact may be undesirable or impractical. CVSM techniques use electromagnetic waves to measure VSs from the body without making contact. These techniques can be used for monitoring HR, respiration rate, and other VSs [13, 14].

In [15], CVSM was analyzed by employing thermal along with RGB cameras as a study of COVID-19 Health Monitoring (HM). '10' healthy individuals, representing diverse ethnic backgrounds with skin tones varying from pale white to deep brown, partook in multiple trials. The absolute error (AE) was 2.70 ± 2.28 beats/min (mean ± standard deviation) betwixt the reference HR as of each experiment and the calculated HR employing the applied approach. Further, in the research study of [16], CVSM was used for HM in the nursing home. Results demonstrated an inaccuracy below 10% in 74%, 52%, and 96% of the cases for HR, RR, along with body temperature measurements, respectively, when directly compared to reference devices.

It is known that CVSM is well utilized in measurements like heart and RR. In the research study of [17], by employing a near-infrared time-of-flight camera, a CVSM system designed for the heart together with RR measurements with motion compensation was evaluated. This method was used to assess a pilot human research that included 29 individuals of various demographics, including age, gender, along with skin color. According to the study, HR measurements' success rate (system measurement within the reference (10%)) was raised to 75% when depth-based motion compensation was employed and 35% when motion compensation was not employed. It is also known that CVSM is increasingly being used for deteriorating patients' early detection in general wards. Deteriorating patients' early detection in general wards was appraised via continuous contactless VS monitoring in [18]. Across all time points, the deterioration group continuously received more notifications than the typically discharged group. There was an average of 16 hours between the initial alert and the clinical deterioration during the final 24 hours before the occurrence of the disease.

### *3.1. PPG and rPPG*

A diagnostic technique often compared to the ankle-brachial index is termed PPG. It involves placing a small blood pressure cuff around the toe along with a PPG sensor, which uses infrared light to assess blood flow near the skin's surface, capturing waveforms and blood pressure readings [19]. The PPG signal reflects arterial blood volume variations corresponding to each heartbeat and is widely used in wearables for heart rate monitoring. Additionally, PPG data contains valuable insights into the cardiac, vascular, respiratory, along with autonomic nervous systems [20].

Multi-Site PPG technology for blood pressure assessment was analysed in the research of [21]. The Pulse Transit Time (PTT), which was more closely associated with blood pressure than the PAT, was the resultant time interval between the first PPG's detection of the pulse wave and the distal PPG's detection. As illustrated in Figure 3, the '2' PPG probes might be relatively proximal-distal, meaning they were not joined directly in the vascular tree (forehead to toe), or else they may be proximal-distal with the same artery (proximal brachial to the distal brachial artery). The method visualization of multi-site PPG to gauge the pulse transit time is elucidated in Figure 3.

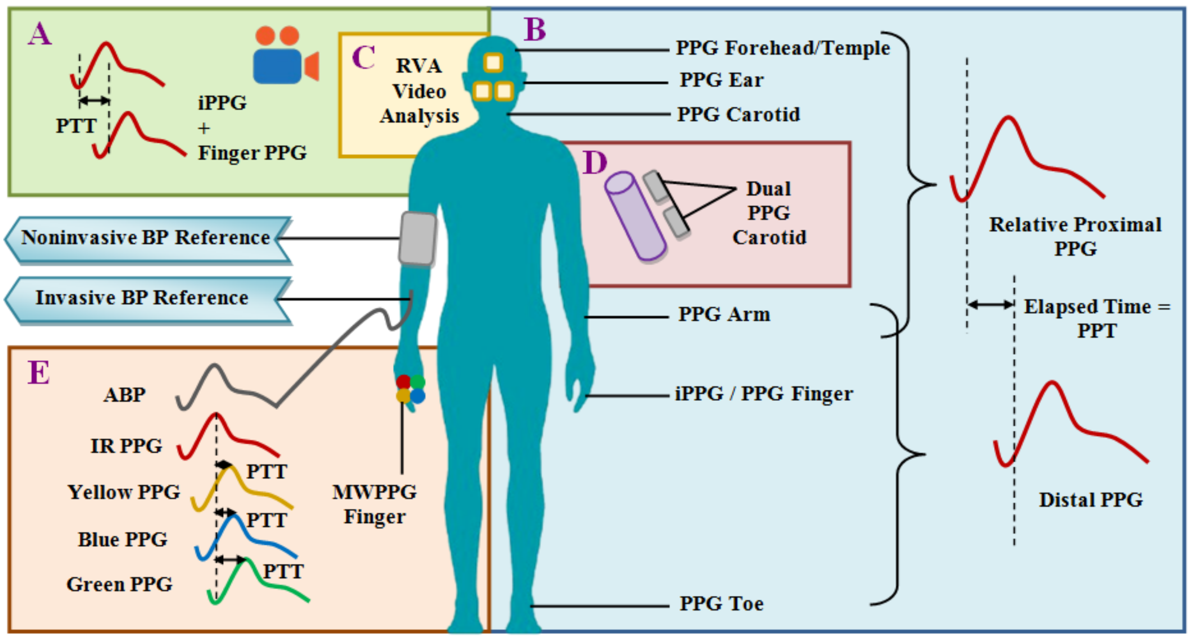


Figure 3: Visualization of the methods of multi-site PPG to measure the pulse transit time

Most studies on multi-site PPG have been conducted with small sample sizes (that is, typically 5–20 healthy subjects), without the inclusion of hypertensive individuals or those with co-morbidities. Consequently, the technology appears to lack sufficient validation in clinical groups. Furthermore, RR has also been examined using PPG. In the study by [22], a PPG-based RR estimation algorithm for HM applications was assessed. The findings indicated that by incorporating the algorithm into a commercially available pulse oximetry device, RR could be continuously and effectively measured in both home and clinical settings.

The advanced form of PPG is rPPG. An emerging technology, which permits for non-invasive monitoring of physiological signals like HR, blood oxygen saturation, together with respiration rate employing a camera, is termed rPPG. rPPG measurement conditions toward telemedicine applications had been evaluated in the study of [23]. In a real telemedicine scenario, it was essential to restrict body motion, particularly head motion, because unrestricted body motion significantly decreased the HRV measurement's accuracy. Moreover, the way to my heart is via contrastive learning as rPPG from the unlabelled video had been analysed in the study of [24]. The results demonstrated that it was feasible to decrease the need for manually designed features. However, the features still offered some interpretability into the behavior of the model and potential failure modes by letting the model learn where to sample the input image. Finally, in the research of [25], Camera-centric remote PPG for blood pressure measurement with current evidence, clinical perspectives, along with future applications had been analyzed. The necessity of remote patient monitoring to slow the spread of infectious diseases has been brought to light, particularly by the COVID-19 pandemic. In addition to other infectious diseases, endemic levels of infection continued even if the pandemic was in remission. Examples of potential clinical uses for remote PPG measuring along with blood pressure estimation are provided in Figure 3.

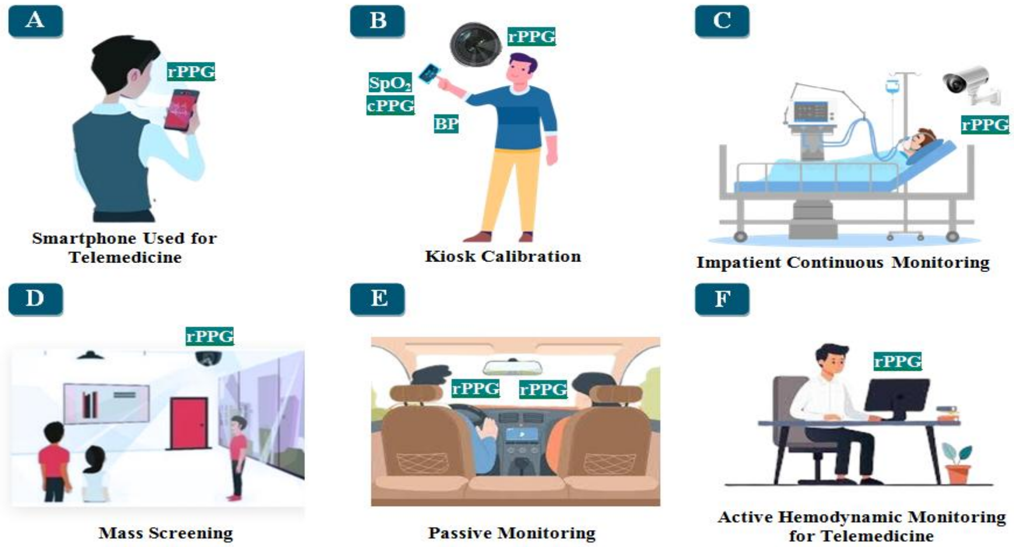


Figure 4: Examples of potential clinical uses for remote PPG measuring and blood pressure estimation

Researchers hypothesized that at least 10 seconds of PPG waveforms might be necessary for BP measurement. This might be done actively or else passively whilst employing camera-equipped devices. A totally cuffless BP experience, however, could not feasibly give the available data as it needed the population model's use. These processes weren't precise enough to offer a universally applicable solution for clinical or consumer use.

## *3.2. Application of PPG and rPPG in remote health monitoring*

As physiological indicators' real-time monitoring is provided, health problems' early detection is facilitated, and a healthy lifestyle is supported, PPG's usage is useful in clinical along with non-clinical settings [26]. To improve patient care through ongoing, non-invasive VS monitoring, it is crucial to comprehend how PPG and rPPG are applied in RHM. By enabling health evaluations without physical contact, these devices improve patient comfort and accessibility and are especially useful in underserved or isolated locations [27]. They can provide healthcare solutions that are more affordable by lowering the need for in-person consultations and hospital stays. Table 1 explains the clinical applications in RHM by PPG and rPPG.

Table 1: Clinical applications in remote health monitoring of each domain by PPG and rPPG

| Applications | | Usages | PPG | rPPG |
|---|---|---|---|---|
| Monitoring | OPD | CVDs (Cardiovascular disease) [28] | [28] | - |
| | Surgery | Anesthesia [29,30] and blood perfusion | [29] | [30] |
| | Pediatrics | Blood pressure [31,32], Respiratory rate, and CVDs | [31] | [32] |
| | COVID-19 | Blood pressure [34], Respiratory rate, and SpO2 [33] | [33,34] | [34] |
| | Dialysis | Arterial steal | [35] | - |
| | Neuro | Multiple sclerosis | [36] | [37] |

Each application has distinct advantages for PPG and rPPG, which are depicted in Table 1. In CVD, both PPG and rPPG are used to monitor HR along with blood oxygen saturation, which is crucial for managing cardiovascular conditions. These technologies enable continuous, non-invasive monitoring, which is vital for patients with CVDs [28]. PPG is commonly used to monitor blood perfusion and oxygen saturation during anesthesia for surgery [29, 30]. rPPG can extend these capabilities by providing remote, contactless monitoring, enhancing patient safety during surgical procedures [30].

PPG is utilized in paediatrics for monitoring blood pressure in children [31, 32], while rPPG can track RR and cardiovascular health without causing discomfort, making it ideal for pediatric applications [32]. PPG has been instrumental in measuring blood pressure and RR during the COVID-19 pandemic [34]. rPPG extends these capabilities by providing remote monitoring of SpO2 levels, ensuring timely intervention for COVID-19 patients [33, 34]. In arterial steal, PPG is used to detect arterial steal syndrome in dialysis patients, ensuring proper blood flow and preventing complications [35]. rPPG's non-contact nature can enhance monitoring accuracy and patient comfort. In neurology, PPG aids in tracking cardiovascular health in patients with multiple sclerosis [36], while rPPG offers a contactless alternative, improving patient compliance and monitoring efficiency [37].

Other than applications, some of the key parameters, namely HR, blood oxygen saturation, along with RR are utilized in the analysis of PPG and rPPG in RHM.

**a)Heart rate**

rPPG is a non-contact technology used to monitor heart activity by detecting subtle color changes within the facial blood vessels. An unconstrained approach is provided by this method, making it widely applicable to HM systems [38]. The PPG signal is used to measure arterial blood volume, which fluctuates with each heartbeat; also, is utilized by numerous wearables for heart rate monitoring.

**b)Blood oxygen saturation**

Usually, PPG deploys a finger-clip photoelectric sensor for estimating the SpO2 saturation by measuring the reflected light intensity of '2' incident light sources with diverse wavelengths, like the red light wavelength (660–700 nm) along with the infrared (IR) light wavelength (800–950 nm)5 [39]. rPPG detects subtle changes in skin color resulting from blood flow variations by analyzing video recordings of a person's skin, allowing for continuous and contactless measurement of SpO2 levels.

**c)Respiratory rate**

PPG is commonly used to detect RR and monitor HR. Most PPG-based RR estimation techniques require either the breakdown of PPG signals or the detection of individual heartbeat peaks, which is time-consuming and has limited performance [40]. An emerging technology, which permits for non-invasive monitoring of physiological signals like HR, blood oxygen saturation, along with respiration rate employing a camera, is termed rPPG.

## 4. CONCLUSION

Here, the advancement of RHM has been significantly enhanced by the development of CVSM technologies, particularly through the use of rPPG and PPG. These non-invasive techniques offered promising solutions for continuous and real-time HM without the need for physical contact, making them particularly valuable in scenarios, where traditional monitoring methods might be inconvenient or infeasible, such as in remote or high-risk environments. Both PPG and rPPG were developed with the aim of revolutionizing healthcare by enabling telemedicine applications, facilitating early detection of health anomalies, and supporting remote monitoring for chronic disease management. These technologies provided a more accessible, economical, and user-friendly option for VS monitoring than conventional techniques. Other than benefits, the limitations identified in the study were subject movement, which had the potential to interfere with both rPPG and PPG. In dynamic surroundings, it might be difficult to get accurate and consistent measurements because activities like talking, head movement, or posture changes could distort the signals that were recorded. In the future, researchers should consider this limitation and find a solution for it. Thus, the combination of rPPG and PPG into everyday HM systems represented a transformative step in personalized healthcare, empowering individuals to track their health in real-time irrespective of their location.

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